University of Sheffield

ClimaFever – iOS app to research the impact of climate change on hay fever sufferers

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Declaration

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Date: June 02, 2021

COVID-19 Impact Statement

The lockdown imposed because of COVID-19 caused additional challenges for the completion of this project. During the whole year, the university switched to online delivery of all teaching, and university buildings were closed. All project meetings were shifted to email correspondence and video meetings.

In addition, my project plan was revised because of worsen mental health, caused by the restrictions imposed. I travelled between my home country and the UK, trying to find a way to preserve my well-being. Furthermore, I was hospitalised during March and was unable to do University-related work for several weeks.

As I was used to studying in the library and other University buildings, the lack of access to them made the whole year very challenging. Sleeping, entertaining yourself and doing work, all from the same small room was very hard. Finding motivation was also a problem, especially in a such unstructured daily routine.

I believe that all of this had a negative impact on my performance, and I believe I could have done more. Nevertheless, I hope that happier times await us.

Acknowledgements

I want to thank my project supervisor, Dr Maria-Cruz Villa-Uriol, for everything she did during the past academic year. She has been amazing and easily among my favourite academics I have met in the past four years! Her feedback was always on point and have helped me to improve the quality of the project deliveries. I am very happy I could work on a project I can relate to. First, I suffer from hay fever myself, so I know the struggle. Second, I started learning iOS development in my free time, during my Placement Year, so was nice to be given the opportunity to put what I have learnt in use while also building my skills further.

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Abstract

Hay fever is a common health condition around the world, with more than 10 million people suffering from it in the UK. A countless number of studies on hay fever and its implications on wellbeing and the economy have been conducted in the past few decades. What seems to be still poorly understood is how climate change affects the hay fever sufferers.

ClimaFever, powered by Ambee's Environmental API, provides hay fever sufferers with essential environmental information with post code accuracy. Additionally, a research-based in-app survey helps gathering quantitative information across Europe and Asia. The data can then be accessed by researchers and an analysis of the correlation between the environment and the onset, duration, and strength of hay fever symptoms can be conducted.

The project combines the best of what is already available on the market with exclusive features, combined with a research aspect on a topic with a great public importance. An extensive user evaluation has confirmed the potential of the platform.

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Chapter 1

Introduction

The prevalence of allergic diseases continues to grow. Climate change has directly been related to this tendency [1]. A few experimental studies have shown that increased CO_2 levels in the environment lead to an increase in the pollen allergenicity [2]. High ozone level has also been linked to worsening in hay fever symptoms [3]. The raising temperature is another consequence of the climate change that affects the hay fever season duration and strength. Asthma sufferers are at even greater risk [4].

Multiple services which provide pollen count information were researched. None of them, including the one maintained by the Met Office, provides real-time data about the pollen count outside the official pollen season [5]. Patients are not receiving vital information which can be useful for managing symptoms and thus, improving wellbeing. It can also influence how people are being diagnosed. This is caused by outdated information being used around the world. Furthermore, the current trend to start preventive medications in mid-March is no longer effective [6].

1.1 Aims and Objectives

The few available studies on how the climate change relates to the hay fever are largely experimental. Moreover, there is a lack of evidence on how these changes translate to sufferers' wellbeing, as quantitative research on the human population has not been conducted. The aims of the project are:

- to provide a way of collecting quantitative data on the relation between the climate change and the onset of hay fever symptoms
- to change the established beliefs about the hay fever season duration by raising awareness of the dynamic nature of the problem
- to make the platform publicly available

The aims will be achieved via a platform, which will allow the correlation between the environment and the onset, duration, and strength of hay fever symptoms to be studied. The main objectives of the project are:

- to build an iOS application that allows users to take part in the research by taking advantage of Apple's ResearchKit framework
- to build a website that displays the collected data in a concise manner

The iOS app will show the air quality index, as well as the pollen count for the different types of pollens (grass, trees, weed). Using innovative technologies and machine learning, an up-to-date data will be available. In combination with the user-collected data, an association between the severity of the symptoms with the air quality, as well as the geographical location, will be made. The collected data will be accessible on a website. The application will also contain several additional features to provide users with important information about the condition.

1.2 Overview of the report

Chapter 2 covers the background information on what hay fever is, how it is diagnosed and treated. It introduces the concept of air quality and pollen count monitoring. As the project benefitc from Apple's ecosystem and the company's healthcare frameworks, they are introduced as part of the literature survey. The currently available iOS applications are compared, and the key findings are presented. Finally, the chapter covers the programming language Swift and the brand-new front-end framework SwiftUI which was used for building the ClimaFever application.

Chapter 3 establishes the technical aspects of the project. It gives an overview of how the system will work, what features it will have, as well as how it will look. Ethical and legal considerations are included. The chapter concludes with discussing the risks identified.

Chapter 4 gives a high-level overview of the system and its components. It also discusses alternative design approaches to some of the requirements defined in Chapter 3. Chapters 3 and 4 combined represents what could be seen as a brief Software Requirements Specification (SRS) document of the system.

Chapter 5 presents the system developed via series of screenshots. Some implementation details are shown with screenshots. The chapter also includes information about the testing that has been performed.

Chapter 6 discusses the final system and the achievements accomplished. The results of an extensive user evaluation are also presented. The chapter identifies the main limitations, as well as what is possible as future improvements.

Chapter 7 concludes the report by revisiting what hay fever is and summarising why the proposed platform has shown potential to be widely used, if introduced to the market.

Chapter 2

Literature Survey

2.1 What is hay fever?

Hay fever is caused by the body reaction to harmless allergens [7]. It can be seasonal (most often caused by pollens from trees, grass, and weeds) and year-long (perennial). Some people suffer from both types. Most people are allergic to the grass pollen. The symptoms include itchy and watery eyes, runny or blocked nose, headache, and earache. It is estimated that more than 10 million people suffer from it in the UK [8]. In the USA, 7.3% of adults are diagnosed with the condition [9]. David Peden, former American Academy of Allergy, Asthma and Immunology president, expects that an additional 10 to 15 percent of the population will suffer from allergies by 2050 [10].

In the USA, two in five people have acknowledged that allergies are serious and can affect the quality of life [11]. Untreated hay fever can lead to an allergy-induced asthma, which affects 60% of people with asthma in America [12].

2.1.1 Diagnosis

Currently, two options for diagnosis of the condition are available – skin prick test and allergy blood test [13]. When skin prick test is performed, a small amount of the allergen is put under the topmost layer of the skin [14]. This triggers the immune system which sends antibodies. The reaction between the allergen and the antibodies causes a release of histamine. This leads to an itchy hive appearing. The blood test measures the amount of the immunoglobulin E (IgE) antibodies. Both options can be unpleasant, especially for children.

In 2020, Prof. Traidl-Hoffmann has experimented with a new way of detecting allergen-specific antibodies using nasal swabs [15]. The study seems encouraging, especially as it claims to be able to detect antibodies which cannot be detected in a blood sample. A similar research, conducted in 2016, also showed similar promising results [16].

2.1.2 Treatment

Hay fever remains widely undertreated. 79% of people are not sure what specialist treats allergies [11]. A research suggests that over 50% of the sufferers had not seen a medical professional in the past year [17].

Currently, there are various ways available for treating hay fever and allergic rhinitis. These include antihistamine tablets, nasal sprays, eye drops and steroid tablets in more severe cases [18]. The medications tackle different symptoms, so often a combination of them is used. Immunotherapy is an alternative option which is effective for people who fail to respond to other ways of treatment. It works by exposing the body to extract of the allergen for a duration of a few years [19]. While this method cannot be used for every allergy, it is effective for grass, grain and weed pollens.

Initially, the treatment was available as subcutaneous immunotherapy (SCIT). This involves injecting the allergens. In 1986, a series of fatalities were reported in the UK [20]. A newer method is the sublingual immunotherapy (SLIT) which involves administering the allergens by the form of drops or tablets, which are kept under the tongue. A case study conducted by the Imperial College London (ICL) showed that both methods are equally effective [21]. However, the sublingual method eliminated the side-effects and reduced the costs related to the subcutaneous route. In 2018, a breakthrough was made by a team of researchers at the Technical University of Munich (TUM). They had managed to develop and patent a test which predicts the outcome of an immunotherapy at its early stage [22]. If made widely available, the test can make the immunotherapy more alluring for patients.

As over-the-counter drugs are available for managing allergic rhinitis, patients do not always seek help from specialist. This delays diagnosis and puts additional burden on the sufferers. They might not be fully aware of what their condition is, what medication (or combination of medications) they need to take, as well as what to expect from it.

2.1.3 Symptom management

As part of a study [23], forty-seven participants were interviewed on how they manage their symptoms. The survey demonstrates the difficulties the sufferers are experiencing. First, it appears that the participants have found it challenging to get the correct diagnosis. Some got “treatment fatigue” and were discouraged after trying multiple different treatments which had not led to the expected results. People are reportedly getting confidence over time, as they become more aware of the patterns of the symptoms. One participant reported they experience “itchy eyes when the pollen count is really high”. Another one described stocking up on antihistamines 2 weeks in advance, as a preventative measure. This shows that being aware of what the current pollen count is, and having a pollen forecast, can be helpful for a group of sufferers. The use of oral medicines is preferred, due to the ease of use. However, some sufferers do not see improvements despite taking them. This has a major impact on the quality of life.

Even if the number of the people interviewed is relatively small, the survey shows the broadness of the issues hay fever sufferers experience day-to-day. This includes the community labelling them as “contagious”, because of the sneezing, related to hay fever. Further evidence is available, showing that teenagers are more likely to feel depressed, due to sleep deprivation, caused by hay fever symptoms, such as rhinorrhoea, nasal congestion, and itchy eyes [24]. A case study from 2007 shows that untreated pollen allergies in schoolchildren leads to 40% increased risk of getting lower grades [25].

It becomes clear that many people prefer to self-manage their symptoms. This can be either because of the costs related to visiting a specialist, negative experience in the past or not wanting to take medications daily. Raising awareness of the importance of getting a proper diagnosis and treatment is vital. Given the fact that the condition is very common, people might not think it requires medical supervision and might not realise the implications of it being left untreated.

2.2 Climate change impact on hay fever

Climate change is defined as a change in the average weather patterns [26]. Its effects have been observed since early 20th century and have been related to human behaviour. Climate change includes changes in precipitation and more intense heatwaves [27]. It is expected these changes to continue in the long-term. A direct consequence is the seasons shifting. Spring arrives earlier and winters are getting shorter [28]. This changes the timing of when flowers and trees bloom which is directly related to the number of pollens in the atmosphere. The amount of pollens produced has been shown to be increasing [29].

Although it is known that the climate change affects individuals with respiratory diseases, the extend of its effect remains unknown [30]. Studies have related compromise in lung function, both in children and adults suffering from asthma to the greenhouse gasses [31, 32]. Long-term exposure to ozone increases the risk of developing asthma in children and adults [33, 34]. Meteorological conditions which allow for the aggregation of air pollutants at ground level also pose a health risk [35].

How the climate change impacts hay fever sufferers is poorly understood. It is suggested that early spring increases the duration of exposure to pollens, whereas late spring leads to exposure to multiple pollens simultaneously [36]. Furthermore, it is expected that the number of people who suffer from ragweed pollen will double by 2041-2060 [37]. The allergy to ragweed will become worse in regions where it already exists and will start occurring in regions where it is currently uncommon. This matches what an experimental study by Peter Wayne found in 2002 – doubling the concentration of CO_2 leads to an increased ragweed-pollen production by 61 percent [2], as well as a 2000 study [38], the results of which are presented below:

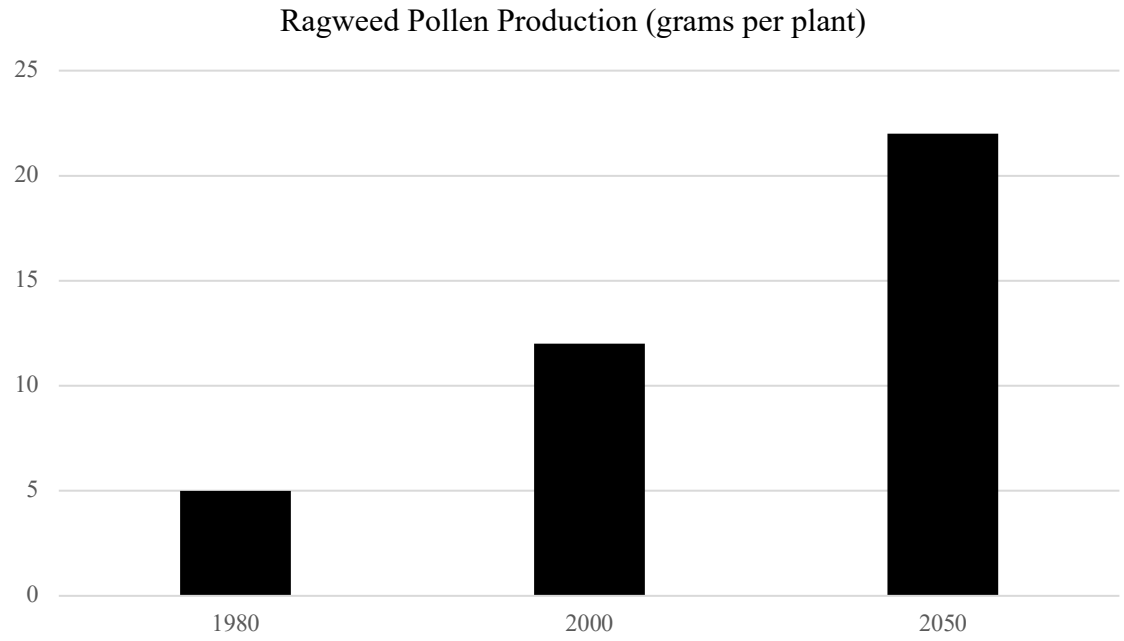

Table 2-1 Ragweed pollen production comparison

These studies share common limitations. First, they are performed in a controlled environment. While they give a good basis for hypothesis, in practise, many variables have to be taken into consideration, in order to draw firm conclusions. These include temperature, rainfall, geographical location and more.

Second, they do not show what the effects of the increased pollen production on the hay fever sufferers are. To change perceptions and ideas that have been applied for many years, an unambiguous study is needed that provides a solid evidence. Finally, it seems that ragweed is the focus of those studies while the trees and grass get neglected.

Understanding how climate change influences the hay fever prevalence and onset of symptoms is vital for proper diagnosis and treatment, as well as for developing mitigation strategy. Finding real-time data about the pollen count outside of the counting period (March to September) is challenging, but necessary, as people start experiencing symptoms earlier.

2.3 Air quality and pollen count monitoring

The process of air quality monitoring (AQM) is challenging. The quantity of the information is dependent on the number of the ground stations available within the region, the pollutants that each station monitors, as well as the rate of reporting the data. These stations are heavy and expensive, and also require regular maintenance [39]. As a result, they are used mostly by governments and authorities. Because of these limitations, the data available can be rather scattered.

With technological advances, an alternative way of air quality monitoring became possible. Wireless networks of low-cost sensors can provide a near real-time data with a dense coverage [40]. They can aid ambient air monitoring, as well as personal exposures. The limitations of this method are related to the quality of data and the capabilities of the sensors. The performance of such networks vary dependant on the atmospheric composition and the meteorological conditions, the sensors and their calibration [39]. Statistical correction might be needed in order to improve the performance [41]. To fulfil the air quality regulations, the traditional approach is still needed.

2.3.1 Air Quality Index (AQI)

In order to assess the air pollution level on a global scale, the Air Quality Index (AQI) was introduced [42]. Globally, there are differences on how AQI is calculated and presented. In Europe, Common AIR Quality Index (CAQI) was introduced. CAQI consists of 5 levels, from Low to Very High, and takes into consideration four major pollutants – nitrogen dioxide (NO_2), ozone (O_3) fine particles ($PM_{2.5}$) and coarse particles (PM_{10}). In the USA, the AQI has 6 levels and includes five pollutants – ozone (O_3), coarse particles (PM_{10}), carbon monoxide (CO), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2).

2.3.2 Monitoring pollen count

Monitoring air quality is regulated around the world (for example, under the Directive 2008/50/EC in Europe) [43]. However, the situation is different when it comes to pollen monitoring. Most stations for biological particles are private and data is not freely accessible [44]. Furthermore, as of 2018, almost 60% of the active pollen monitoring stations were in Europe. An interactive online map, built by the European Academy of Allergy and Clinical Immunology, shows that some European countries might still have very poor pollen monitoring coverage (i.e., Bulgaria and Romania have only one station, where as Greece has only three stations, all located in the same city) [45]. The country with the weakest coverage is Africa, while Japan, Italy and the USA are among the countries with the best coverage.

Figure 2-1 Worldwide map of pollen monitoring stations
Screenshot of Worldwide Map of Pollen Monitoring Stations [45]. Taken on November 18, 2020

Most of the stations use Hirst-type spore traps (HTST). The method works by blowing air into a slit [46]. The particles get stuck to an adhesive tape which is then manually examined. The spores are identified and counted. This results in a delay of the reporting and can also introduce errors.

2.3.3 APIs available

To accomplish the aims of the project, air quality and pollen count data provider has to be chosen. The essential requirements are real-time data reporting and to be accessible via an API. Additional desired features are multi-country data availability and pollen forecast. Weather and climate data are out of scope for this project.

It turned out that options available are very limited and only two potential solutions were identified – **BreezoMeter** and **Ambee**. Both attempts to tackle the issues related to air quality reporting in similar ways. This consists of a combination of ground stations, historical data, and highly sophisticated computational approaches. BreezoMeter claims that they report air quality with a micro-resolution of 5m² (compared to 200 m² by Ambee) [47]. The company manages to do so by mapping air pollution between the ground sensors, considering traffic patterns, satellite data, land cover and more, in combination with machine learning techniques. Ambee's technology, AIONN-MetNet (Aggregation & Interpolation of Meteorology Data over Neural Network), takes similar approach.

The features provided by both solutions were examined. BreezoMeter seems to be superior and provides additional features such as pollen forecast (for up to three days), pollen count for thirteen plants, as well as better resolution. The service is trusted by world leaders such as BOSCH, AstraZeneca and Siemens [48]. Moreover, starting with iOS 14.3, the AQI displayed within the Weather app is provided by BreezoMeter [49].

An evaluation plan is offered, but it is too limited for the purposes of the project. The attempt to contact the company, in order to agree on an option to use the API as part of the project, was unsuccessful.

Ambee is a product by an Indian start-up, founded in 2017. It offers similar features to BreezoMeter. The evaluation plan provides a hundred free API calls a day, followed by a pay-as-you-go pricing of £0.00015 per call. They claim to be reporting air quality data for over 90 countries and 1.6 million postcodes with 85% accuracy at all times [50].

2.4 Using smartphones as medical devices

Smartphones are among the most significant technologies, introduced in the recent years. There is no official information on the number of the apps available on the app stores, however, Statista reports that 1 820 000 are available on the Apple's App Store as of 2020 [51]. Furthermore, During the Q1 earning call in 2019, Apple's chief financial officer (CFO), Luca Maestri, announced that, as of the end of December 2018, there were 900 million active iPhones. The number of Americans who have smartphones at the beginning of 2019 was 81% - an increase from 35% in 2011 [52]. As of 2020, it is estimated that there are 3.5 billion smartphone users worldwide and an increase to 3.8 billion is expected in 2021 [53].

Medicine is among the disciplines which have been greatly benefiting from the availability of the smartphones. Just by skimming the medical apps top chart in the Apple's UK App Store, a wide variety of applications can be found. They help with tasks, such as booking GP appointments, staying safe during the COVID-19 pandemic, getting personalised acne treatment, obtaining NHS prescriptions, tracking body temperature and much more. The app for booking GP appointments, Patient Access, has a rating 4.8 out of 5, based on 418 thousand reviews [54]. This is a clear indication of the usefulness of the app for its users. Currently, there are medical apps available for screening and diagnosis, monitoring, clinical communication and many more. iOS is the most popular platform for such applications [55]. As the adoption rate of smartphones goes up every year, as well as with the introduction of new hardware capabilities and software enhancements, it is expected that smartphones will become an essential part of the health care. This is further supported by a survey conducted among medical students and junior doctors in the United Kingdom which shows that most participants have between 1 and 5 medical-related apps installed, with the iPhone users being much more likely to use apps [56]. However, others believe that more high-quality studies are needed to come to a definite conclusion about the smartphones role in the field [57].

2.4.1 Apple ResearchKit & Research App

ResearchKit is part of the Apple's ongoing effort to improve users' wellbeing. The open-source framework was released in 2015, alongside the first Apple Watch [58]. It allows users to participate in studies on the go. This has proven to be a great success. For example, 11,000 people have signed for a Parkinson's research within 24 hours [59]. Alan Yeung, medical director of Stanford Cardiovascular Health, stated this amount of enrolment would usually require a year and 50 physical locations. Since its introduction, ResearchKit has been used for studies related to autism (Autism & Beyond by Duke University), seizures (EpiWatch by Johns Hopkins University), heart health (MyHeart Counts by Stanford University), diabetes (GlucoSuccess by Massachusetts General Hospital) and many more [60, 61].

ResearchKit consists of four main parts – Informed Consent, Surveys, Active Tasks and Charts [62]. Charts allows data to be displayed in charts and graphs. Active Tasks allows users to perform activities under partially controlled conditions. iPhone sensors, such as accelerometer, gyroscope, and GPS, can be used to monitor activities within seven categories – Motor Activities, Fitness, Cognition, Speech, Hearing, Hand Dexterity and Vision.

Consent is needed for every research that involve human subjects. ResearchKit provides developers with a way to produce such consents, using several predefined sections. ResearchKit also allows creating surveys, based on predefined templates. Multiple answer formats are available.

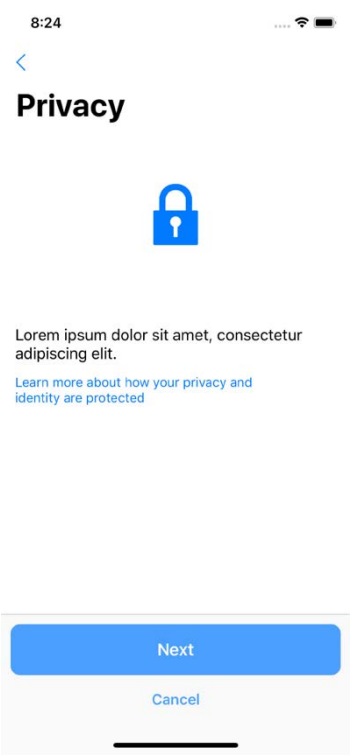

Figure 2-2 ResearchKit privacy view
Source: Apple [63]

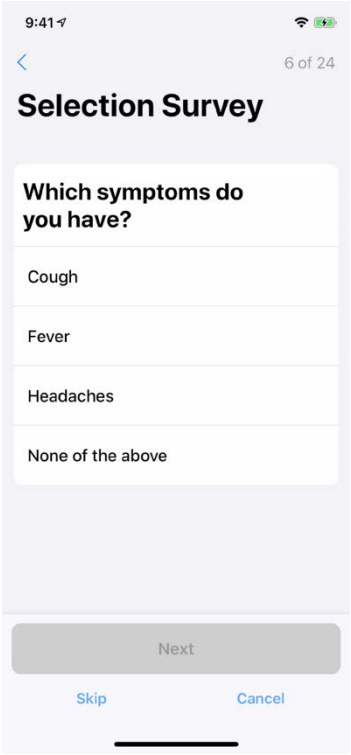

Figure 2-3 ResearchKit text choice view
Source: Apple [64]

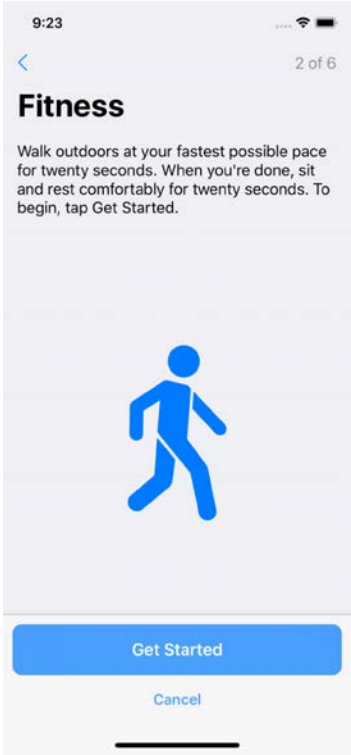

Figure 2-4 ResearchKit fitness activity view
Source: Apple [65]

In November 2019, Apple released a new Research app (available only in the USA) [66]. It combines the currently available studies in one place and lets users enrol if eligible. All available tasks from each individual study are also presented in the app.

Figure 2-5 Apple Research app
Source: Apple [67]

2.4.2 Apple CareKit

CareKit helps patients to follow treatment plans, log symptoms and other data, and share the information with health care providers. The framework is used to track heart attack recovery (Corrie Health by Johns Hopkins), improving wellbeing of children with complex medical issues (Caremap by Duke and Boston Children's Hospital), to manage diabetes (Diabetes care by One Drop) and more [60]. It has been suggested that a CareKit-enabled app could be built for tracking COVID-19 symptoms [68, 69].

CareKit 2.0 was released in 2019 [70]. It has been completely rewritten on Swift 5. The update also provides SwiftUI and Apple Watch compatibility. Another major change is the addition of remote store synchronisation. The components of the framework have been split into CareKitUI and CareKitStore. CareKitUI is a package of reusable views, whereas CareKitStore is built on top of CoreData and provides an on-device datastore. Both packages can be used independently from one another, giving the option to developers to only implement the one they need.

CareKitUI consists of three different type of views – tasks, charts and contacts [71].

- **Tasks** are prescribed actions, such as taking medication.
- **Charts** help visualising data and trends.
- **Contacts** provide an easy way for patients to contact the care team.

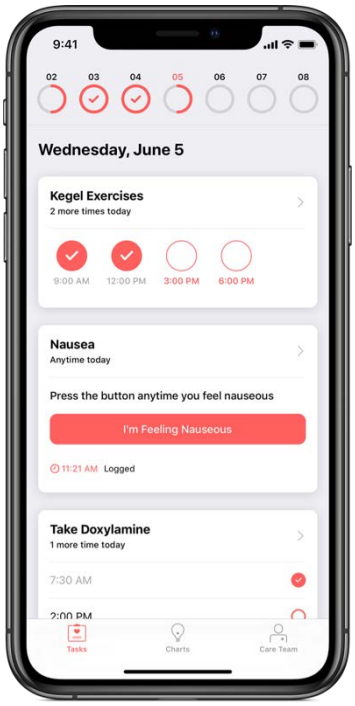

Figure 2-6 CareKit task view
Source: Apple [72]

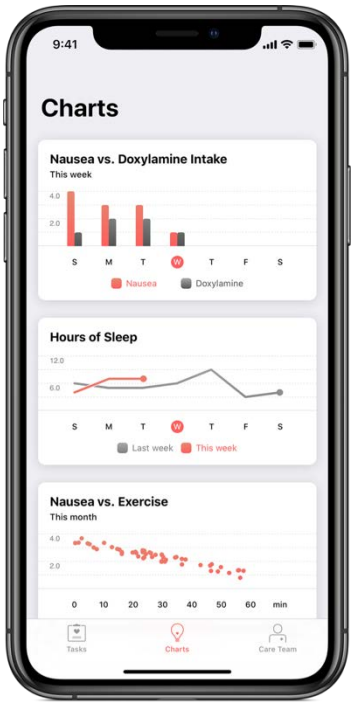

Figure 2-7 CareKit charts view
Source: Apple [72]

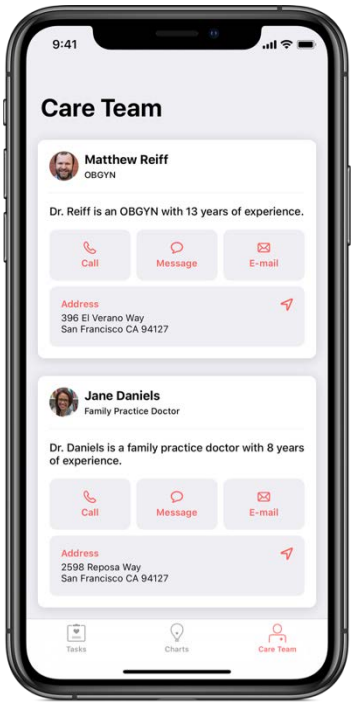

Figure 2-8 CareKit contacts view
Source: Apple [72]

As ResearchKit and CareKit provide individual customizable modules, both frameworks can be used together to build a feature-rich app. An example is the CheckCOVID app (available in the USA only), developed by the University of Nebraska Medical Center [73]. The app provides users with a questionnaire about symptoms and exposure. Using CareKit, the data can then be shared with a healthcare provider.

Additionally, a public health risk assessment survey, built using HealthKit, is also available. The Corrie Health app uses the Consent and Surveys modules from ResearchKit and the Tasks, Contacts and Core Plan Store modules from CareKit [74].

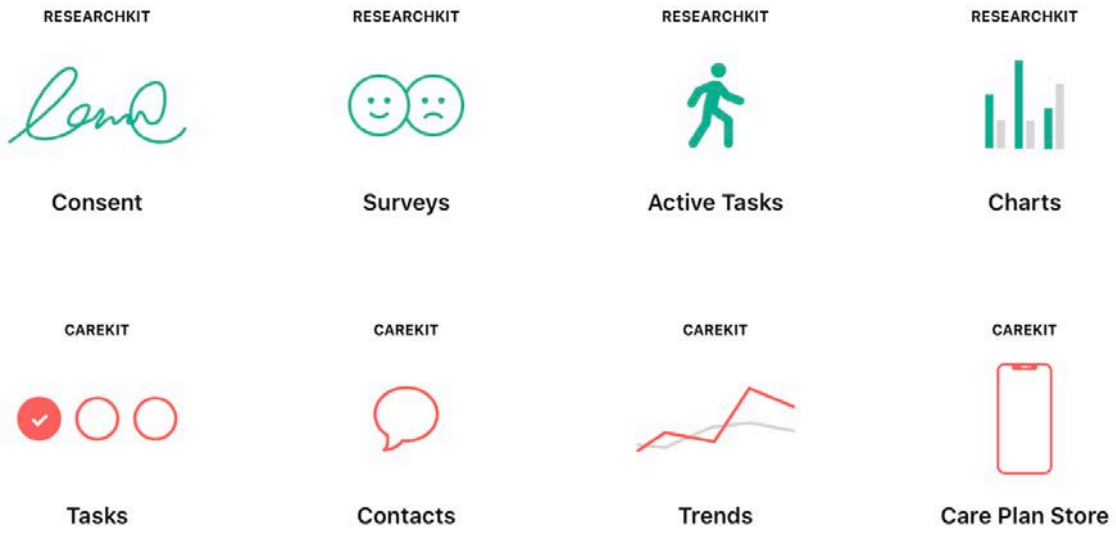

Figure 2-9 ResearchKit and CareKit features
Source: Adapted from Apple [75]

2.4.3 Apple HealthKit and Health App

Apple HealthKit and the Health app were released in 2014, as part of iOS 8. Since its release, the Health app has been redesigned multiple times. It is where the user's health and fitness data, gathered from the iPhone, Apple Watch, and 3rd parties, is summarised, and presented in an easy-to-understand manner. A relatively new feature is the Health Records which displays the user's health history, including lab results, medications, allergies and more. A potentially life-saving feature of the Health app is "Medical ID". It allows first responders to access critical information about the iPhone owner while the device is locked [76].

Figure 2-10 Apple Health app and Apple Watch
Source: Apple [77]

HealthKit gives apps and accessories the power to communicate with each other, by writing and accessing information stored in the Health app [77]. In that way, a better insight into the user's health can be gained.

2.4.4 Medical devices regulations

Medical devices are currently regulated by the European Union Medical Device Regulation (MDR) in the EU and the U.S. Food and Drug Administration (FDA) in the USA. After the Brexit transition period is over, starting from 1st of January 2021, the Medicines and Healthcare products Regulatory Agency (MHRA) will become responsible for regulating medical devices on the UK market [78].

The medical devices can be fitted into several classes – I (low risk) to III (high risk). The MHRA guidance on class I medical devices outlines the requirements needed to be followed by the manufacturers [79]. Even for low-risk devices, the regulations require preparing technical documentation, carrying out a clinical evaluation by a certified 3rd party, as well as implementing procedures for reviewing the experience in the post-production phase.

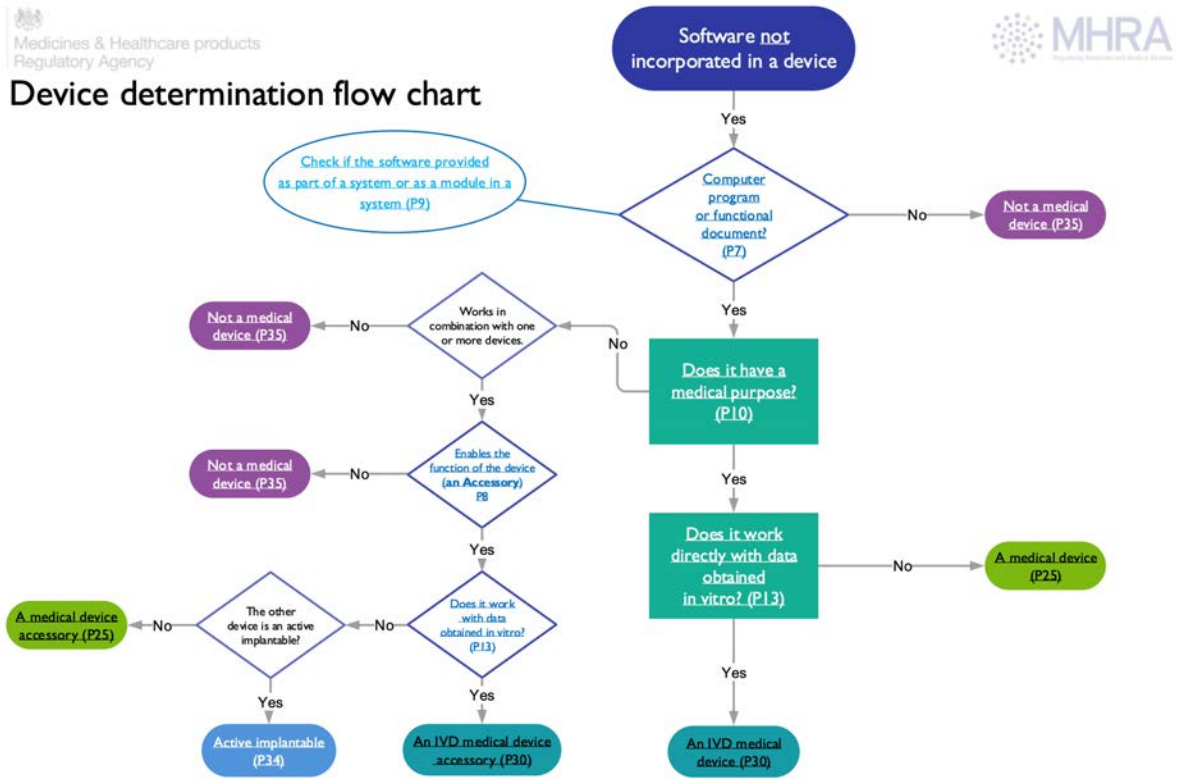

Figure 2-11 MHRA Device Determination Flow Chart
Source: MHRA [80]

Software products also fall under the directive for medical devices. Under the Medical Devices Regulations 2002, if the intended purpose of a software is to prevent, diagnose or monitor a disease, it is classified as a medical device [81]. The software is classified as IIa if the software allows direct diagnosis. For some software products, that require certification under the EU directive, FDA might exercise enforcement discretion [82].

An application does not classify as a medical device, if it allows the user to log their symptoms (replacing paper logs), if it provides general advice and recommendations or signposting to the appropriate services.

The application will include an onboarding screen, showing detailed information about the purpose of the app. It will be explicit that the app has been built as part of a dissertation project and only the usability of the app is to be evaluated. The users will be asked to agree with the notice before being able to fill in the survey. The other features, such as monitoring pollen count, do not require additional certification. Even if the app will not fall under the classification of a medical device, the best practises, specified by the MDR, will be followed during the development.

2.5 Currently available iOS applications

There are various apps available which provide different advantages to patients suffering from hay fever. As part of the project, four iOS apps on the UK App Store were compared. They are My Pollen Forecast UK, klarify, ambee and Mask Air.

My Pollen Forecast UK [83] seems to be the most popular with 4.6/5 points out of 3.7K ratings (as of October 15, 2020). The data it provides is limited to the UK. A quick review of the comments reveals the benefits it brings to its users. Examples include: "*without this app life would be so much more difficult*" and "*my asthma is exacerbated by allergies and so getting a forecast helps me plan my days better*".
Some of the reviews suggest room for improvement — "*...it's rubbish when it comes to allowing you to keep a diary of the bad days and the good days…*", "*...needs a widget app support for quick glancing…*". Others are complaining of issues, such as battery draining, as well as excessive data usage. A user has said that, in London, tree pollen allergies are common from February, but the app does not report the pollen count outside of the counting period. The developer has replied that the app is using the Met Office data, as it is "the best source for pollen information in the UK".

klarify [84] has 4.6/5 points out of 455 ratings (as of October 15, 2020). The application is using data provided by BreezoMeter, Met Office, DWD (Deutscher Wetterdienst) and Astma-Allergi Danmark. The app does not provide up-to-date information outside of the official pollen counting period (March - October) and it assumes a low pollen count instead. Only data for UK, USA, and Germany is available. Most of the reviews are positive. People find it helpful to self-manage their symptoms ("… *I feel it helps me to know when I need to be careful and when I need to take my antihistamine. It also helped me to find which type of antihistamine would not make me feel drowsy*…"), as well as to plan their activities ("*... the pollen data and the pollution data help to plan activities*."). The negative reviews are related to the app not showing information for a specific country or report issues with signing up/signing in.

Ambee [85] is not concerned with hay fever, so it does not show pollen count. Instead, it focuses on the air quality and different pollutants, such as PM_{25}, PM_{10}, CO, SO_2 and NO_2. It shows basic recommendations, based on the AQI, as well as additional details about each of the air pollutants. It also contains a page with links to research papers related to the air pollution effect on the health. Again, the app does not have any reviews.

Mask Air [86] is available in 23 countries around the world and is developed by FMC VIA-LR with collaboration with ARIA (Allergic Rhinitis and its Impact on Asthma), which collaborates with the World Health Organization (WHO). The app focuses on allowing users to keep track of the symptoms they are experiencing and treatment they are taking. The application is concerned with collecting and sharing the data with a healthcare professional. The application provides access to additional questionaries (such as impact of allergy on activities, asthma, and allergic rhinitis control test, as well as impact of allergy on sleep and drowsiness). The developer suggests that the data, collected via the app, is also used for research purposes. The app does not have any reviews on the App Store.

There are many other apps, such as the Met Office Weather Forecast and BBC Weather. These, however, are preliminarily concerned with reporting a wide variety of weather conditions and are not specifically targeted to users suffering from allergies and hay fever. Even if some aspects of these apps might be useful for hay fever sufferers, comparing the apps is out of the scope of this paper.

The features provided by each app can be summarized as follows:

	My Pollen Forecast UK [83]	klarify [84]	ambee [85]	Mask Air [86]
Pollen count	✓	✓	✗	✗
Pollen forecast	✓	✓	✗	✗
Pollutants count	✗	✗	✓	✗
Weather conditions	✓	✓	✗	✗
AQI	✗	✓	✓	✗
Recommendations	✓	✓	✓	✗
Diary	✓	✓	✗	✓
Research-focused questionnaires	✗	✗	✗	✓
Treatment options	✗	✓	✗	✗
Test options	✗	✓	✗	✗
Triggers information	✗	✓	✗	✗
Pollutant information	✗	✗	✓	✗
Multi-country data availability	✗	✗	✓	**NA**[1]

Table 2-2 Similar apps comparison

It becomes clear that the applications can be divided into two groups:

The first one is concerned with self-management of symptoms, by providing users with pollen count and weather conditions data, as well as means to keep track of the symptoms over time. Klarify goes further by providing users with detailed information about the different treatment and test options, as well as details about each allergen. Ambee, on the other hand, is focused solely on the air quality, so it provides information about the different air pollutants. Even the most well-thought-out apps have some limitations. For example, klarify provides data for a limited subset of locations (UK, USA, and Germany). The apps available do not provide up-to-date pollen count information out of the pollen counting period and assume low pollen count instead.

[1] Mask Air does not report any environment-related data

The second group, consisting of Mask Air only, is concerned with collecting data for research purposes. When used as a diagnostic aid, the patient is asked to record their symptoms for 7 consecutive days and then share the data with a healthcare provider. This might help the doctor diagnose the patient with allergic rhinitis, however, it does not help the patient to self-manage the symptoms. As it does not provide pollen count or weather conditions data, it will not be possible for the user to understand their condition without referring to other sources of information or seeking medical advice.

Retention is a key component needed for the success of any research. An asthma study, also conducted using a HealthKit-enabled iOS app, reported a "significant decline in study retention over time" [87]. As it can be seen from the popularity of the application on the App Store and their reviews, the app for solely research purposes is much less popular than the ones which provide users with useful information. However, this could be to the marketing of the app or the group of users the app is targeted towards. Nevertheless, if an app is deemed beneficial for the users, they are more likely to come back to it. To achieve this, the project aims to combine the usefulness of the first group of apps (useful for the patients) with the importance of the second group (useful for researchers and the wider community).

2.6 Software development life cycle models

Multiple software development life cycle models exist. They can be put in three categories – sequential, incremental and evolutionary [88]. All define similar stages, such as analysis, requirements elicitation, development, testing and maintenance. The main difference is how these stages are performed and how, and if, they interact with each other.

2.6.1 Waterfall model

The waterfall was the first method and was introduced back 1970 [89].

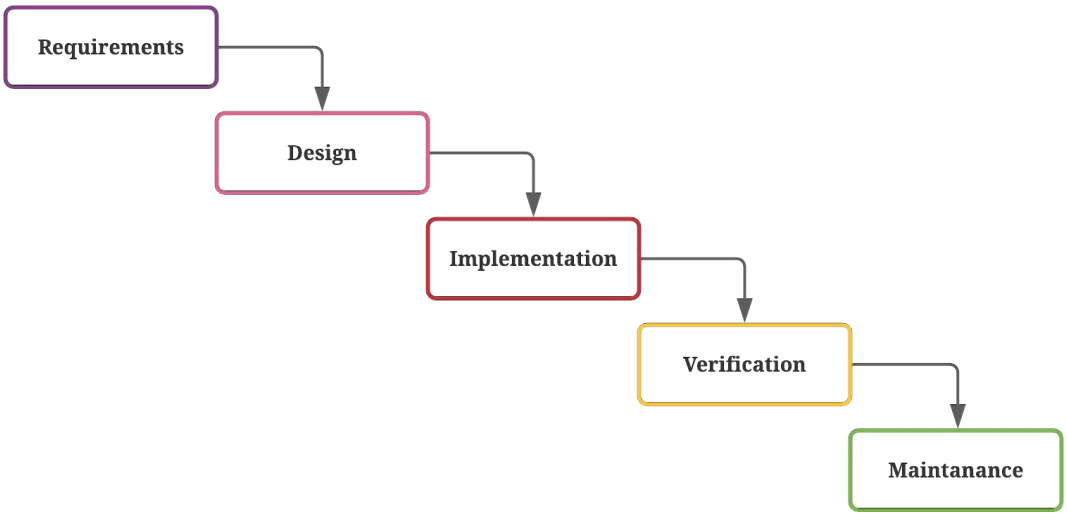

Figure 2-12 Waterfall method

It is a sequential model. Each stage starts when the previous one has been completed. This requires very good planning at the beginning, which helps with estimating project costs. The method allows for easily measuring performance, as the deliverables of each sage are clearly defined.

A major drawback is that changing requirements is very expensive or impossible at later stages. There is no commination with the client during the development. Deployment is at the end which does not allow for an on-time feedback. This, combined with the increasing complexity of software, renders the waterfall unsuitable for medium to large projects [90]. A variation of the waterfall is the V-Model, where testing is performed in parallel to each corresponding development stage [91].

2.6.2 Iterative models

Multiple iterative methods have been adopted. These include prototyping models (evolutionary, incremental, extreme), iterative and incremental model, RAD model, and spiral development. Iterative approaches reduce the risk related to changing requirements. They also focus on delivering a working prototype early in the development process.

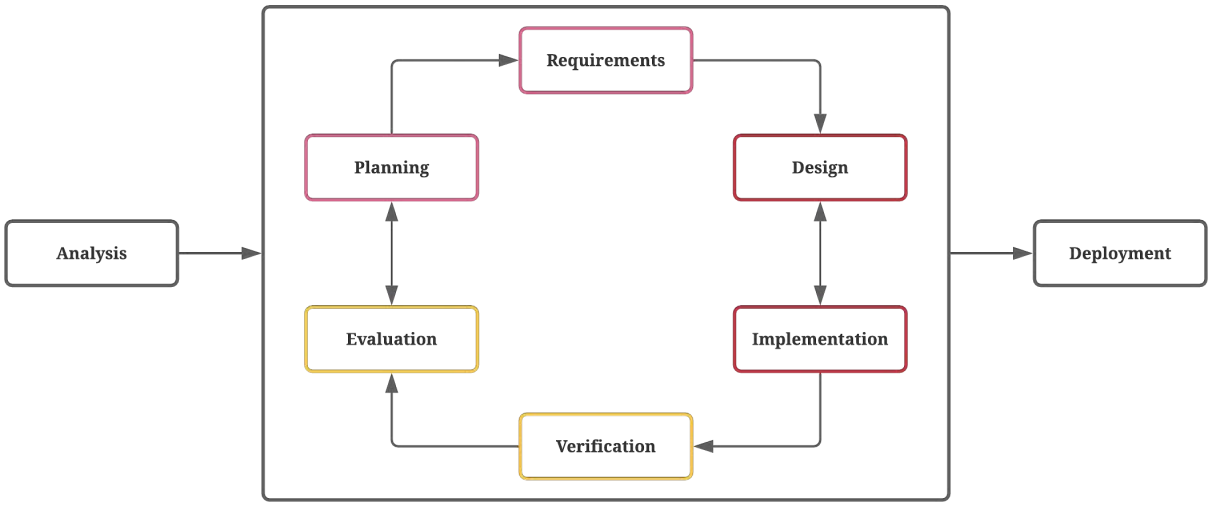

Figure 2-13 Iterative and incremental model

The iterative and incremental model consists of both iterative and incremental development. The incremental development aims at delivering new features as part of each iteration. On the other hand, the incremental development aims at revisiting the deliverables of the previous iterations and improving them [92]. In the iterative and incremental model, each iteration identifies which requirements will be implemented and what defects from the previous iteration have to be resolved. As the system is developed in several iterations, the initial delivery is faster and the costs, associated with it, are lower. Users can provide feedback early in the development process. Requirements changes can be easily implemented. However, this approach still requires a substantial documentation [93]. It also might make it hard to integrate features between iterations. The outcome might be hard to predict.

The Rapid Application Development (RAD) model combines prototyping and iterative development. It prioritises initial release and fast iterations over in-dept planning and requirement elicitation [94]. The Spiral model combines waterfall and prototyping. The model is used with medium to high risk projects, as risk analysis is involved in each stage [95]. This allows for early termination if risk is deemed too high.

2.6.3 Agile

Finally, the Agile methodology is examined. The methodology was born in 2000, as a response to the need of more flexible development models with less overhead required [96]. The Agile manifesto defines four values which are at the core of the development model [97]. They are:

- Individual iterations over processes and tools
- Working software over comprehensive documentation
- Customer collaboration over contract negotiation
- Responding to change over following a plan

As of 2020, 95% of the companies have reportedly adopted Agile methods [98]. The top three reasons for that are the rapid software delivery, allowing teams to adapt to changes to requirements, as well as increase in productivity. To achieve this, five key agile techniques are widely used – daily scrum, retrospectives, iteration planning and review, as well as short iterations. As it can be seen, Agile promotes behaviours related to the incremental and evolutionary models.

2.7 Swift

Swift is an open-source programming language, announced by Apple in 2014. Until then, Objective-C (introduced in 1984) was used for iOS development. Both languages are native to iOS, however, Swift brings major benefits:

- **It is easier to learn and use.** Objective-C is based on C, so it uses complex syntax. Swift, on the other hand, has a syntax which resembles English language. It also shares similarities with other modern programming languages, such as Python and Ruby.
  The following example illustrates initialising an Int array in Objective-C and Swift:

```
NSMutableArray * array =[[NSMutableArray alloc] init];
var array =[Int]()
```

- **It is faster.** When announced, Apple claimed the language was 2.6 times faster than Objective-C and 8.4 times faster than the now outdated Python 2.7 [99]. With time, the Swift performance has improved and is now 6 times better than Objective-C in some scenarios [100].
- **It is type and memory safe.** Unlike Objective-C, Swift does not use pointers. Features, such as generics, optionals and type inference ensure the code, written in Swift, is less error-prone and easier to debug.

Application binary interface (ABI) stability was achieved with Swift 5 [101]. Now, the Swift runtime libraries are shipped with the operating systems (iOS, macOS, tvOS, watchOS), instead of being included in each application. This decreases the applications bundle size. Furthermore, code, written with the current version of Swift, will be compatible with newer versions, reducing the overhead needed to migrate the source code.
In January 2019, an analysis of the top 110 apps on the App Store revealed that 42% were (partially) built using Swift [102]. In comparison, just three years earlier, the percentage was much lower – only 11%. The number is even higher when taking in consideration only the non-game apps – 57% of the 79 apps were built with Swift. This, combined with Apple using the programming language more extensively across their platforms, shows that Swift is going to be the new gold standard for native iOS, macOS, tvOS and watchOS development.

2.8 SwiftUI

SwiftUI is a front-end framework, made available in 2019. It allows for creating user interfaces in a declarative way [103]. Creating a text label with content "Hello" is as simple as writing `Text("Hello")`. As the framework is native to all Apple platforms, the label will be visualised differently on each of them. Furthermore, the appearance will depend on the context. For example, a text label placed within a form will be styled differently to a text label outside of a form.

Prior SwiftUI, user interfaces used to be created using the UIKit framework and Storyboards. Developers can either define layouts programmatically or use Storyboards to lay the elements on a canvas (called storyboard) which can then be connected with the code using outlets. When using UIKit, constrains must be set for each element, so that layout appears correctly on different screen sizes and orientations. As SwiftUI still does not have all features of UIKit, interfacing between both is possible.

Behind the science, SwiftUI is built on top of UIKit. SwiftUI takes care of the heavy lifting, so the focus can be on creating user-friendly interfaces. They can be created quickly, providing an early glimpse of what the final product might look like. SwiftUI also promotes reusability – custom views[2] can be extracted and reused wherever needed. Views can be nested to build complex layouts. Alternatively, the pre-defined components can be embraced to provide experience similar to the one provided by the stock apps. In this way, apps feel instantaneously familiar to any iOS user.

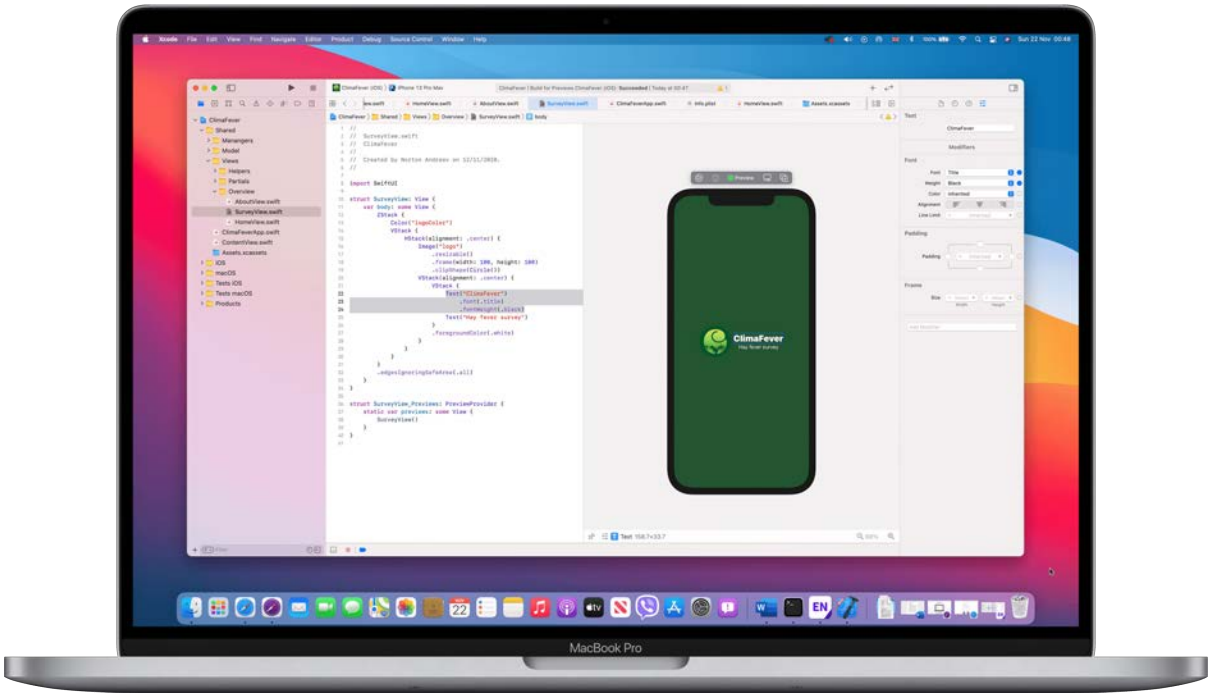

Figure 2-14 Composing a simple view using SwiftUI

The screenshot showcases the composition of a simple view. It utilises lay outing views, such as `VStack` (which replaces UIStackView in UIKit), as well as content ones, such as `Text` and `Image`. Modifiers[3] (such as `.frame` and `.foregroundColor`) have been applied to some of the views.

[2] View in SwiftUI is any UI component
[3] Modifier in SwiftUI takes a view and applies a change to it

Finally, the screenshot shows how the editor, the canvas, and the attributes inspector work together to aid the design process. Selecting the code in the editor selects the matching view on the canvas (and vice-versa). When a view is selected, the attributes inspector displays the available modifiers that can be applied. The canvas is updated when the code changes and can be interacted with. This can save time from opening the Simulator.

A major difference between SwiftUI and UIKit is the way views are updated [104]. UIKit is event driven. As such, it requires step-by-step instructions on how to achieve the desired state [105]. Normally, the UI is updated based on the state of the values stored within a program. If the UI does not update, what is displayed to the user and what is stored internally is different. Conversely, SwiftUI uses a declarative approach, and the desired state is directly described. Its state management is based around the concept of a "single source of truth". Views are bound to data and are automatically updated when the data changes [106]. While this can restrict the options over the control flow, it prevents bugs related to data inconsistency.

SwiftUI 2 was released in September 2020. Some of the major new features are **lazy grids** (which initialise its contents only when it is needed), **synchronised animations** (using matched geometry effect), **new property wrappers** (such as @AppStorage for accessing UserDefaults[4]) and more. Apple has started adopting the framework across its products. For example, widgets for macOS Big Sur and iOS 14 must be created with SwiftUI. SwiftUI is also used to design the macOS Big Sur's notification centre. While the framework is still very new and by no means enough to build a complex app, the first year of its existence has been very promising and it might not take long until it is widely used.

[4] Local datastore for basic data types

2.9 Accessibility

Accessibility is the practise of making sure that an application can be used by everyone, regardless of their disabilities. As one in seven suffers from some sort of disability, it is important to take special considerations in order to accommodate the needs of these users [107].

iOS provides multiple built-in accessibility features and system-wide settings [108]. Apple's Human Design Guidelines outlines the best practices for inclusive design [109]. Most of them can easily be implemented when developing with SwiftUI, especially when using system components. While all recommendations will be followed, two examples are listed below:

- **System colours** - when using system instead of custom colours for text, the text responds to the system-wide accessibility settings, such as Invert Colors and Increase Contrast [110].
- **Dynamic Type** - it allows the text to scale automatically, based on the system-wide Larger Accessibility Sizes setting [111].

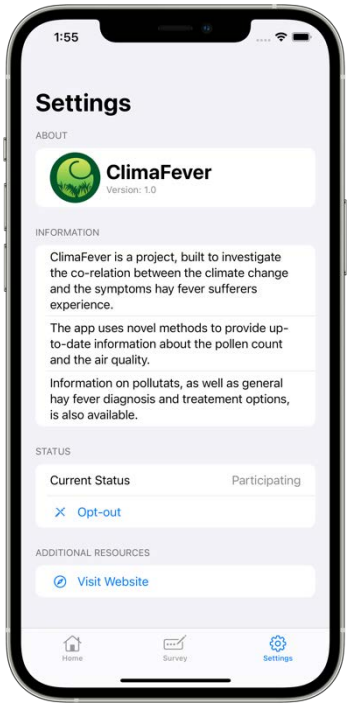

Figure 2-15 Settings view

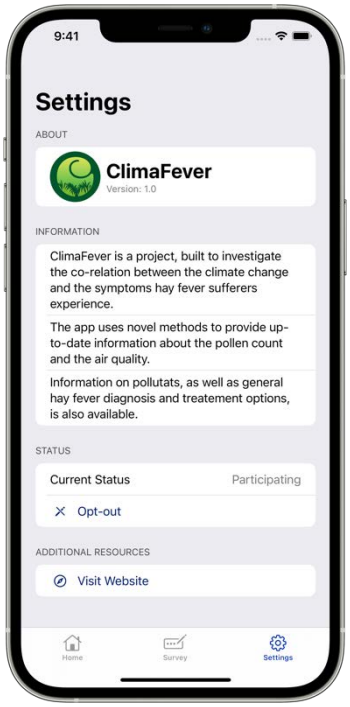

Figure 2-16 Settings view with Increase Contrast on

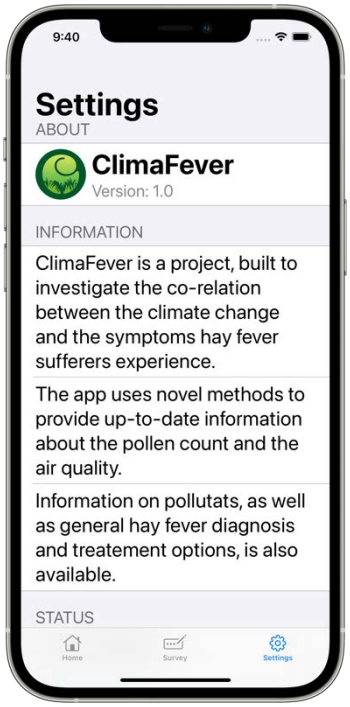

Figure 2-17 Settings view with Larger Accessibility Sizes on

When it comes to websites, the World Wide Web Consortium (W3C) has developed the Web Content Accessibility Guidelines (WCAG). It defines four principles - **perceivable**, **operable**, **understandable**, and **robust** – each one containing 12-13 guidelines [112]. Each guideline specifies testable success criteria, which corresponds to either level A, AA or AAA, with A being the least strict one. Level AA is required for legal compliance and is the one the project will aim to achieve [113]. Some of the best practices that will be followed are using **semantic tags**, **responsive text** and maintaining **good colour contrast ratios**.

Accessibility testing will be performed as part of the usability testing of the platform. For the iOS application, it will be performed manually, using Xcode's environment overrides and accessibility inspector. The website will be verified with an automated accessibility checker.

2.10 Development environment

The system is developed on MacBook Pro 16’ (2019) with a 2.6 GHz 6-Core Intel Core i7, 16 GB of RAM, Intel UHD Graphics 630 video card and 512 GB SSD. The operating system is macOS Big Sur 11. The iOS app is tested on iPhone 12 and iPhone 12 Pro Max, both running iOS 14. The project is to be developed using Xcode 12. Additionally, Visual Studio Code is going to be used for developing the website.

Minor versions (.X) of the software and the operating systems are not specified, as the most up-to-date versions will be used at any time. This would allow for taking benefits of the latest changes of the SDKs. Furthermore, as SwiftUI is still a new framework, bug fixes are constantly being delivered, thus frequent updates are needed.

2.10.1 Xcode

Xcode is an integrated development environment (IDE) for macOS, developed by Apple. It allows building iOS, macOS, watchOS and tvOS applications and provides developer with tools to test, analyse, optimise, and submit apps to the App Store. Xcode comes with a simulator which allows for testing the applications on different devices and under different environments – such as system appearance (light or dark) and various accessibility settings.

Version 12, released in September 2020, comes with many notable improvements. These include a brand-new look for macOS Big Sur, document tabs and improved code completion. The new version can also build Universal applications. They work natively on both Intel-based CPUs and Apple Silicon.

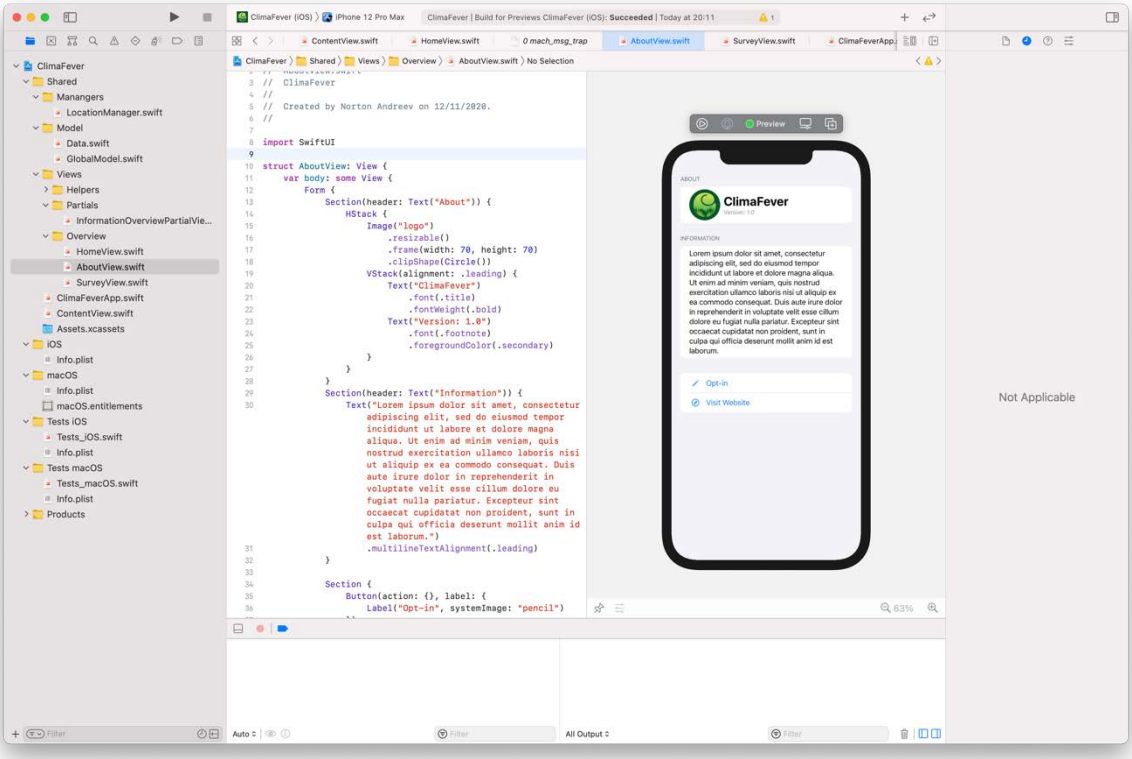

Figure 2-18 Xcode 12.3 running on macOS Big Sur

Chapter 3

Requirements and analysis

3.1 System description

The system consists of an iOS application and a website. The iOS application will be available on the App Store for anyone to download. Information about the pollen count and the air quality at the user's location will be presented. The values will be associated with a respective risk level. Users will be able to see what each pollutant is and how it can be dangerous for health. Additionally, general recommendations will be provided. For example, users will be advised to avoid outdoor activities, when the air quality is considered unhealthy. As the project is based around hay fever, information on diagnosis, treatment and symptoms management will be available.

A short research survey will be part of the iOS application. It will ask the users if they have been diagnosed with hay fever before, as well as what symptoms, if any, they have experienced during the day. The following information will be stored together as a single entry:

- user's location
- user's response to the survey
- current pollen count at that location
- current air pollutants levels
- current date and time

The summarised data will be displayed on a website. In that way, the connection between the graphical location, air pollution, pollen count and the symptoms onset can be analysed.

As the user's personal information is not needed for the purposes of the research, users will not be required to create accounts. This will allow for data anonymization. In order to be able to track if the user has given consent to participate in the research, an invitation system will be developed.

User will be given a random **Invitation ID**. It will be associated with a status – either "**Invited**", "**Participating**", "**Restricted**" or "**Withdrawn**". The user will have to type in the ID within the application, in order to get the survey option activated. Once used, the ID will be stored locally on the device and will become invalid for consecutive use. This would prevent it from being shared with others. As it is important for participants to give consent, the invalidation will protect the data integrity. If the user decides to opt-out, the survey feature will get locked. A limitation of this method is that users will have to request a new Invitation ID if they reinstall iOS or move to a new phone. However, this should not be an obstacle for the purposes of the project and the benefits outweigh this limitation.

A pre-set test account will be used for the website's usability evaluation and will be distributed to the testers. Account creation from within the website will be disabled. Even if the data on the website will be anonymous, this will ensure even further protection.

As a future development, it is possible to add additional features using the CareKit framework. This would allow for users to see statistics about their symptoms, as well as to get reminded to take their medication. As this data is not required for the purposes of the research, it can either be stored locally or under the user's personal iCloud account (utilising Apple's CloudKit framework).

The use case diagram is a high-level representation of the user's interaction with the system.

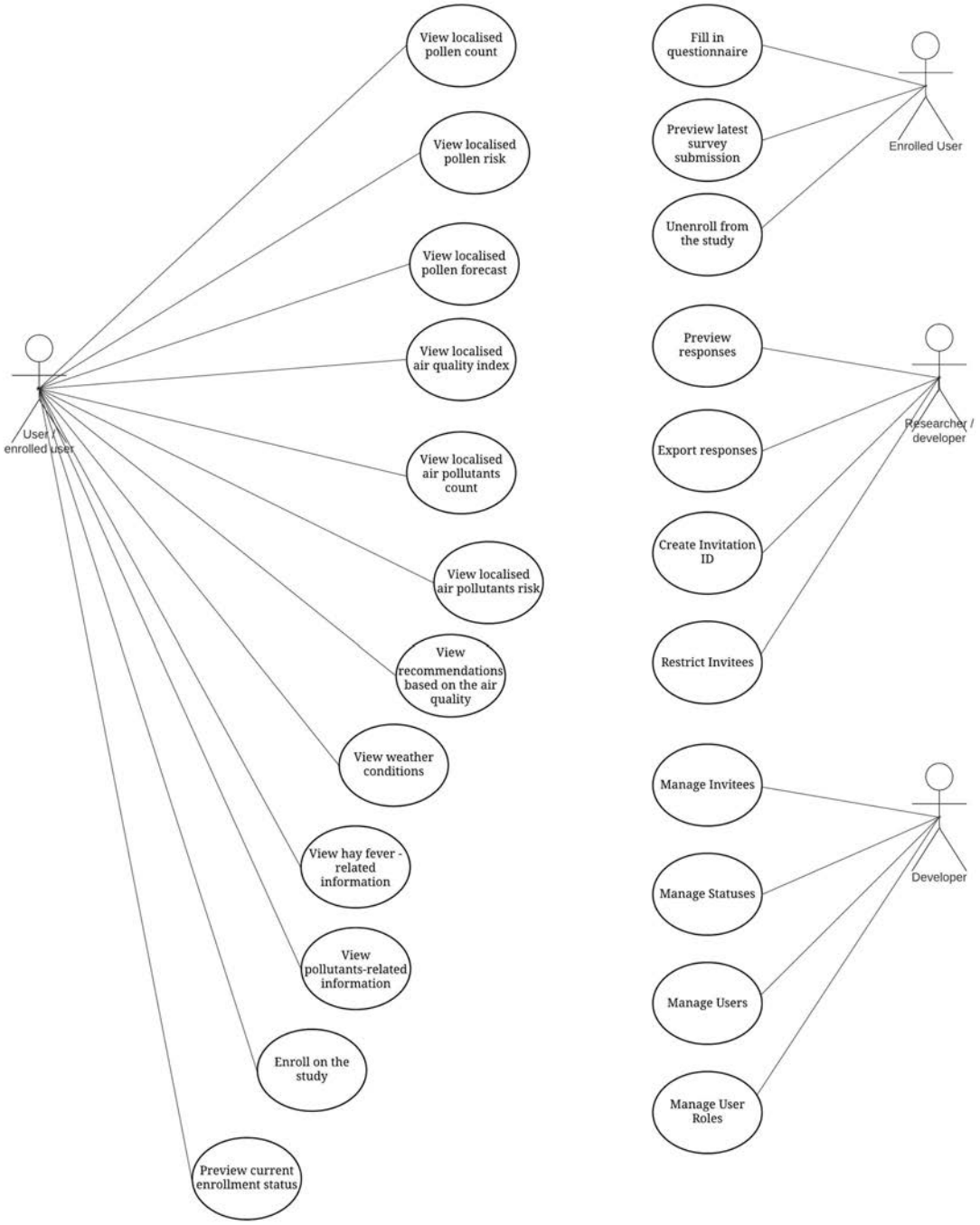

Figure 3-1 ClimaFever use case diagram

3.2 Requirements

The requirements of the system are presented as user stories. They are commonly used in the Agile software development and provide a high-level description of the desired software functionality [114].

The user stories follow the structure:

As a <*type of user*> I want <*goal*> so that <*reason*>.

The possible <*type of user*> are:

- **user** – anyone who have access to the application (via TestFlight or App Store)
- **enrolled user** – anyone who has been given an Invitation ID and has given consent to participate in the evaluation of the research questionnaire
- **researcher** – anyone who has been given access to the website which provides the results from collected from the enrolled users
- **developer** – the developer who access to the website and can perform all CRUD operations

A popular mnemonic for writing Agile user stories is INVEST. It stands for Independent, Negotiable, Valuable, Estimable, Small and Testable. Summarising, each user story short be as independent as possible, valuable for the client, able to be estimated (so that it can be prioritised), small, as well as testable, in order to show that it has been completed.

Each story contains an acceptance criterion. Not only it aims at communicating the outcome of the story with the client, but also helps developers have the same perspective on what and how a given user story should achieve [115]. For the purpose of the project, the acceptance criteria are presented as a set of steps, which, when followed in sequence, should achieve the goal of the story.

Finally, each user story should be prioritised. The MoSCoW model has been adopted for prioritising by value. MoSCoW stands for **m**ust have, **s**hould have, **c**ould have, **w**ould have (or alternatively, will not have this time) [116].

The full list of user stories can be found in **Appendix A User Stories**.

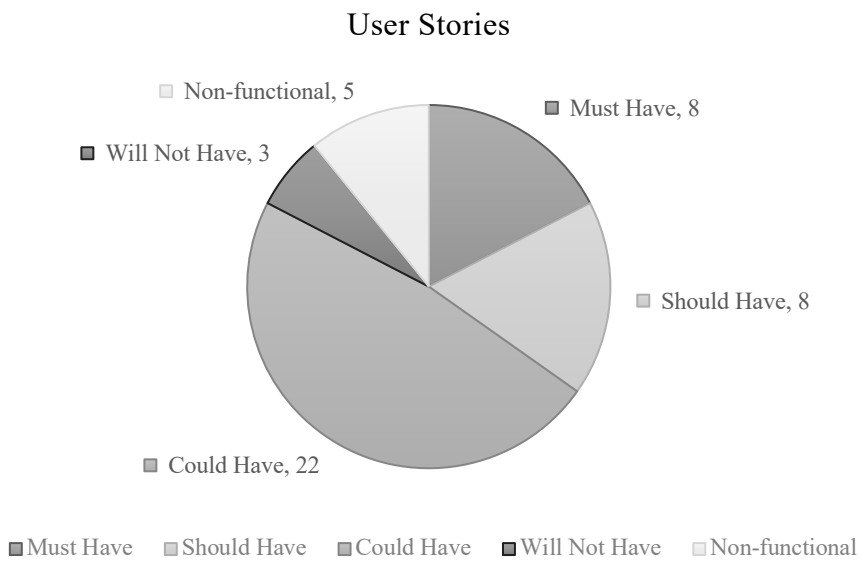

Figure 3-2 User stories distribution

There are eight essential stories needed to be implemented in order to achieve the main goals of the project. These include enrolling and unenrolling in the study, filling in the survey and allowing for the data to be accessed from a website. The must have requirements include building the whole system. This includes the integration with ResearchKit, the API to be used for pollen and air quality data, the connection with the database, as well as the website itself.

While the pollen count and air quality data will be stored alongside the survey responses, it is not essential for the users to be able to see this data. However, as the project focuses on hay fever, knowing the pollution level can be very helpful, so the data will be presented to the users. All features, related to that, are part of the "Should Have" user stories.

"Could Have" user stories focus on supplemental features, such as Apple Watch complication and an iOS Widget. While not essential for the project, these features will provide additional value for the users. Furthermore, none of the currently existing apps, targeted at hay fever users, have them. In addition, access to information about hay fever and pollutants will be made available. The "could have" user stories also include features which would be useful for the users with role developer. These will made testing and implementation easier.

Most of the "Will not have" user stories are related to features which are not required for fulfilling the aims of the project. An example is integration with CareKit which can provide ability for users to log their symptoms so that they can see trends and share them with a health care provider.

The development project will be split in two iterations. The first one will cover all the essential user stories (must have). Upon completion, "should have" and "could have" will be implemented. This will be followed by a short period of evaluation and planning of the second iteration. It will focus on fixing bugs, found in the initial delivery, acting on feedback, gathered during the evaluation, as well as implementing CareKit integration, if time allows.

3.3 User Interface

As SwiftUI allows for fast prototyping, the mock-ups of the app were created directly with it. This has a few benefits – it saves from development time and gives a realistic idea of what the final application will look like in the very early stages. Some of the key views are presented below:

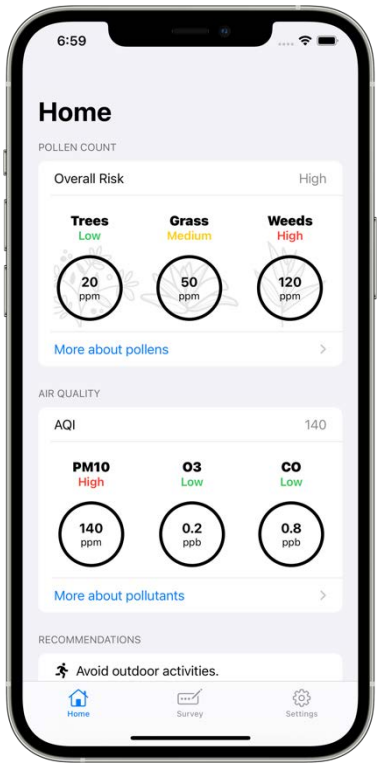

Figure 3-3 Home view (Light Appearance)

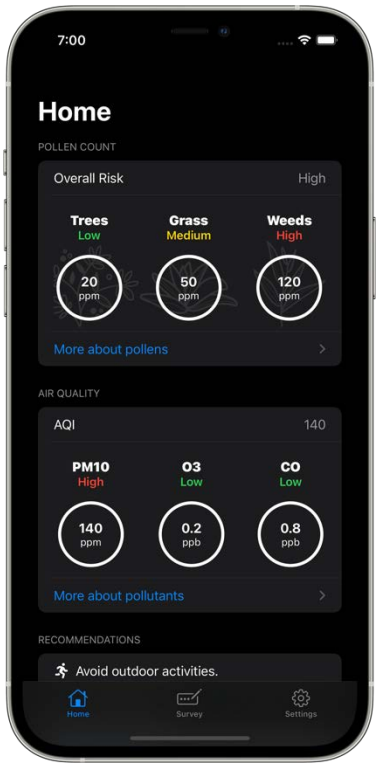

Figure 3-4 Home view (Dark Appearance)

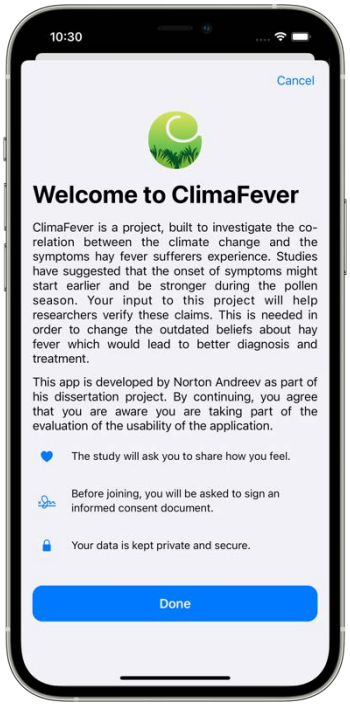

Figure 3-5 Research onboarding view

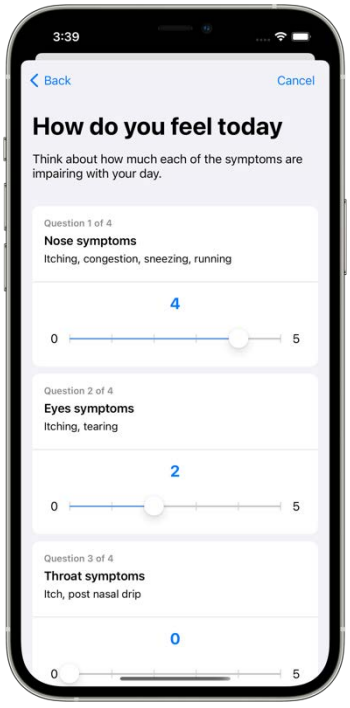

Figure 3-6 Questionnaire view

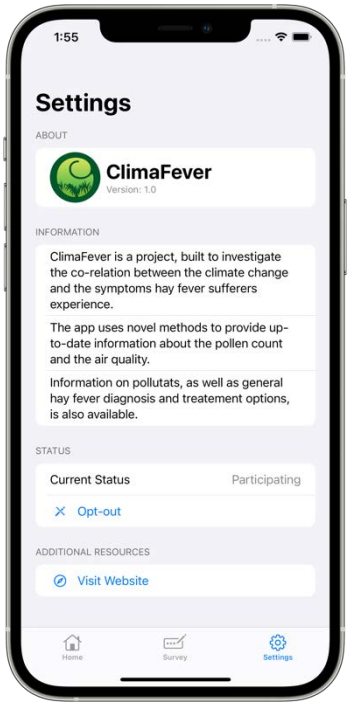

Figure 3-7 Settings view

3.4 Risk Analysis

As part of the project, a risk analysis has been performed. The risk register has been revisited multiple times to ensure new risks identified are taken into consideration promptly. Only some of the risks are discussed here, the others can be found in the risk register (see **Appendix B Risk Register**). The major risks are:

- **Bugs in the IDE and the SDKs** – especially as SwiftUI, which is going to be used for the project, is a new framework, bugs are unavoidable. Always the most up-to-date versions will be used, to ensure bug fixes are applied as soon as they are made available.
- **Incompatible tools or frameworks required for achieving the requirements** – this is a potential risk, as many tools lack support for SwiftUI. To mitigate this, either compatibility is ensured before finalising the requirements or alternatives are identified. For example, if integrating ResearchKit into a SwiftUI application turns out to be impossible or time-consuming beyond what is reasonable, a custom questionnaire will be developed instead.
- **Insufficient time to complete the project** – which might lead to delivering the project in a non-satisfactory state. To ensure being up to speed, a Gantt chart is used to track the progress made. Requirements are carefully prioritised, putting the core ones as the most important. The project repository will always contain a ready to deliver build of the project. The work on the project will be done evenly throughout the year. Regular meetings with the supervisor will be scheduled. Christmas and Easter holidays will be used to make progress.
- **Inability to evaluate the usability of the project** – this might be tricky, as it is largely dependent on how many people will participate in the evaluation. To mitigate the risk, each story has an easy-to-follow acceptance criteria, so that anyone can assess the completeness of the user stories. Furthermore, unit and manuals tests will be produced.

What would be a high risk in a production system, is classified as a medium risk in the context of the project:

- **The API(s) used might provide unreliable or low-quality data** – as discussed in section 2.3, monitoring air quality and pollen count is difficult. The data used comes a 3rd parties which rely on machine learning techniques to collect and report the data. Combined with other issues, such as poor pollen monitoring coverage and its manual counting nature, this means the data cannot be accurate at all times. As the project builds an experimental platform and the evaluation focuses on the software usability instead, this is less of an issue.
  However, to ensure all best practices are followed, the users will be made aware of the fact that the data might not be fully accurate, nor that it should be used in any medical context (cannot be used for diagnosis or to help with symptom management). Furthermore, the API communication will be made via a protocol, so that the API can easily be replaced with a different one in the future, without making many changes to the code.

3.5 Ethics

As various stages of the project include human participants, ethics approval was sought from the University of Sheffield. The application form can be found in **Appendix C Ethics Application**. The supporting materials are in **appendices D – J**. The ethics approval letter can be found in **Appendix K**.

As ClimaFever consists of a web app and a mobile app, evaluation of both is needed. Furthermore, the researched-based questionary available within the app also needs an informed consent. The ethics approval covers the evaluation of the application which includes answering an online survey about the usability and the user experience, as well as participating in the researched-based survey within the application to perform the evaluation.

To follow the best practices, the participant's data is anonymised (where possible) and is kept on encrypted storage for a duration agreed on in advance. Each stage, that requires human participants, has its own informed consent which participants must agree with to proceed with their contribution to the project.

Ambee has agreed to share its experience when it comes to the API for air quality and pollen count monitoring. An interview was scheduled to discuss use cases of the product they provide. As a relatively new service, plans for future development were also discussed. As the Ambee's API is integrated within the project, this gave insight of what some of the future improvements of the ClimaFever app might be.

3.6 Legal Considerations

Special care will be taken where information or assets from 3rd parties are used:

- **Air quality and pollen count information** is taken from an API built for that purpose.
- **General diagnosis and treatment information**, that will be presented within the app, was decided to be directly linked to the websites which host the content. Trusted sources were used, and no issues are raised, as the data is not reused within the application, but the user is sent to the website instead.
- The creators of all **royalty-free stock photos and illustrations** used are attributed under "Acknowledgements" section within the application.

Chapter 4

Design

4.1 System Design

ClimaFever consists of an iOS app and a dynamic website. SwiftUI is the framework used for the front-end of the iOS application. In order to be able to store, summarise and display the information collected via the app, a back-end is needed. ResearchKit does not provide data management solution [117].

As of 2021, there are numerous of web framework. Some of the most popular ones are Ruby on Rails, Laravel, Express and Django. A newer framework, based on Swift, is Vapor. The decision on which one to use is based on previous experience and project requirements.

The back-end solution chosen is Ruby on Rails. Rails is a server-side framework which incorporates the best software engineering practices, such as DRY (do not repeat yourself) and convention over configuration [118]. Some benchmarks suggest that Rails is among the slowest options available and far behind Vapor [119]. Slow performance and scalability issues can become apparent in very big apps and when bad software engineering practices are followed. As ClimaFever is a relatively small project, the performance and scalability concerns are out of scope. Rails is a mature system that has been receiving continuous updates with major improvements, both feature and performance wise. Some popular companies, which use Rails, are Airbnb, GitHub, Twitter, Hulu and others [120].

Using Rails, the iOS and the web application share a common back-end, so the data is easily available between them. The data flow diagram below represents a high-level of this architecture.

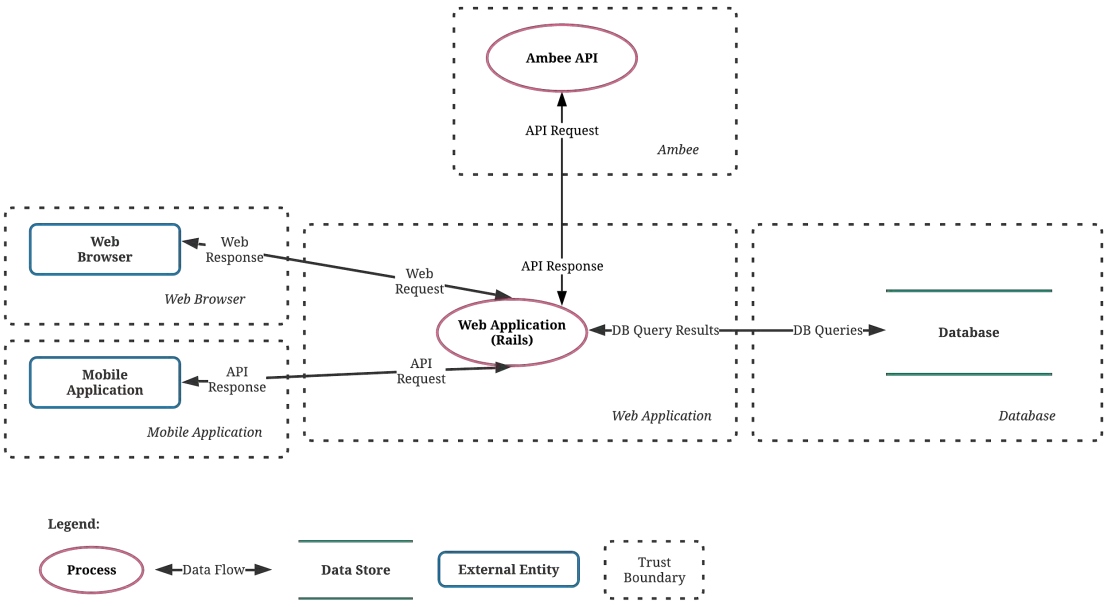

Figure 4-1 Data flow diagram

The Rails back-end also handles the requests to the Ambee API. This ensures that **API secret keys protection**, as they are not stored on the client, but as an environment variable on the server instead. Having this architecture also allows for better testing, as different errors can easily be simulated during development.

4.2 Design Patterns

The project relies on two widely used software design patterns – **MVC** and **MVVM**. Rails is based on MVC, while SwiftUI works with MVVM. UIKit also uses MVC and, as ResearchKit is UIKit-based, it can be said that combination of both is incorporated within the iOS application.

4.2.1 Model-View-Controller

MVC contains the following components:

- **Model** – represents the data and defines the business logic
- **View** – displays the model to the user and allows user interaction
- **Controller** – intermediary between the models and the views

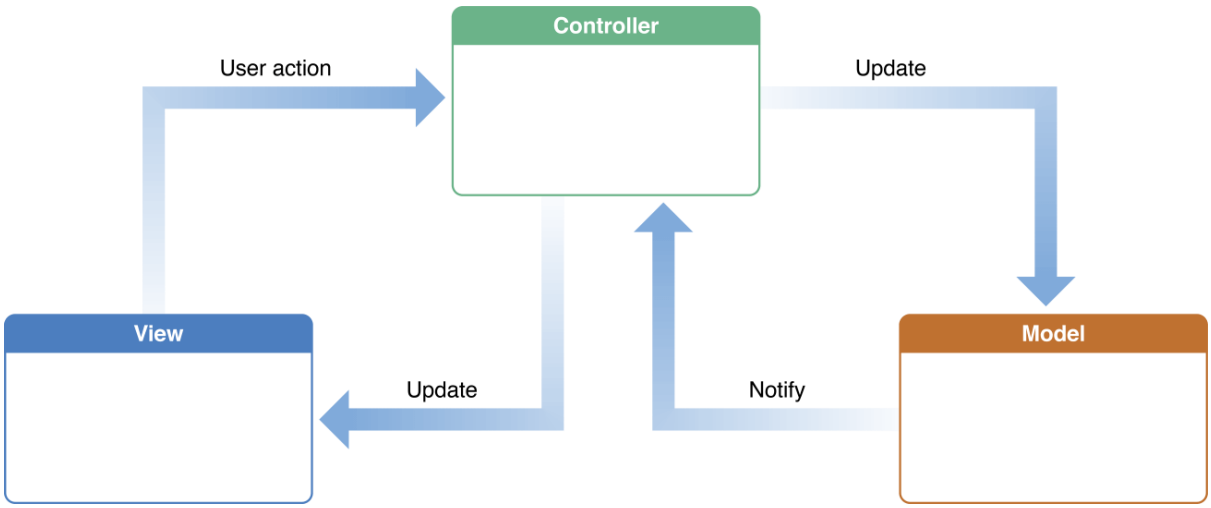

Figure 4-2 MVC Design Pattern
Source: Apple [121]

When the user interacts with a view, the action is communicated through the controller which in turn modifies or deletes the data in the model. Once the operation has been executed, the model notifies back the controller, which initialises an update of the view.

4.2.2 Model-View-ViewModel

The main aim of MVVM is separation of the GUI from the business logic of the application. Like MVC, in MVVM, the Model defines the data, and the View is responsible for displaying the data and handling user interactions. However, the ViewModel is seen as an abstraction of the View while providing a wrapper of the Model data [122]. The ViewModel binds View to Model. It notices changes in the Model and publishes them. The View is automatically observing the publications and invalidates and rebuilds when a change is observed (also known as **reactive programming**). In this way, the view cannot out of sync with the model, which can easily occur if using the MVC pattern. The ViewModel is also responsible for receiving user intent from the view and modifying the model.

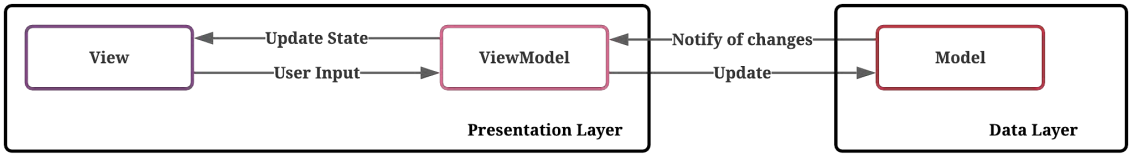

Figure 4-3 MVVM Design Pattern

While there are various ways of implementing the MVVM pattern. One way is to separate the services that manage the business logic from the ViewModel. However, it was decided to put the business logic in the ViewModels instead, in order to ensure low coupling[5]. The ViewModels in ClimaFever are named as "services". Three of them are defined to fulfil the core operations:

- **EnvironmentalService** – responsible for obtaining the Environmental data from Ambee's API, responds to changes in user's location and provides helpers for the View, in order to ensure that the data is displayed correctly (for example, handles operations such as rounding of Doubles).
- **UserDataService** – responsible for checking the Invitee status and reads and stores values to the UserDefaults.
- **SurveyResponseService** – responsible for submitting responses to and retrieving responses from the server.

4.3 Project File Structure

The Rails application uses the default file structure, so it is not discussed here. The general project structure of the iOS application is presented below:

Folder	***Purpose***
Networking	Contains the custom-built networking module and all files its dependant on. Can easily be extracted and reused in another project
Configuration	Contains the Xcode Build Configuration Files for the different environments (Development and Production)
Helpers	Contains a collection of files which provide helpful additions to existing features (such as extensions), as well as helpers for the Views
Managers	Contains a collection of classes which monitor specific trait of the environment (such as connectivity or location)
Model	Contains the modes, as well as the viewmodels
Views	Contains the SwiftUI views

Table 4-1 ClimaFever App File Structure

[5] the degree of interdependence between software modules

4.4 Database Design

The database diagram below represents the database design of the system.

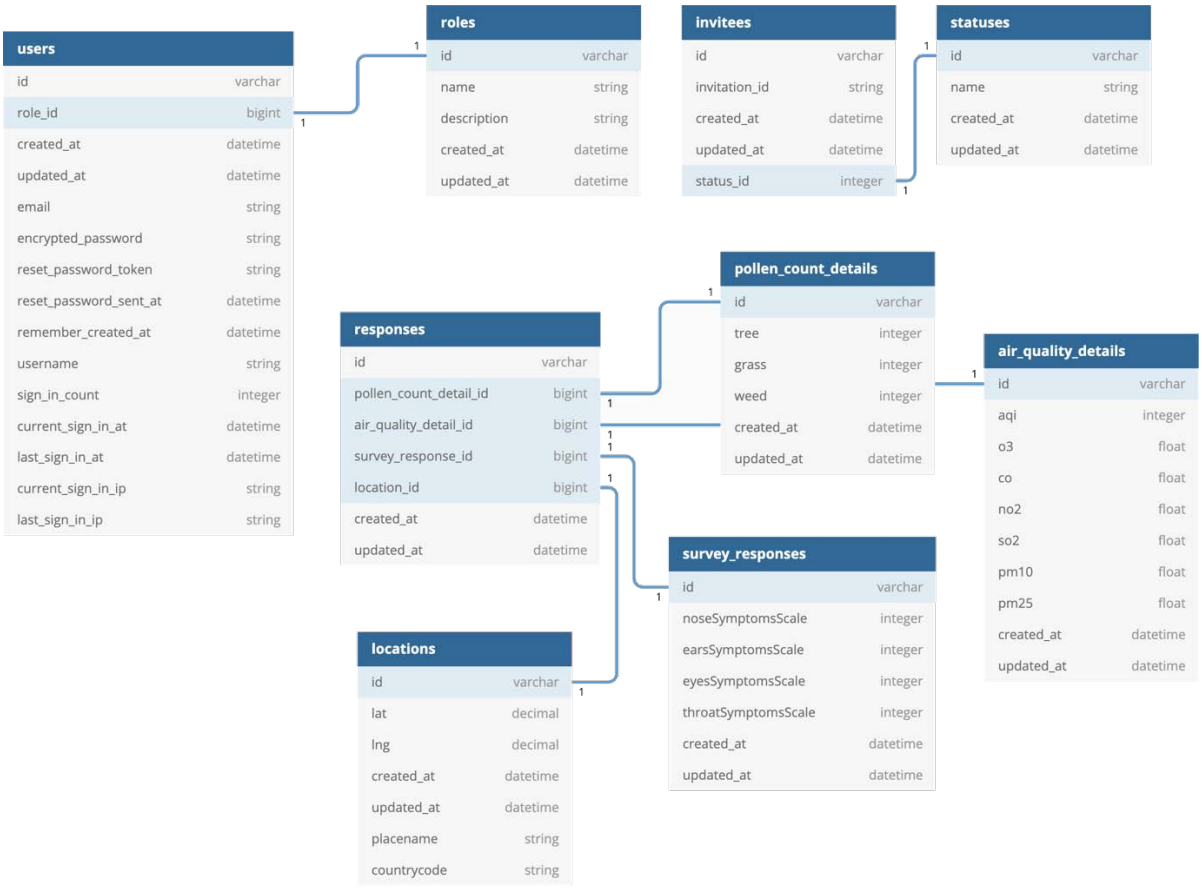

Figure 4-4 Database diagram

The main entities are:

4.4.1 User

The User model stores the users that have access to the ClimaFever website. Each user is assigned a role which is granted the required permissions (as specified in **Section 4.3 Roles and Access Control**).

4.4.2 Invitee

Invitees are those who have been invited to participate in the research project. Once invited, they can use their Invitation ID number to register within the iOS app and access the ResearchKit survey. **The Invitation ID is an alpha-numeric and consists of five characters.** Each Invitee is associated with a status within the system - **Invited, Participating, Withdrawn** or **Restricted**

4.4.3 Response

Once an invitee has submitted their response to the ResearchKit survey, the reported symptoms, the pollen count, the air quality data, and the invitee's location are stored together. The data is then accessible on the website and can be exported as an Excel spreadsheet for analysis.

4.5 Roles and Access Control

The ClimaFever website implements Role-Based Access Control (RBAC). This allows for roles to be created for various functions. The permission to perform a certain operation is dependent on the role.

In mathematical terms, RBAC is formalised as:

- A set ROLES
- A set USERS
- A relation User Assignment (UA) defined as UA ⊆ U × R
- A relation Permission Assignment (PA) defined as PA ⊆ R × P

Deriving the relation between user and permission is derived by joining the relations UA and PA [123].

ClimaFever website supports two type of roles – **Developer** and **Researcher**. Their permissions are defined as follows:

	Researcher	**Developer**
Responses	View	View, Delete
Invitees	View, Create, Restrict	CRUD[6], Restrict
Statuses	✗	CRUD
Users	✗	CRUD
Roles	✗	CRUD

Table 4-2 Role Permissions

The **Developer** role is given permissions to perform operations which are either destructive or differ from the established requirements of the platform. For example, the Invitee statuses are defined with the same enumeration in the iOS application and match the software specification. A mismatch would lead to a runtime crash. Another example is with the invitees – they are not supposed to be deleted after once created. While they can be restricted (and thus user will be prevented from accessing the ResearchKit survey within the iOS application), deletion means that the retention could not be measured. In that sense, the **Developer** role is useful for development and debugging purposes.

To avoid unwanted creation of new users, the user creation process is saved for the Developer role. This ensures that evaluators of the platform cannot delete, edit, or create new accounts. Such operations are usually reserved for the roles with the highest permissions in a real-world system as well.

[6] Create, Read, Update, and Delete

4.6 Networking

As data is requested and sent over the internet, networking is fundamental aspect of every modern mobile application. Swift supports URLSession API for downloading data from and uploading data to different endpoints [124]. It has been available for over seven years now. Alamofire is an alternative, third-party, solution. Alamofire is built on top of the URLSession API and is one of the most used Swift libraries [125]. Some of its benefits are that the syntax is shorter, and it is easier to use. While Alamofire is very well maintained, adding a third-party library to any project can always cause integration or other types of issues, as well as security concerns. After an evaluation of the requirements, it was decided that implementing a custom networking layer would be a better fit for the project.

4.6.1 API & API Endpoints

APIs allow for two or more systems to be integrated and communicate together. The client makes the requests, while the server sends back information. Each API can have one or more endpoints which allows for resources to be accessed. The endpoints are defined with URLs (Uniform Resource Locator) which is their address. The communication is most often via RESTful API. In those cases, the requests are managed through HTTP and should support POST, GET, PUT, PATCH and DELETE methods. The ClimaFever iOS application communicates with the back-end using the following endpoints:

Endpoint	Method	Description
/api/v1/environment_data/get_latest_pollen_data	POST	Requests the latest pollen data from Ambee API and returns it back to the client
/api/v1/environment_data/get_forecast_pollen_data	POST	Requests the latest forecast pollen data from Ambee API and returns it back to the client
/api/v1/environment_data/get_latest_airquality_data	POST	Requests the latest air quality data from Ambee API and returns it back to the client
/api/v1/environment_data/get_latest_weather_data	POST	Requests the latest weather data from Ambee API and returns it back to the client
/api/v1/responses/get_response	GET	Returns the requested Response from the database
/api/v1/responses/post_response	POST	Stores a Response to the database
/api/v1/invitees/get_invitee	GET	Returns the requested Invitee from the database
/api/v1/invitees/update_invitee_status	POST	Updates the Invitee status

Table 4-3 API Endpoints

Instead of the client communicating with Ambee API and obtaining the environmental data directly, this task is delegated to the server. This has some benefits. For example, the iOS app can be debugged and tested much more easily, as the developer has control over what the backend returns. This is useful for simulating different error conditions. It is also cost-effective, as requests to external APIs are usually charged and would incur unnecessary cost during development and testing.

4.6.2 Error Conditions

The implemented networking layer should be able to handle different HTTP client and server errors that can occur. The supported errors are:

Error Code	Error Description
400	Bad Request
401	Unauthorised
403	Forbidden
404	Not Found
429	Too Many Requests
503	Service Unavailable

Table 4-4 HTTP error status codes

Furthermore, the networking layer is also responsible for decoding JSON data as objects once a response has been received. This can cause an exception if the response does not match the expected object. Exceptions can also be raised from the URLSession API itself. This means that a few additional errors must be defined and handled:

- Invalid Response Received
- Malformed URL
- Request Time Out
- Network Connection Was Lost
- Unknown Error

More error conditions can be added in future, if deemed necessary. However, these cover the minimum needed to provide a reliable user experience.

4.7 Features

There are some features that could have been implemented in different ways. This section presents them and justifies the approach taken with each of them.

4.7.1 ResearchKit Questionnaire

After receiving an Invitation ID, following on-screen instructions, and giving consent to participate in the research project, users are presented with short survey which asks about what impact their hay fever symptoms has on their daily activities (**0 – none impact, 1 – low impact, 2 – medium impact, 3 – high impact**). This is split into the following categories:

Affects:	**Symptoms:**
Nose	Itching, congestion, sneezing, running
Eyes	Itching, tearing
Throat	Itch, postnasal drip
Ears	Itching, blockage

Table 4-5 Self-assessment questionnaire content

The survey could have alternatively just asked for the overall state without going into details, but this would have made it way too short. Furthermore, it might have made it harder for users to judge what their overall state is, without any further guidance. It is also possible that some might not associate a certain symptom with hay fever and thus respond with a lower impact score than what the reality is.

While other symptoms, such as tiredness, headache and loss of smell can also be attributed to hay fever, they are way too broad and were excluded from the survey [126].

A design decision in regard to when users can submit the survey had to be taken. The initial requirements stated that the user should be able to fill in the survey once every 24 hours. However, this might not capture how the user felt during the day. For instance, a user might fill in the survey in the morning, answering they do not experience any symptoms, but their might start to do so during the day. A possible solution would be to store the Invitee ID alongside the survey response, so that, if the survey is resubmitted, only the last submission for the given day is kept. However, this idea was rejected, so to keep the responses anonymous. Another option would have been to guide the users to fill in the survey at the end of the day, or, even more limiting, to make the survey available only in the last few hours of the day. The main concern was that limiting users would most probably lead to less responses and lower overall user satisfaction with the system.

4.7.2 Pollen Health Risk

The customised health risk associated with the pollen count is one of the unique ClimaFever's features. Ambee API provides the risk value ("High", "Medium", "Low") associated with each of the three main type of pollens. However, how to calculate the overall risk for the user does not become apparent immediately.

One of the considered options was converting the risk of each pollen type to a respective numeric value (3 – high, 2 – medium, 1 – low) and taking its average. For example, having a high pollen risk associated with tree pollen, medium associated with grass and low associated with weed would result in a medium overall risk (3 + 2 + 1 / 3 = 2). The disadvantages of this method are related to either under- or overestimating the risk. For example, having medium risk associated with grass, medium associated with trees and high associated with weeds would result in either medium or high risk, based on if the floor or the ceiling of the value is taken. If a person has an allergy to more than one type of pollen and the floor is taken, a medium health risk would be an underestimate of the actual risk. On the other hand, if the values are low, low, and high instead, and the ceiling is taken, the result would be a medium risk. However, if the person is only allergic to one of the pollens, which has a low concentration in the air, and thus a low risk, a medium risk will be an overestimate Because of drawbacks of this method, it was decided to use the risk for the grass pollen as a default and display it as the overall health risk, as this is what most people who suffer from hay fever are allergic to [127]. If known, users can select what type of pollen they are the most sensitive to – **tree**, **grass** or **weed**. This changes the overall risk displayed to match the user's selection.

An alternative way would be to still use the average, based on the numeric value, while also considering the user pollen sensitivity selection. In that way, if the average is between two risks categories, the selected sensitivity can decide on if to go with the lower or the higher risk. For example, if the average is a value of 1.6 and the selected sensitivity is for a pollen that has a low count, a value of low can be displayed. Instead, if the sensitivity is to a pollen that has a medium count, a medium risk can be displayed. This might be a more sophisticated way of calculating the overall risk, however, as there is not a certain answer about what is the best way of implementing this requirement, it is not something which is necessarily seen as a priority for further investigation or implementation.

4.7.3 AQI and Recommendations

As ClimaFever uses data from Ambee (an Indian company), the AQI index reported matches the Indian National Air Quality Index. Within the ClimaFever app, the Health Risk associated with the Air Quality is reported based on the AQI value. The values are summarised below:

AQI	Remark	Health Risk	Colour Code
0 – 50	Good	None	
51 – 100	Satisfactory	Low	
101 – 200	Moderate	Moderate	
201 – 300	Poor	High	
301 – 400	Very Poor	Very High	
401 – 500	Severe	Hazardous	

Table 4-6 National Air Quality Index
Source: Central Pollution Control Board [128]

The ClimaFever iOS application provides suggestions, based on the AQI. The recommendations are based on the Air Quality Guide for Particle Pollution published by EPA (United States Environmental Protection Agency).

Air Quality Index	Who needs to be concerned?	What should I do?
Good 0 – 50		It's a great day to be active outside.
Moderate 51 – 100	Some people who may be unusually sensitive to particle pollution.	**Unusually sensitive people:** Consider reducing prolonged or heavy exertion. Watch for symptoms such as coughing or shortness of breath. These are signs to take it easier. **Everyone else:** It's a good day to be active outside.
Unhealthy for Sensitive Groups 101 – 150	Sensitive groups include people with heart or lung disease, older adults, children, and teenagers.	**Sensitive groups:** Reduce prolonged or heavy exertion. It's OK to be active outside but take more breaks and do less intense activities. Watch for symptoms such as coughing or shortness of breath. **People with asthma** should follow their asthma action plans and keep quick relief medicine handy.
Unhealthy 151 – 200	Everyone	**Sensitive groups:** Avoid prolonged or heavy exertion. Consider moving activities indoors or rescheduling. **Everyone else:** Reduce prolonged or heavy exertion. Take more breaks during outdoor activities.
Very Unhealthy 201 – 300	Everyone	**Sensitive groups:** Avoid all physical activity outdoors. Move activities indoors or reschedule to a time when air quality is better. **Everyone else:** Avoid prolonged or heavy exertion. Consider moving activities indoors or rescheduling to a time when air quality is better.
Hazardous 301 – 500	Everyone	**Everyone:** Avoid all physical activity outdoors. **Sensitive groups:** Remain indoors and keep activity levels low. Follow tips for keeping particle levels low indoors.

Table 4-7 Air Quality Guide for Particle Pollution
Source: United States Environmental Protection Agency [129]

To display the USA-based recommendation using the Indian AQI values, the following mappings are used:

EPA Air Quality Index	**National Air Quality Index**
Good 0 – 50	Good 0 – 50
Moderate 51 – 100	Satisfactory 51 – 100
Unhealthy for Sensitive Groups 101 – 150	Moderate 101 – 200
Unhealthy 151 – 200	Poor 201 – 300
Very Unhealthy 201 – 300	Very Poor 301 – 400
Hazardous 301 – 500	Severe 401 – 500

Table 4-8 EPA AQI vs NAQI

Chapter 5

Implementation and Testing

5.1 iOS Application

This section showcases the features implemented within the iOS application.

5.1.1 Onboarding Experience

The first time ClimaFever is opened, an onboarding screen is presented to the user. It consists of two views – a features overview and settings.

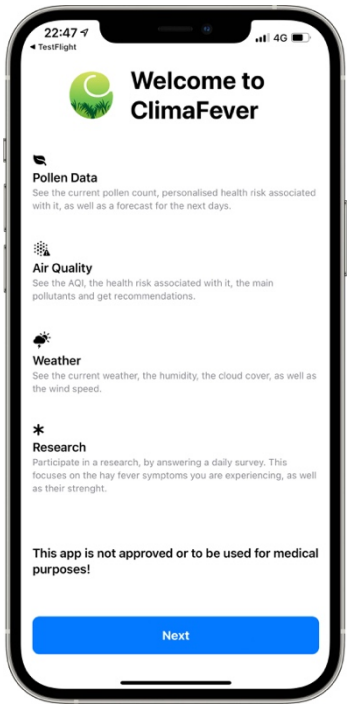

Figure 5-1 Features Overview View (Onboarding)

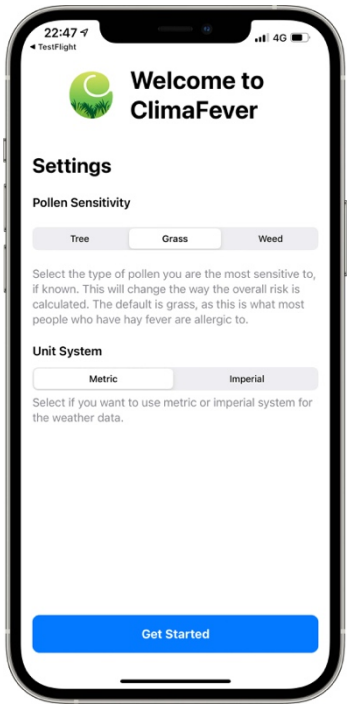

Figure 5-2 Settings View (Onboarding)

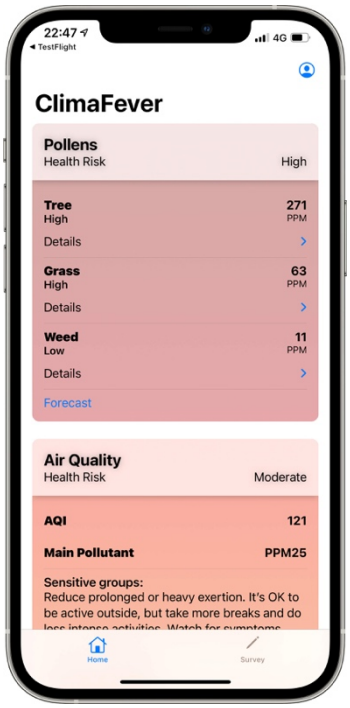

Figure 5-3 ClimaFever Home View

The settings view allows the user to **select their pollen sensitivity**, that is, the pollen they are known to be allergic to. If not known, grass pollen is selected by default, as most people are allergic to it. Additionally, the settings view allows the user to **choose between the Metric and the Imperial unit systems**. The selection is used for displaying the weather data. On tapping "Get Started", the Home view appears. The home view gives overview to all data users might be interested in – pollen data and the customised health risk associated with it, the air quality data, and the weather conditions. Adhering to good design principles, **everything the user might be interested in is easy to find and does not require navigating in a deep hierarchy**. The application uses Tab Bar[7] navigation, which is inherent to most native iOS applications.

[7] appears at the bottom of an app screen and lets people quickly switch among different sections of an app

5.1.2 Pollen Data

The first card in the Home screen displays the pollens data. The top of the card shows the personalised health risk, which is based on the user preselected pollen sensitivity.

Figure 5-4 Low Risk Card

Figure 5-5 Moderate Risk

Figure 5-6 High Risk

The card background changes based on the health risk associated. This extends to the Air Quality card as well. The main content of the card contains information about the health risk associated with each individual type of pollen (tree, grass, and weed). Each of the types can be expanded to show subtypes, as shown in **Figure 5-7 Pollen Subtypes**.

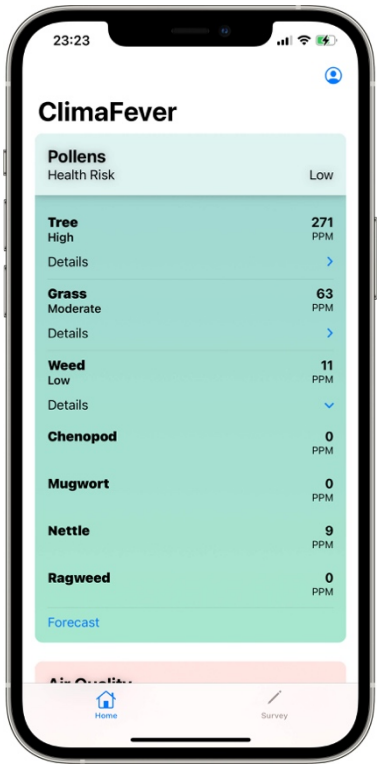

Figure 5-7 Pollen Subtypes

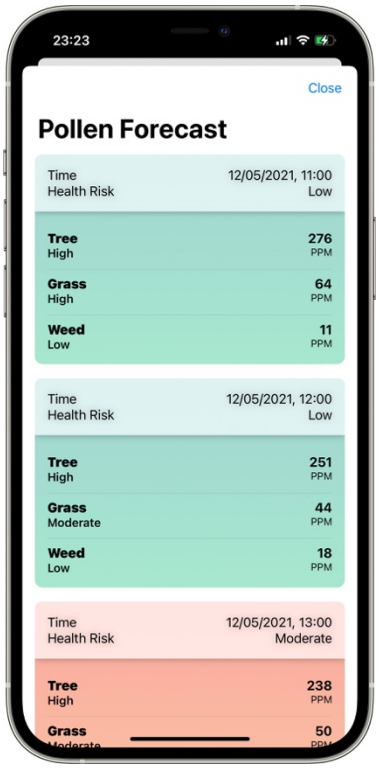

Figure 5-8 Pollen Forecast

At the end of the card, there is a “Forecast” button that opens an hourly, 2-day forecast. In shows the information using the same card design, so that it is instantly familiar to the user. However, is also shows the date and time the card is showing information for. Pollen subtypes are not available for the forecast. While this data is obtained, it was decided it is not as important for this view.

5.1.3 Air Quality Data

The second section of the Home view presents Air Quality information to the user. Similar to the pollen card, the health risk, associated with the Air Quality Index is shown at the top. The background is also based on the value of the risk, as specified in **Section 4.5.3 AQI and Recommendations**. The card displays the AQI value, as well as the main pollutant. This is followed by health recommendations, based on the Air Quality Guide for Particle Pollution.

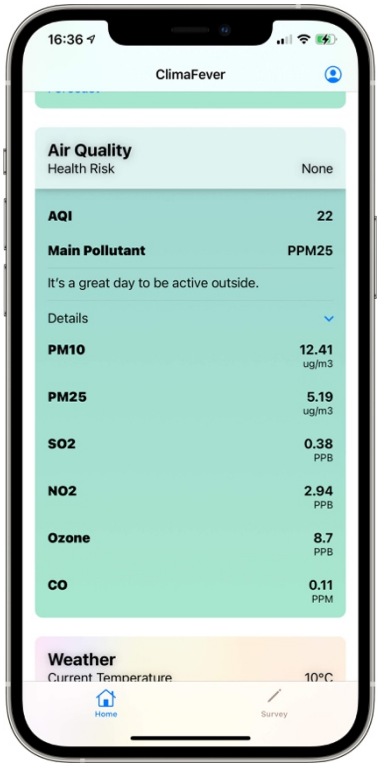

Figure 5-9 Air Quality Card Low Risk

Figure 5-10 Air Quality Card Moderate Risk

In order to keep the interface clean and to present only the essential information on the screen, it was decided to hide the individual pollutants information within a disclosure group. Unlike pollens, coming up with health risk associated with each pollutant would have been very challenging, as the air quality guidelines specify acceptable ranges within a specific period of time. Presenting a health risk associated with the current value of a given pollutant could be misleading and was avoided.

```
DisclosureGroup("Details", isExpanded: $showDetails) {
    VStack {
        DataRowElementView(heading: "PM10",
                           valueString: environmentalService.pm10DisplayValue,
                           valueMetric: Metric.ugm3.rawValue)
                               .padding(.bottom)
        ...
        DataRowElementView(heading: "CO",
                           valueString: environmentalService.coDisplayValue,
                           valueMetric: Metric.ppm.rawValue)
    }
        .padding(.top)
}
```

Figure 5-11 DisclosureGroup (Code Snippet)

The code snippet above is for the “Details” section. The initialiser takes the string key to be used for the label of the **`DisclosureGroup`**, a binding to the expansion state (which is defined as a `@State`), as well as the body of the disclosure group.

The code snippet also demonstrates code reusability by initialising custom made **`DataRowEelementView`** views. The same partials are used for the “Pollen” and the “Weather” cards as well.

```
struct DataRowElementView: View {

    var heading: String
    var subheading: String?
    var valueInt: Int?
    var valueString: String?
    var valueMetric: String?

    var body: some View {
        HStack(alignment: .firstTextBaseline) {
            VStack(alignment: .leading) {
                Text(heading)
                    .font(.headline)
                    .fontWeight(.black)
                if let subheading = subheading {
                    Text(subheading)
                        .font(.subheadline)
                        .fontWeight(.semibold)
                }
            }
            Spacer()
            VStack(alignment: .trailing) {
                if let valueInt = valueInt {
                    Text(String(valueInt))
                        .fontWeight(.bold)
                } else if let valueString = valueString {
                    Text(valueString)
                        .fontWeight(.bold)
                }
                if let valueMetric = valueMetric {
                    Text(valueMetric)
                        .font(.footnote)
                }
            }
        }
    }

}
```

Figure 5-12 DataRowElementView (Code Snippet)

The **`DataRowEelementView`** is initialised with a mandatory heading. The other properties, such as subheading, and the different types of values, are optional types. This is so that the partial can be reused for all different types of data which is displayed on any of the cards. For example, the subheading is used to display the health risk. It is defined as optional, as it is available for the pollens, however, it is not available for the individual air pollutants. How the information is displayed is based on what is provided on the initialiser. This is handled by the `if` statements within the definition of the body.

5.1.4 Weather Conditions

The next section gives an overview of the current weather conditions. While it was not a planned feature originally, it was among the most requested ones during the Evaluation stage. Subsequentially, it was implemented as part of the second iteration.

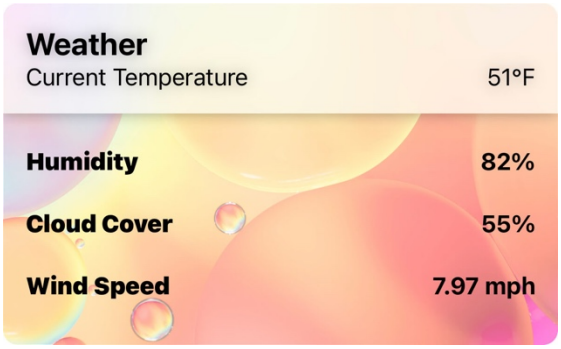

Figure 5-13 Weather Conditions Card (Imperial Unit System)

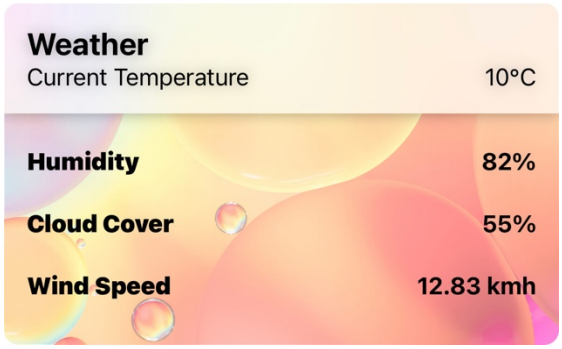

Figure 5-14 Weather Conditions Card (Metric Unit System)

The card presents the current temperature, the humidity, the cloud cover, as well as the wind speed. As mentioned in **Section 5.1.1 Onboarding Experience**, the user can set the Unit System they want to use – Imperial or Metric. As the weather conditions were the last added feature, there was no time to customise the background of the card. However, it would have been useful to have the background based on the time of the day, as well as the cloud cover, similarly to the iOS Weather app.

Figure 5-15 iOS Weather App (Sunny Conditions)

Figure 5-16 iOS Weather App (Cloudy Conditions)

5.1.5 Additional Resources

The last section of the Home view gives access to additional resources, related with hay fever and air pollutants.

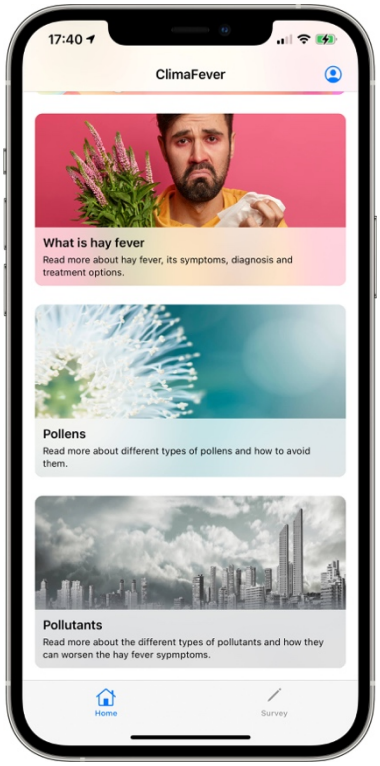

Figure 5-17 Additional Resources Section

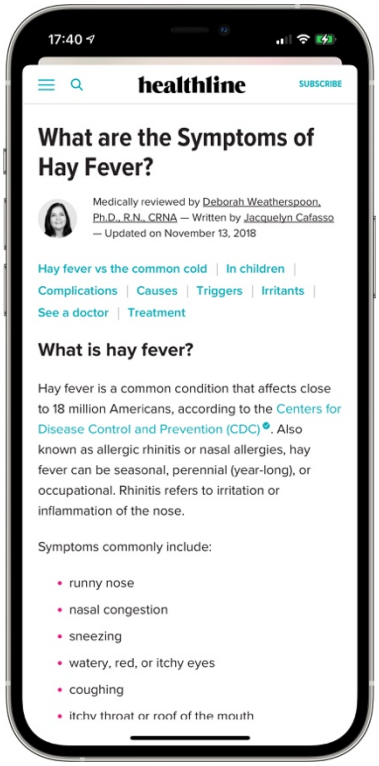

Figure 5-18 "What is Hay Fever?" WebView

Instead of making custom views for each resource, it was decided to implement **`WKWebView`** which loads a specified URL. Websites with high-quality information were selected. By linking to a 3rd party, some issues, such as reusing copyrighted content without permission are avoided. Furthermore, users might trust the information more, if they see it coming from a reputable source. As a drawback, the application relies on the 3rd party server being up and the information delivered being up to date.

`WKWebView` is a platform-native view which allows displaying web content within the app's UI. `WKWebView` is an UIKit object, so linking between UIKit and SwiftUI had to be done via the `UIViewRepresentable` wrapper.

In the original version of the implementation, multiple `.sheet` modifiers were applied to `ScrollView` view that wraps the whole Home view. On tapping any of the cards, the value of the properties defined with the `@State` wrapper change to `true`, which invalidates the view and recomputes the body of the `HomeView` struct. The sheets are initialised with the initialiser that takes a binding and a content to be displayed. A bug in iOS was found when multiple sheets are chained to the same view. In this example, four sheets are chained to the `ScrollView` view. The bug has been fixed in iOS 14.6, however, in order to ensure that evaluation can run smoothly, a workaround was implemented so to support previous versions of iOS (14.1 and above, as per the specification). The original implementation is shown in the code snippet below (all irrelevant code has been stripped out):

```
struct HomeView: View {
  @State private var showingWhatIsHayFeverSheet = false
  @State private var showingPollensSheet = false
  @State private var showingPollutantsSheet = false

  NavigationView {
    ScrollView(.vertical, showsIndicators: false) {
      ...
      CardView(image: "sick-young-man-suffering-from-allergy-isolated", title: "What is hay fever",
               content: "Read more about hay fever, its symptoms, diagnosis and treatment options."
              )
              .onTapGesture { showingWhatIsHayFeverSheet = true }
      CardView(image: "dandelion-seeds", title: "Pollens",
               content: "Read more about different types of pollens and how to avoid them."
              )
              .onTapGesture { showingPollensSheet = true }
      CardView(image: "polluted-city-background", title: "Pollutants",
               content: "Read more about the different types of pollutants and how they can worsen the hay fever sypmptoms."
              )
              .onTapGesture { showingPollutantsSheet = true }
    }
    .sheet(isPresented: $showingWhatIsHayFeverSheet) {
        WebView(url: "https://www.healthline.com/health/hay-fever-symptoms")
    }
    .sheet(isPresented: $showingPollensSheet) {
        WebView(url: "https://www.healthline.com/health/allergies/pollen")
    }
    .sheet(isPresented: $showingPollutantsSheet) {
        WebView(url: "https://www.blf.org.uk/support-for-you/air-pollution/types")
    }
  }
}
```

Figure 5-19 Chaining Sheets

The alternative implementation consists of introducing an Enum with the possible sheets to be displayed. The state property `currentSheet` stores a type of sheet. A switch statement decides which view to be displayed, based on the value of the `currentSheet` property.

```
enum CurrentSheet: Identifiable {
    var id: Int {
        get {
            hashValue
        }
    }
    case hayfever, pollens, pollutants
}

struct HomeView: View {
  @State private var currentSheet: CurrentSheet?
  NavigationView {
    ScrollView(.vertical, showsIndicators: false) {
      ...
      CardView(image: "sick-young-man-suffering-from-allergy-isolated", title: "What is hay fever",
               content: "Read more about hay fever, its symptoms, diagnosis and treatment options."
              )
              .onTapGesture { currentSheet = .hayfever }
      CardView(image: "dandelion-seeds", title: "Pollens",
               content: "Read more about different types of pollens and how to avoid them."
              )
              .onTapGesture { currentSheet = .pollens }
      CardView(image: "polluted-city-background", title: "Pollutants",
               content: "Read more about the different types of pollutants and how they can worsen the hay fever sypmptoms."
              )
              .onTapGesture { currentSheet = .pollutants }
    }
    .sheet(item: $currentSheet, onDismiss: { currentSheet = nil }) { item in
        switch item {
        case .hayfever:
            WebView(url: "https://www.healthline.com/health/hay-fever-symptoms")
        case .pollens:
            WebView(url: "https://www.healthline.com/health/allergies/pollen")
        case .pollutants:
            WebView(url: "https://www.blf.org.uk/support-for-you/air-pollution/types")
        }
  }
}
```

Figure 5-20 Chaining Sheets (Workaround)

While the alternative implementation is slightly bigger when it comes to lines of code, one could argue that using an Enum rather than Boolean properties is a better option when it comes to semantics.

5.1.6 Settings

The settings view provides access to the pollen sensitivity and the unit system settings. It also displays the participation status of the user. If the user is not participating, the Invitation ID can be typed in in a text field. This is then followed by a validation of the provided data with the server. If the provided ID is valid and the status of the Invitee is “Invited”, the ResearchKit Informed Consent view gets presented. If not, an alert with an error message is displayed instead.

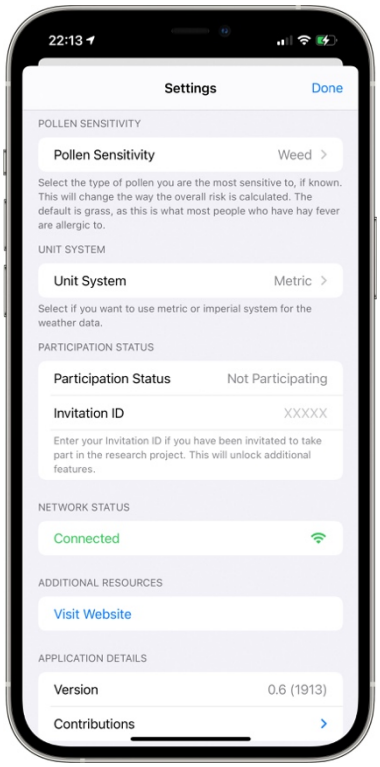

Figure 5-21 Settings View (Not Participating Status)

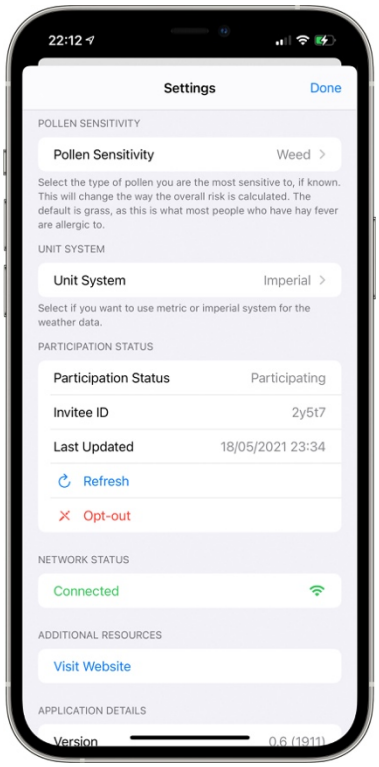

Figure 5-22 Settings View (Participating Status)

Some optimisations were made, so to ensure efficiency. For example, the validity of the Invitation ID does not get checked unless it contains five characters. Once the Invitation ID is typed in, a progress indicator is shown to give feedback to the user while the ID is validated.

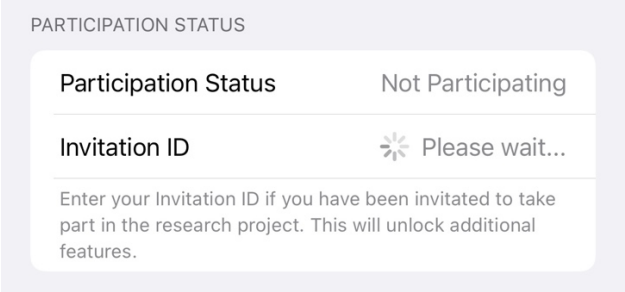

Figure 5-23 Loading Indicator (Settings View)

Once the user has signed the informed consent, the **Invitation ID** field gets renamed to **Invitee ID**, in order to recognise that the user has accepted the invitation. However, both terms are used interchangeably across the system and relate to the same functionality.

The settings, among some other properties, such as the Invitation ID, are stored in `UserDefaults`. SwiftUI 2 has introduced a new property wrapper – `@AppStorage` – which allows easy manipulation of `UserDefaults`. The code snippet below shows how one would read and store a String.

```
import SwiftUI

final class UserDataService: ObservableObject {
    static let shared = UserDataService()
    let defaults = UserDefaults.standard

    @Published var inviteeID: String? {
        willSet {
            if newValue != inviteeID {
                defaults.set(newValue, forKey: Constants.iviteeIDKey)
            }
        }
    }

    ...

    private init() {
        let invitee = defaults.string(forKey: Constants.iviteeIDKey)
        if let invitee = invitee {
            inviteeID = invitee
        }

        ...
    }

}
```

Figure 5-24 Accessing Invitee ID

In SwiftUI 2 this can be simplified to the following code:

```
import SwiftUI

final class UserDataService: ObservableObject {
    static let shared = UserDataService()
    let defaults = UserDefaults.standard

    @AppStorage(Constants.iviteeIDKey) var inviteeID: String?
}
```

Figure 5-25 Accessing Invitee ID using AppStorage

ClimaFever makes use of the `NWPathMonitor`. It is an observer that monitors and reacts to network changes. A `NetworkMonitor` class with the following properties was created:

- **`isConnected`** – a Boolean indicating if the device is connected to the Internet
- **`isExpensive`** – a Boolean indicating if the interface used is considered expected (such as Cellular network or Hotspot)
- **`isConstrained`** – a Boolean indicating if the user has turned Low Power Mode on

By having this information, ClimaFever can respect the user's settings. Furthermore, it prevents actions which cannot be executed offline.

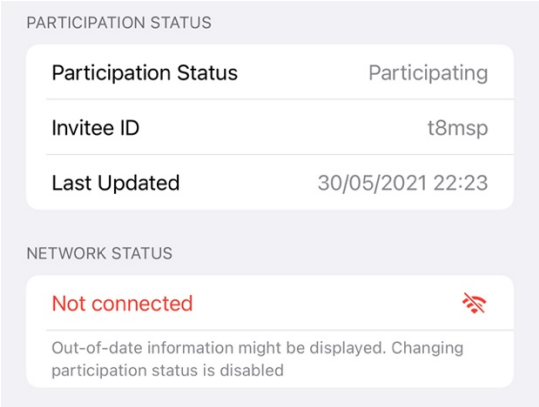

Figure 5-26 Not Connected Status (Settings View)

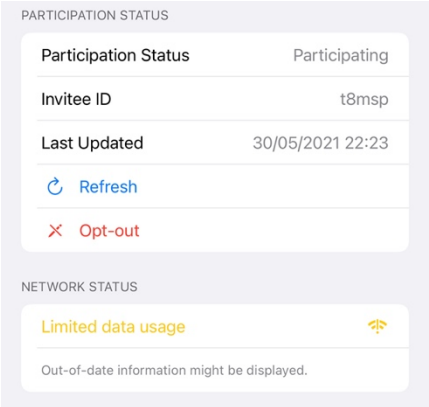

Figure 5-27 Limited Data Usage Mode (Setting View)

If the device is not connected to the Internet, the Network Status under "Settings" changes to "Not Connected". A brief description of what this means in terms of functionality is also shown. Internet-dependant features, such as opting out and refreshing status, are unavailable under this condition. If low power mode is on instead, critical features remain active, but the network-heavy ones get postponed.

5.2 ResearchKit Integration

The ResearchKit integration is in the core of the ClimaFever project. In order users to participate in the research, two conditions must be fulfilled:

- The user has to be invited, and have given their consent
- The current environmental data has to be loaded, as it is stored alongside the user's respond

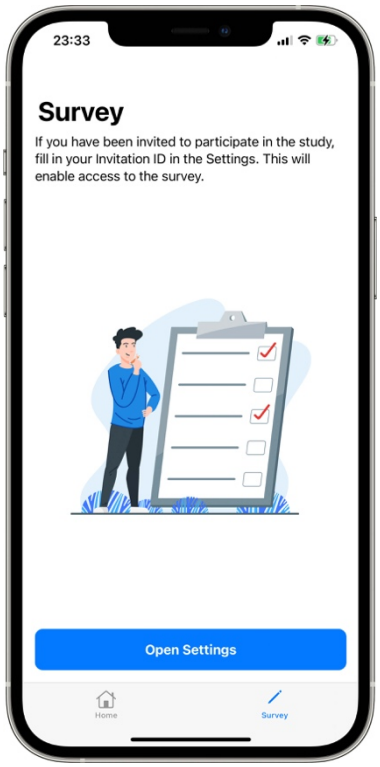

Figure 5-28 Non-participating user (Survey View)

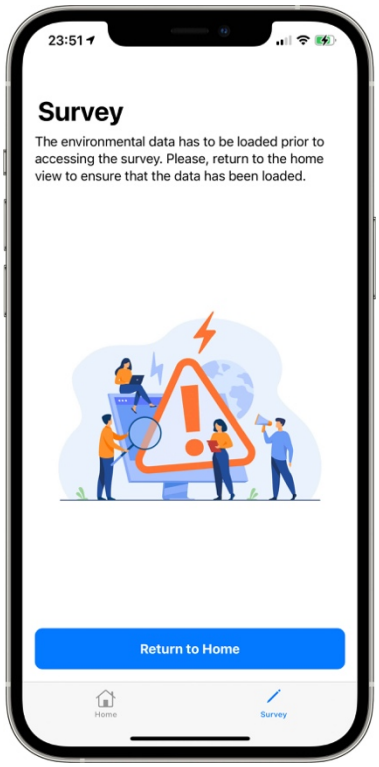

Figure 5-29 Missing Environmental Data (Survey View)

In both cases, there is a corresponding view which guides the user what to do if any of the conditions is not fulfilled.

5.2.1 Informed Consent

The user can join the research by either clicking "**Open Settings**" on the Survey view or accessing settings directly from the Home view. Upon server-side verification of the Invitation ID supplied, the user will be presented with the study onboarding, followed by a consent document.

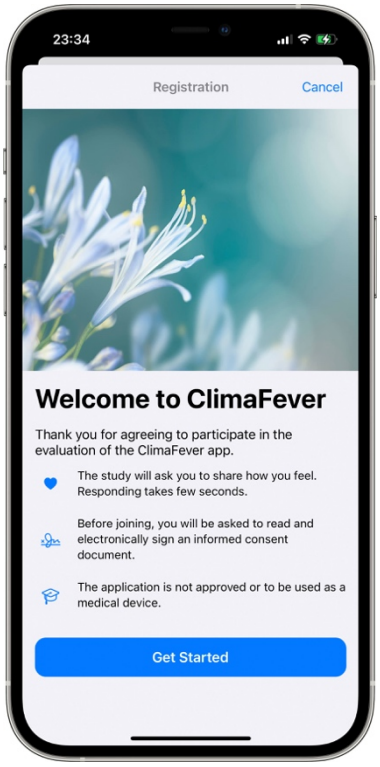

Figure 5-30 Study Onboarding

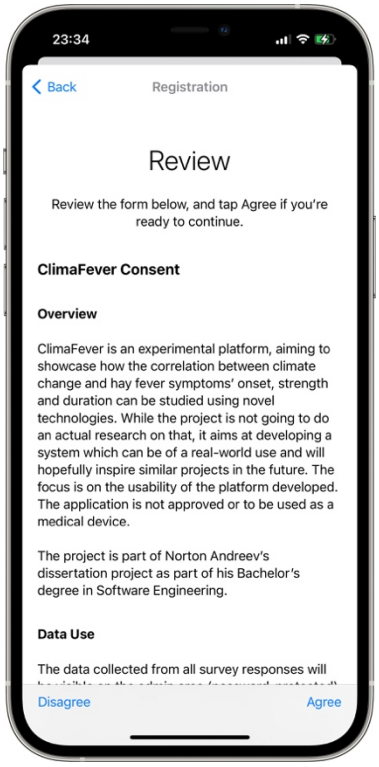

Figure 5-31 Consent Document

For the user to participate, they must sign the consent electronically, by providing their name and signature. This is done directly within the application, powered by the ResearchKit Informed Consent template views. The signed consent document can then be shared via AirDrop, or as a message or an email. This allows the participant to keep a copy of the document for future reference.

Figure 5-32 Consent Step 1

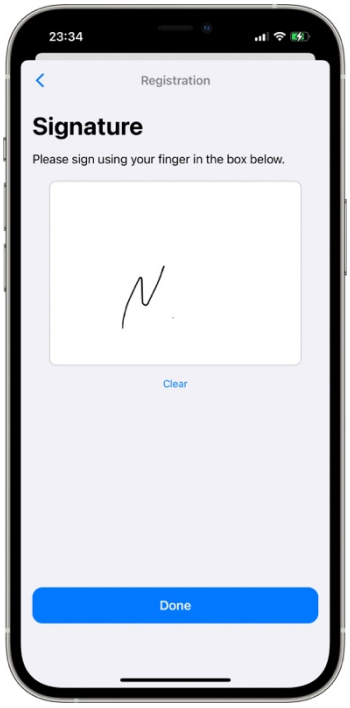

Figure 5-33 Consent Step 2

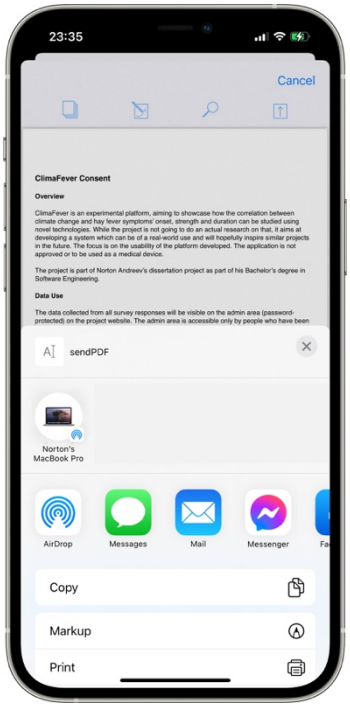

Figure 5-34 Share Signed Consent

5.2.2 Daily Survey

Once after the user's participation status has changed to "Participating", the Survey view will display the daily in-app survey.

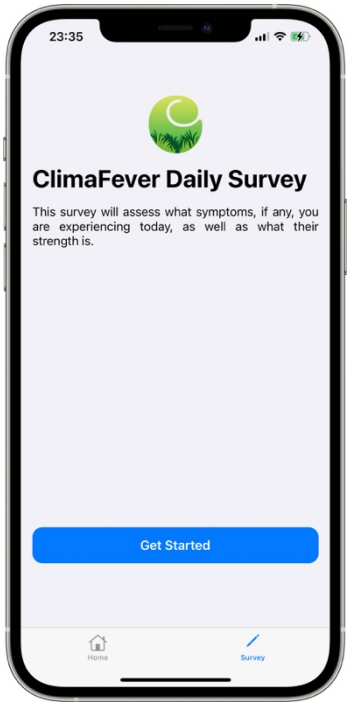

Figure 5-35 Daily Survey Overview

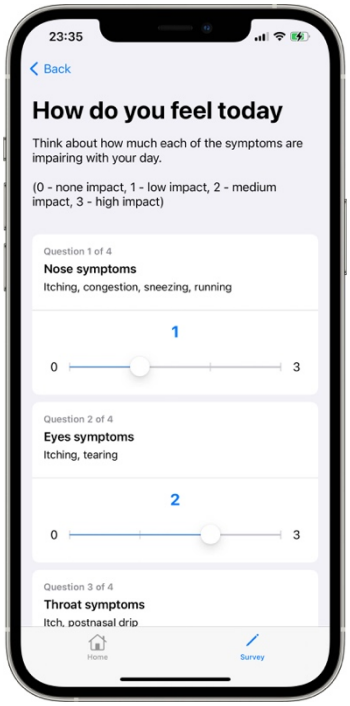

Figure 5-36 Daily Survey View

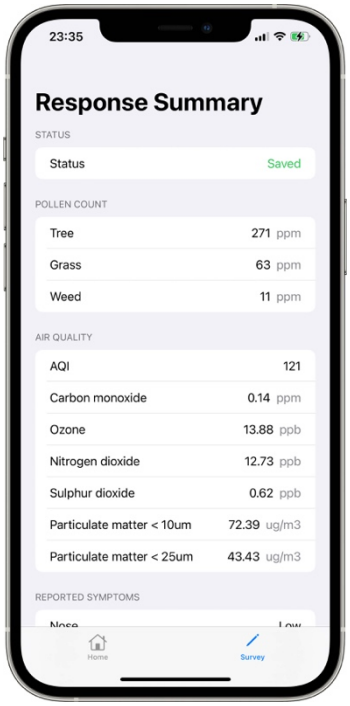

Figure 5-37 Response Summary View

The first view gives a brief introduction to the survey. The second view is the survey itself. It consists of four scale answer type questions. In terms of implementation, each one is an **ORKFormItem** with an **ORKScaleAnswerFormat** answer format, as shown below:

```
        let formItemNose = ORKFormItem(identifier: "Nose", text: "Nose symptoms",
answerFormat: ORKScaleAnswerFormat(maximumValue: 3, minimumValue: 0, defaultValue: 0,
step: 1))
        formItemNose.detailText = "Itching, congestion, sneezing, running"
        formItemNose.isOptional = false

        let formItemEyes = ORKFormItem(identifier: "Eyes", text: "Eyes symptoms",
answerFormat: ORKScaleAnswerFormat(maximumValue: 3, minimumValue: 0, defaultValue: 0,
step: 1))
        formItemEyes.detailText = "Itching, tearing"
        formItemEyes.isOptional = false

        let formItemThroat = ORKFormItem(identifier: "Throat", text: "Throat symptoms",
answerFormat: ORKScaleAnswerFormat(maximumValue: 3, minimumValue: 0, defaultValue: 0,
step: 1))
        formItemThroat.detailText = "Itch, postnasal drip"
        formItemThroat.isOptional = false

        let formItemEars = ORKFormItem(identifier: "Ears", text: "Ears symptoms",
answerFormat: ORKScaleAnswerFormat(maximumValue: 3, minimumValue: 0, defaultValue: 0,
step: 1))
        formItemEars.detailText = "Itching, blockage"
        formItemEars.isOptional = false
```

Figure 5-38 Survey Questions (Code Snippet)

Following the submission of the survey, the user is presented with a Response Survey view. It is shown for the next 24 hours, as users are supposed to submit a response once a day. The Survey Response contains all the Environmental information that was available at the time of the survey submission, as well as the strength of the symptoms the user has reported via the survey.

The view ends with a section including the user's location (country, place name), as well as a map, showing where the user was located when the response was submitted.

5.2.3 UIKit in SwiftUI

The main challenge when it comes to the ResearchKit integration is that ResearchKit is built with UIKit, rather than SwiftUI. Interfacing with UIKit was need.

Going back to the MVC and the MVVM discussion, views in UIKit are using the MVC pattern. Unlike SwiftUI, where Views are directly presented on the screen, in MVC views are grouped together and controlled by a controller which is presented to the user. Apple provides two APIs which aid the integration of UIKit within a SwiftUI-based application – the protocols **`UIViewRepresentable`** (which turns a view into a SwiftUI view) and **`UIViewControllerRepresentable`** (which turns a controller into a SwiftUI view).

As UIKit is not reactive as SwiftUI, it relies on the delegation pattern. Controllers and views in UIKit delegate functionality to other objects which are constrained by a protocol with the delegatable functionality.

The main components of `UIViewRepresentable` and `UIViewControllerRepresentable` are:

- a function which creates the UIKit view/controller
- a function which updates the UIKit view/controller
- a Coordinator object which handles the delegate activity
- a Context, which contains the Coordinator, as well as the SwiftUI environment

The SwiftUI views which were built using these protocols are the web view, the survey consent onboarding, the survey itself, as well as the view which allows for the consent document to be exported as PDF.

The `PDFViewer` struct is simpler than the survey or the consent document views, however, it contains all the components, needed to present a UIKit controller as a SwiftUI view as is thus used for demonstration purposes. The same principle applies to all of the other views.

```swift
import SwiftUI
import UIKit
import ResearchKit

struct PDFViewer: UIViewControllerRepresentable {

    func makeUIViewController(context: Context) -> ORKTaskViewController {
        let pdfViewer = ORKTaskViewController(task: ConsentPDFViewerTask, taskRun: nil)
        pdfViewer.delegate = context.coordinator
        return pdfViewer
    }

    public var ConsentPDFViewerTask: ORKOrderedTask {
        var docURL = (FileManager.default.urls(for: .documentDirectory, in: .userDomainMask)).last
        docURL = docURL?.appendingPathComponent("ClimaFeverConsent.pdf")
        let PDFViewerStep = ORKPDFViewerStep.init(identifier: "ConsentPDFViewer", pdfURL: docURL)
        PDFViewerStep.title = "Consent"
        let task = ORKOrderedTask(identifier: String("ConsentPDF"), steps: [PDFViewerStep])
        return task
    }

    func updateUIViewController(_ uiViewController: ORKTaskViewController, context: Context) {}

    func makeCoordinator() -> Coordinator {
        Coordinator()
    }

    class Coordinator: NSObject, ORKTaskViewControllerDelegate {
        func taskViewController(_ taskViewController: ORKTaskViewController,
                                didFinishWith reason: ORKTaskViewControllerFinishReason, error: Error?) {
            taskViewController.dismiss(animated: true, completion: nil)
        }
    }

}
```

Figure 5-39 PDFViewer Struct Code

- The **`makeUIViewController()`** function creates the UIKit controller (which is an `ORKTaskViewController`, provided by ResearchKit).
- The **`updateUIViewController()`** method is called by SwiftUI when the state of the application changes. The UIKit controller can be updated to match the new state information, using the `context` parameter.
- The **`makeCoordinator()`** function creates a custom instance which is used to communicate changes from the view controller to SwiftUI.
- Finally, the Coordinator handles the delegated activity. In this case, it implements the **`taskViewController:didFinishWithReason:error:`** delegate which gets called when the `ORKTaskView` controller is dismissed.

5.3 Website

The ClimaFever website consists of two main parts – the home page, which introduces the visitors to the project, as well as the admin panel, which is password-protected. The website is deployed on www.climafever.tech.

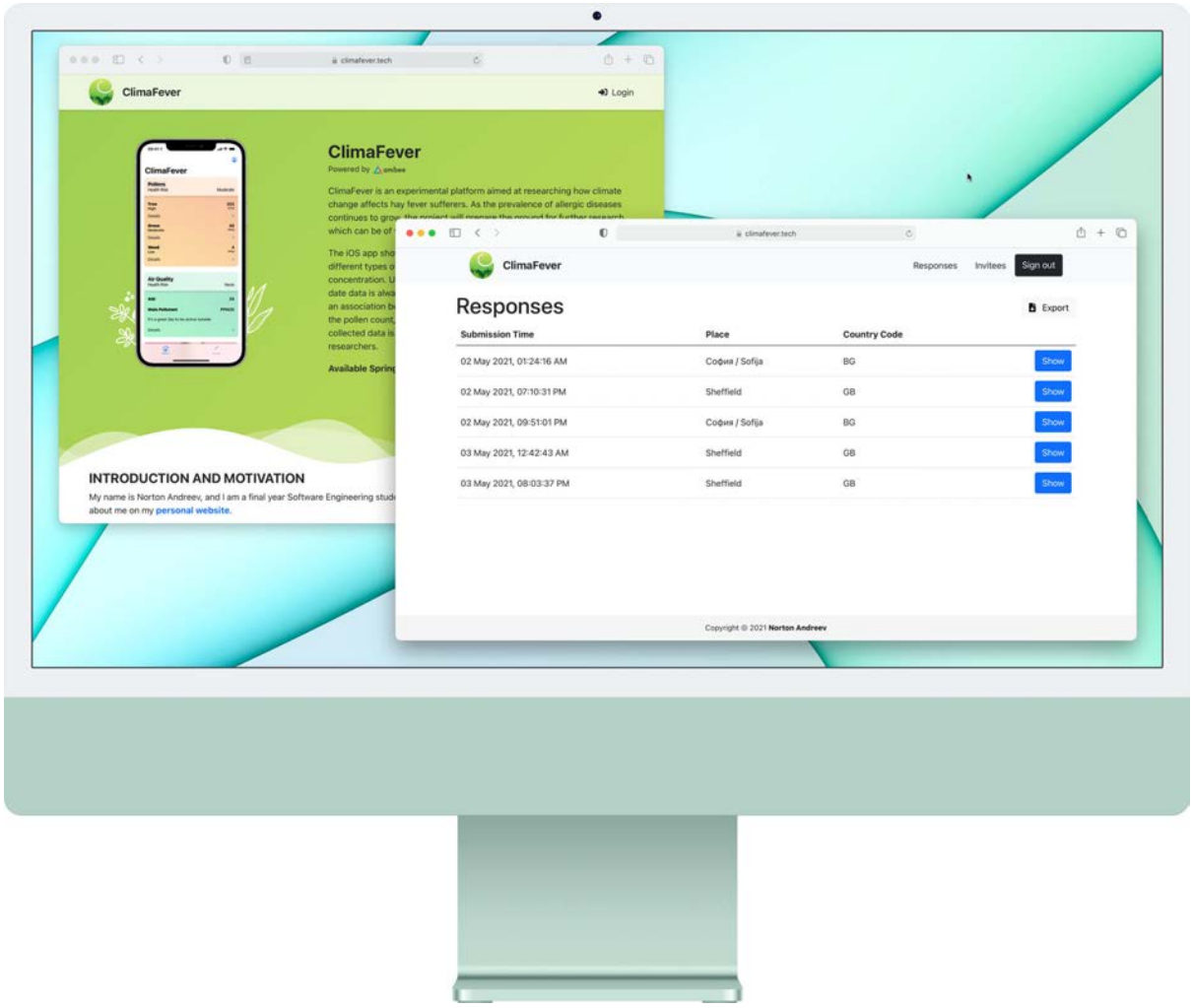

Figure 5-40 ClimaFever Website

As per the specifications, two types of user roles were defined – a **Researcher** and a **Developer**. The researcher has access to the Responses stored on the system, as well as the Invitees. Researchers cannot perform destructive actions. Restricting Invitees is the closest when it comes to such operations. The idea behind this implementation is that whoever is benefiting from the system would like to know how many people have been invited, how many are participating, how many have withdrawn and how many have been restricted. This allows for an analysis on the efficacy of the system to be performed.

The authentication is implemented via the **Devise** gem, while the authorisation – using **CanCan**. Devise is modular, meaning that not all of its features have to be used. For example, user creation for people without an account was disabled (and was made exclusive to the Developer role). This is to avoid user creation, as accessing the collected data should be limited to users who were authorised to do so. While limiting access is required in order to comply with the ethics application, it is also a characteristic the production version of the system should have.

The Role-Based Access Control is easy to achieve with CanCan. The class Ability defines what operations should be accessible for each role.

```ruby
# app/models/ability.rb

class Ability
  include CanCan::Ability

  def initialize(user)

    if user.developer?
      can :manage, :all
    elsif user.researcher?
      can :read, Response
      can :read, Invitee
      can :restrict, Invitee
      can :create, Invitee
    end
  end
end
```

Figure 5-41 Ability Class (Code Snippet)

As it can be seen, the operations are defined within a simple `if` statement. The Developer role can execute all CRUD operations on all models, while the Researcher role can only do a subset of what is available to the developers.

Once the rules are defined in the Ability class, the permissions can be checked using the `can?` and `cannot?` methods in views and controllers.

```erb
# app/views/invitees/index.html.erb

<div class="container">
    ...
    <% if can? :create, Invitee %>
      <a class="btn btn-primary h-100 w-100" href="<%= new_invitee_path %>">Create Invitee</a>
    <% end %>
    ...
</div>
```

Figure 5-42 Invitees View (Code Snippet)

The code above checks if the currently authenticated user has the permission to create a new Invitee, and, if so, the link to create a new invitee is displayed on the page. Additionally, an authorisation has to be performed in the controller. This is done using the `authorize!` method which would throw an exception, if the user cannot perform the action. Alternatively, the `load_and_authorize_resource` method can be called at the beginning of the controller, which automatically authorises all RESTful actions.

5.3.1 Responses

Once the user has logged in, the Responses view gets displayed. It presents all responses from the users who are participating in the study and have filled in the in-app survey.

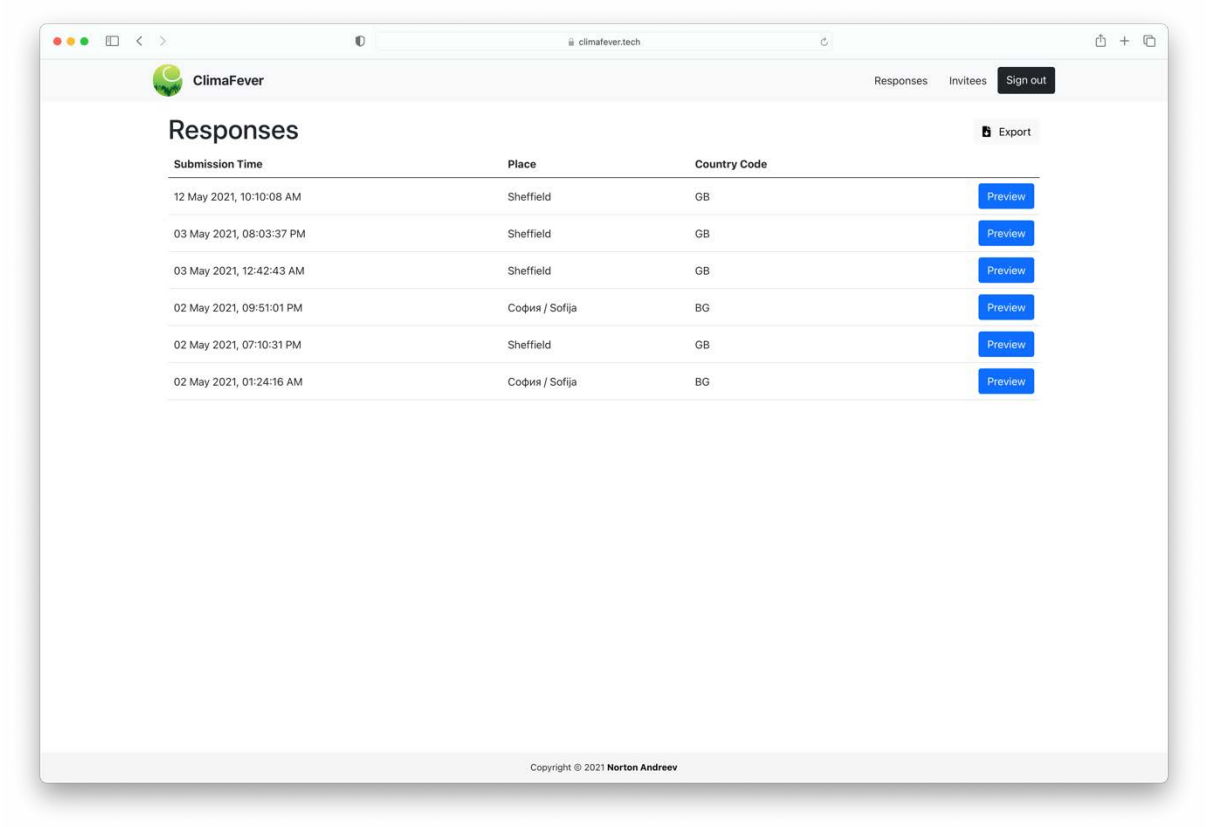

Figure 5-43 Responses Page

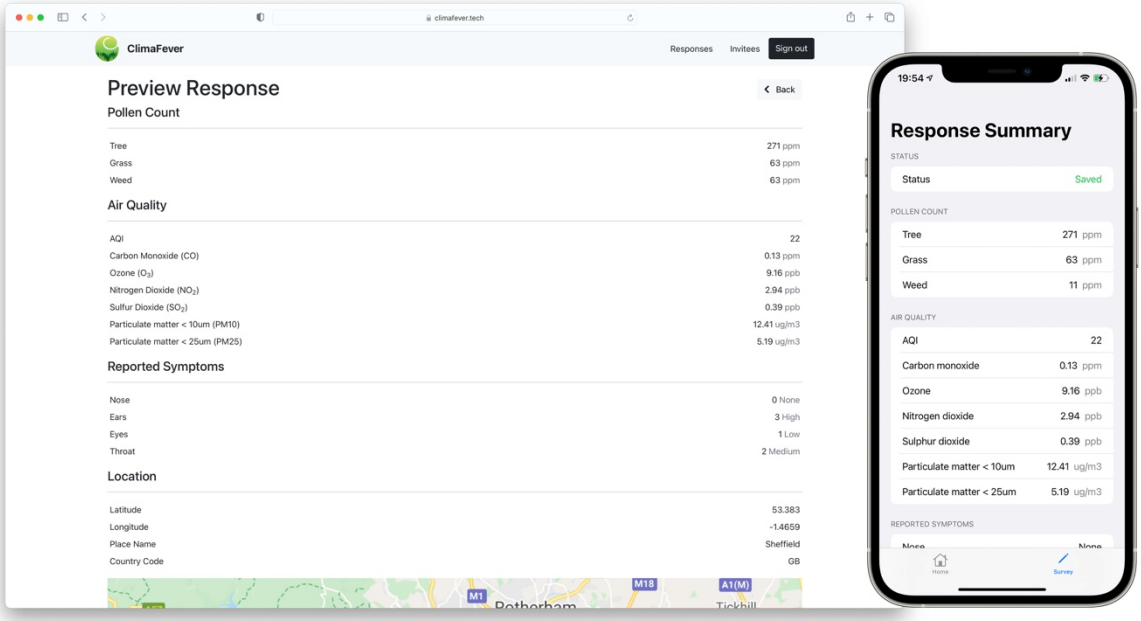

Figure 5-44 Individual Response Preview

As an overview, the submission date, the place and the country code of the responses are presented. The responses are sorted by the submission time. As a potential improvement, the table could have been implemented in a way that would allow for the responses to be sorted by either submission time, place name or country code, however, it was decided that this would not have a huge effect on the usability, as individual responses are not as interesting as the overall population. Individual responses can also be previewed, if needed. The information shown is mirrored with what users would see when they submit the survey response on their iPhone, as shown on **Figure 5-44**.

Finally, the responses can be exported as an Excel spreadsheet. The feature was implemented using the **caxlsx** gem. The template of the spreadsheet is defined as an axlsx file. The data is separated in four spreadsheets and matches the structure of the individual responses (pollen count information, air quality information, symptoms severity and location). The template is highly customisable, so modification in the style or the structure can be made easily.

```
# app/views/responses/responses.xlsx.axlsx

wb = xlsx_package.workbook

wb.styles do |style|
  project_heading = style.add_style(b: true, sz: 14)
  heading = style.add_style(b: true)

    wb.add_worksheet(name: "Responses Summary") do |sheet|
        # Add a title row
        sheet.add_row ["Responses"], style: project_heading
        # Add the date this was downloaded
        sheet.add_row ["Downloaded at", Time.now.strftime("%b %-d, %Y")]
        # Add a blank row
        sheet.add_row []
        # Header
        sheet.add_row ["ID", "Submission Time", "Latitude", "Longitude", "Place Name", "Country Code"]

        @responses.each do |response|
            sheet.add_row [response.id, response.created_at.strftime("%d %b %Y, %r"), response.location.lat, response.location.lng,
response.location.placename, response.location.countrycode]
        end
    end

    wb.add_worksheet(name: "Pollen Count Data") do |sheet|
        # Add a title row
        sheet.add_row ["Responses"], style: project_heading
        # Add the date this was downloaded
        sheet.add_row ["Downloaded at", Time.now.strftime("%b %-d, %Y")]
        # Add a blank row
        sheet.add_row []
        # Header
        sheet.add_row ["ID", "Tree Pollen Count", "Grass Pollen Count", "Weed Pollen Count"]

        @responses.each do |response|
            sheet.add_row [response.id, response.pollen_count_detail.tree, response.pollen_count_detail.grass, response.pollen_count_detail.weed]
        end
    end

    ...

end
```

Figure 5-45 Responses Excel Spreadsheet Template Snippet

5.3.2 Invitees

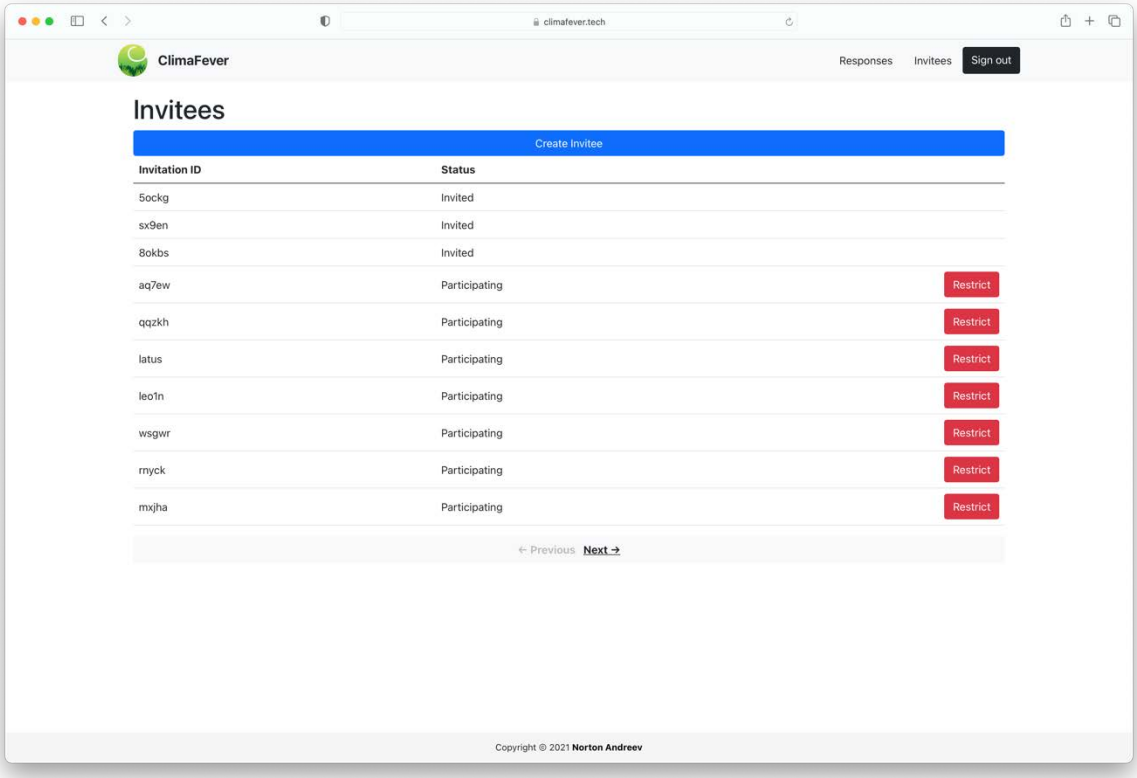

Figure 5-46 Invitees Page

The Invitees page allows for Researchers to create a new invitee, as well as to restrict current ones. The entries are sorted by invitation status in the following order – "Invited", "Participating", "Restricted" and "Withdrawn". As expected, pressing the "Create Invitee" button generates a random Invitation ID with five characters, while "Restrict" restricts the access of an existing Invitee. The iOS application checks for the Invitee status once every 24 hours. If status has changed to "Restricted", the access to the in-app survey gets disabled for that particular user. As the storage of the Invitation ID is done locally, on using the `AppStorage`, the user can reinstall the application (which will delete the local data) and be allowed to enrol to the study again, if provided with a new Invitation ID.

5.3.3 Developer View

Developers are given access to additional features, such as managing Statuses, Roles and Users. **Figure 5-47** illustrates how Statuses can be managed. It is important to note that the iOS application relies on the statuses being the same, as per the software specification, so deleting existing ones would require an update to the iOS application, otherwise an error condition will occur. Most of what is available as functionality to the developers is to aid the development process.

The Users view, presented in **Figure 5-48**, allows developers to create new roles, as well as new users. It was decided to provide what is needed to manage the User and the Role models on the same page, as they are dependent on one another (similarly to how the Statuses are presented on the Invitees page). To display the information, a nested table was created with the top level being the role. Roles can only be deleted if no users are associated with them – avoiding potential human mistakes.

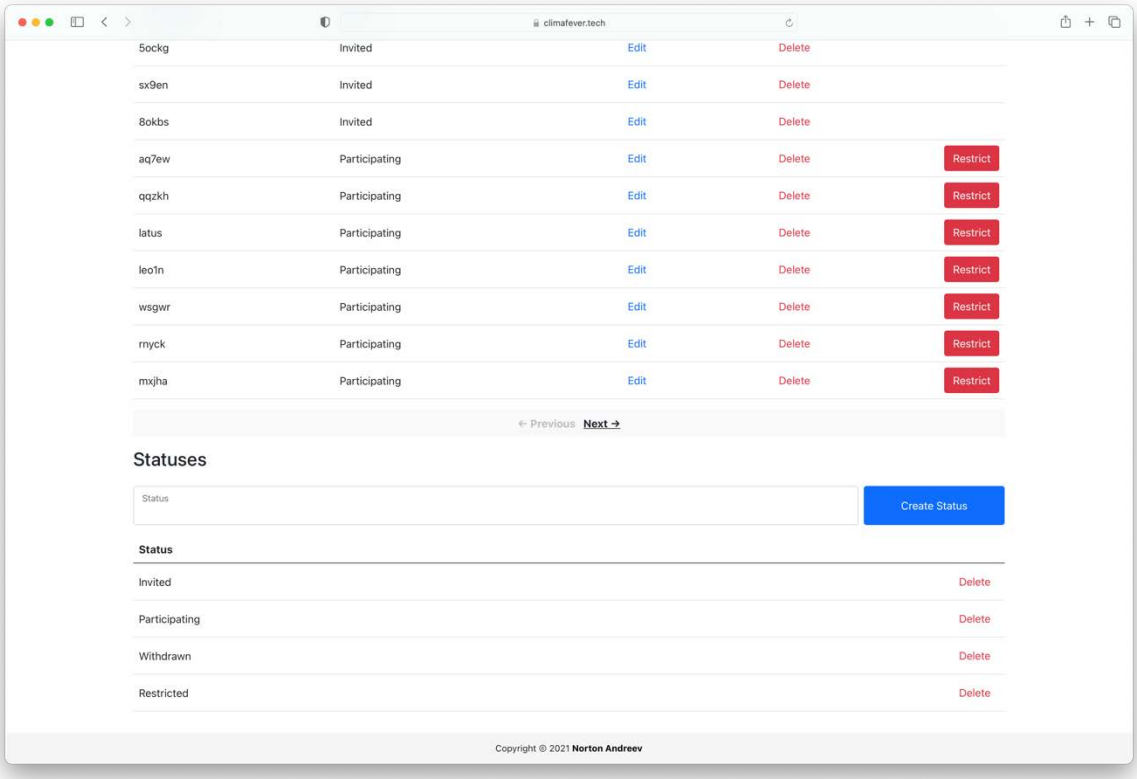

Figure 5-47 Managing Statuses (Admin View)

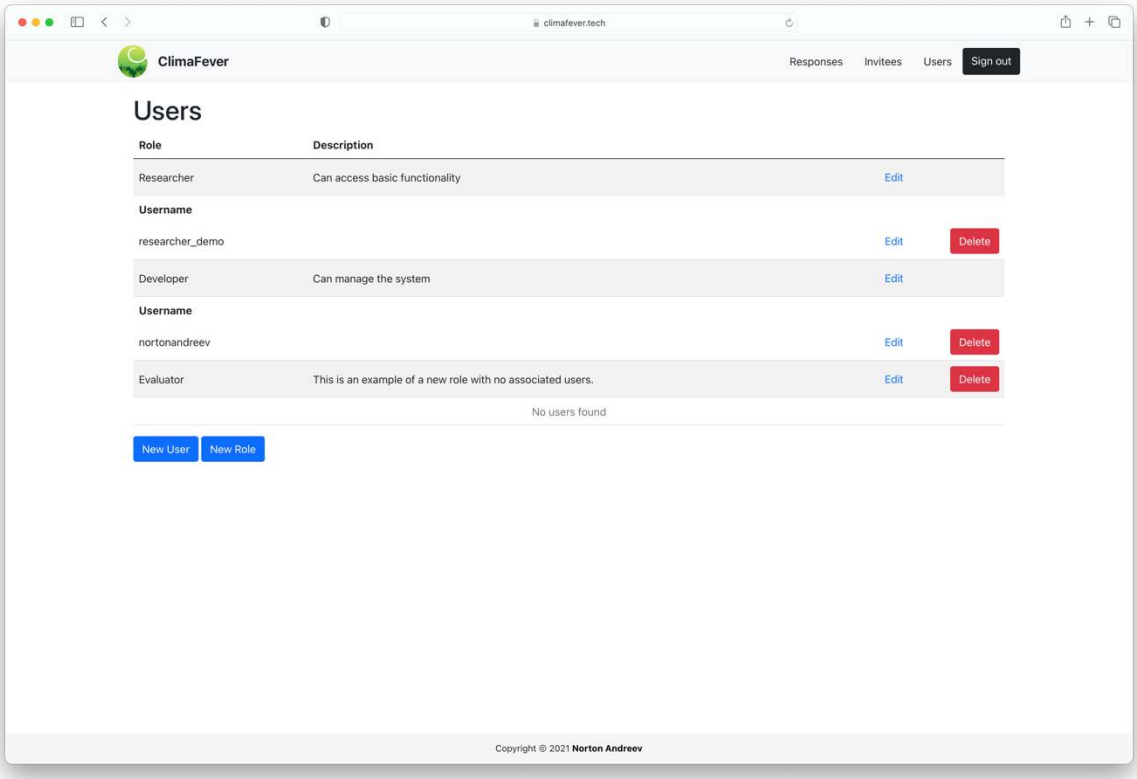

Figure 5-48 Managing Users (Admin View)

5.4 Networking Layer

The networking layer is discussed on its own, as it is not a user-facing feature of the iOS application. Moreover, it can be extracted as a module and reused within another project.

The implemented networking layer has to be flexible enough to be able to perform both POST and GET requests. It should also be capable of dealing with different endpoints. The Networking module implemented consists of two main components:

- **`NetworkManager`** class which handles the request. It defines a static function, `request()`, which takes an `Endpoint` and returns a completion with a `Result` tuple that contains either the result of the request or an error. The errors are defined as a `NetworkError` and are based on the specification (**Section 4.6.2 Error Conditions**). The request method makes use of Generics – as the response type will be dependent on the type of the request made and the endpoint used. This is done by defining a placeholder type name and ensuring that whatever is passed confirms to the Codable [8]protocol.
- The **`Endpoint`** itself. It is defined as a protocol with several fields, such as `baseURL`, `port` and `path`.

The individual endpoints are Enums that define a separate case for each endpoint. As these Enums implement the `Endpoint` protocol, they have to provide implementations for each of the Endpoint's fields. A snippet of the `UserEndpoint` is demonstrated below:

```
enum  UserEndpoint: Endpoint {
    case getInvitee(id: String)
    case updateInviteeStatus(id: String, status: String)

    var scheme: String {
        switch self {
        default:
            return EnvironmentConfiguration.scheme
        }
    }
    ...
    var path: String {
        switch self {
        case .getInvitee:
            return "/api/v1/invitees/get_invitee"
        case .updateInviteeStatus:
            return "/api/v1/invitees/update_invitee_status"
        }
    }
    ...
    var method: String {
        switch self {
        case .getInvitee:
            return "GET"
        case .updateInviteeStatus:
            return "POST"
        }
    }
}
```

Figure 5-49 UserEndpoint (Code Snippet)

[8] a type alias for the Encodable and Decodable protocols

When it comes to users, there are two endpoints – one that returns the invitee by the provided URL and one which updates the Invitee's status to the provided value. As it can be seen, based on which case is used, the path and the method of the request differ.

```
NetworkManager.request(endpoint: UserEndpoint.getInvitee(id: inviteeID!)) { (result: Result<Invitee, NetworkError>) in
    switch result {
    case .success(let data):
        ...
    case .failure(let error):
        ...
    }
}
```

Figure 5-50 Network Request (Code Snippet)

The code snippet above shows how a request to the */api/v1/invitees/get_invitee* endpoint is made. Notice the **Invitee** type within the `result` closure. This is the actual type that gets used in place of the placeholder. As previously stated, the type would have to confirm to Codable, so that the JSON network response can be decoded to an instance of the data type. Finally, within the closure, a `switch` on the result determines if a result has been obtained or if an error has occurred. With the Result type, the Enum either contains either a result or an error – it is not possible to have both at the same time.

It is important to note that the network requests are executed on a background thread. This is because they are time consuming (can take minutes in some cases). Execution of these operations on the main thread would lead to deadlocks[9]. User interface redrawing based on the returned data, should be executed on the main thread.

[9] situation in which no progress can be made by either process

5.5 Testing

Software can be tested in various ways during the different stages of the software development. The V-Model depicts the testing levels and how they relate to the various software development activities. Usually, tests are designed concurrently with each development activity. This is so to identify defects in the design early on. It should be noted that the V-Model does not mirror or imply the Waterfall software development model.

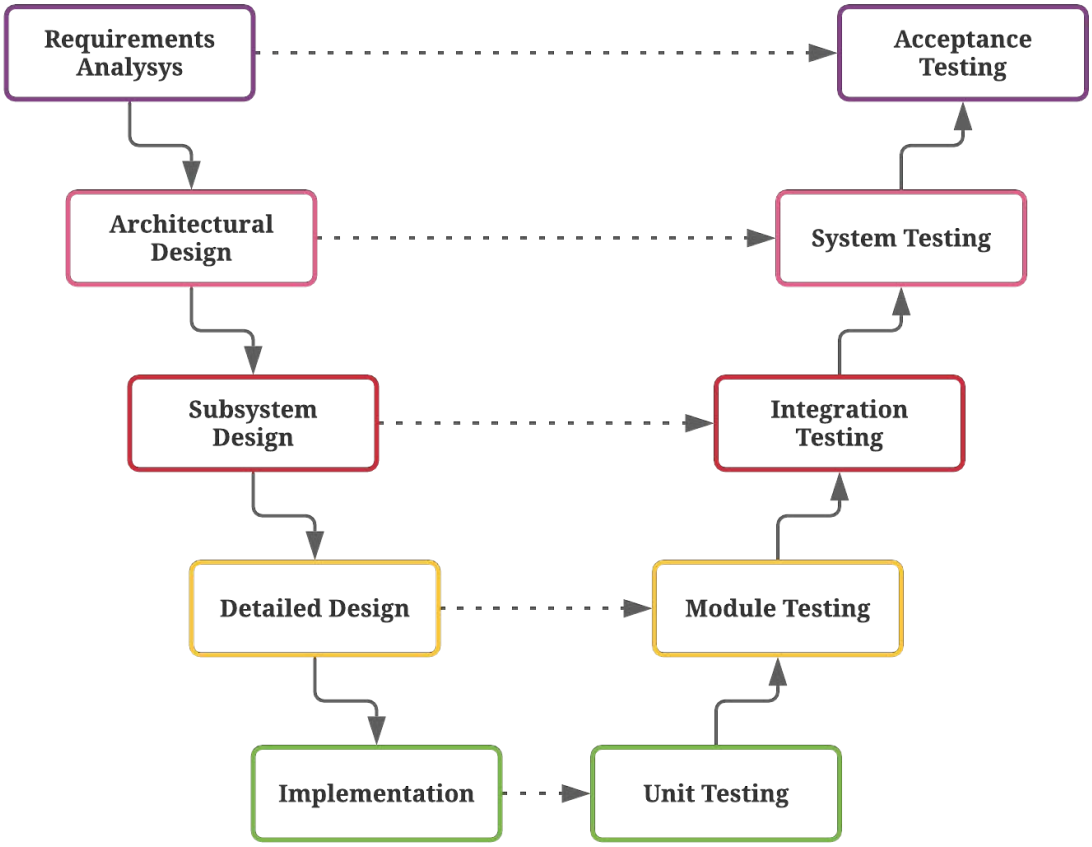

Figure 5-51 V-Model

Acceptance Testing is concerned with if the system meets the customer's needs. It involves the stakeholders and requires strong domain knowledge. **System Testing** determines if the system meets the specifications. It assumes that the pieces work together individually. This type of testing helps finding design and specification problems, although low-level faults found at this stage are expensive to fix. **Integration Testing** assess whether the interfaces between the modules in a given subsystem communicate correctly. **Module Testing** evaluates the individual modules in isolation. Modules consists of related units (for example, *functions* in Swift or *methods* in Java). Finally, the **Unit testing** is concerned with the units produced. It is the lowest level of testing.

Some other types of testing, not shown in the V-Model, are Regression Testing and Usability Testing. **Regression Testing** is done as part of the software maintenance phase and aims at identifying broken functionality after updates have been made. It goes well with the continuous integration (CI) practice. In order to perform the testing, an automated test suit is executed daily, typically overnight.

Obviously, the test suit should be large enough to cover all of the requirements, however, as complete software testing is incomputable, a passing test suite does not guarantee the absence of bugs or correctness of the system.

During the development process, initially bugs were logged in Jira once they were discovered. They were prioritised in terms of how critical fixing them is for fulfilling the main objectives of the system, how long it will take, as well as based on the probability that the implementation of the feature that contains the bug will be changed or removed in future. During the second iteration, closer to the delivery of the project, the strategy was changed and instead of logging and prioritising, bugs were resolved as they were discovered. This makes sense, as the second iteration was primary concerned with resolving issues found after the completion of the first iteration.

There are still some known low-priority bugs. However, it is a common practice for software development companies to schedule bugfixes for future releases (for bigger system, such as iOS, it could take months). Furthermore, as the resources are usually limited, no matter if it comes to the number of developers or cost involved, one has to balance between polishing existing features, fixing bugs and doing refactoring, while also introducing new functionality.

5.5.1 Acceptance Testing

Acceptance testing refers to the user requirements which have been agreed on prior to implementation and assesses if the functionality is working as expected. To aid the process, each user story contains a detailed acceptance criterion which contains the following traits – it is **testable**, **clear** and **concise**, and written in a **user-friendly** way.

As part of the development, the user stories were reworked multiple times, so to ensure that each functionality is contained within a separate user story and thus ensure that each user story can be tested. An example of a user story with its acceptance criterion is presented below:

Story	Acceptance Criteria	Status
As a user/enrolled user I can see my current participation status.	1. Open ClimaFever 2. Go to “Survey” view 3. Go to “Settings” view by clicking the user icon on the upper right corner	**Implemented**

Table 5-1 Example User Story with Acceptance Criteria

To determine if a story user has been implemented, and thus a requirement fulfilled, the steps in the acceptance criterion have been executed. While this would be an activity for the customer to perform, it was done by the developer in the context of the project.

5.5.2 System and Integration Testing

ClimaFever is formed of multiple subsystems. These include the iOS application (which includes the ResearchKit framework as a subsystem), the website and its API which is used by the iOS application, as well as the Ambee's API that the iOS application communicates to via the server. There are various places where integration of subsystems can lead to failures – for example, if unexpected data is returned from the Ambee's API.

As the iOS application communicates with the Ambee's API via the ClimaFever server, it was possible to simulate the behaviour of real objects in a controlled way – also known as **Mock Testing**. The different type of responses received from the Ambee API were stored as JSON files on the server. When testing was performed, the snapshot responses were returned from the server. This was used for building and experimenting with the user interface when different error conditions occur. Furthermore, by reusing these objects, no external calls to the Ambee API were made. This made the development process faster and cheaper (as calls to the API are charged).

```ruby
# app/controllers/api/v1/environment_controller.rb
module Api
    module V1
        class EnvironmentController < ApplicationController
            ...
            def get_latest_pollen_data
                # Production
                lat = params[:lat]
                lng = params[:lng]

                url =  "https://api.ambeedata.com/latest/pollen/by-lat-lng?lat=#{lat}&lng=#{lng}"
                headers = {
                    "Content-Type": 'application/json',
                    "x-api-key": ENV["AMBEE_API_TOKEN"]
                }

                response = HTTParty.get(url, headers: headers)
                puts response.body
                render json: response.body if response.code == 200

                # Debug
                file = File.read(Rails.public_path.join('current_pollen.json'))

                response = JSON.parse(file)
                puts response
                render json: response
            end
            ...
        end
    end
end
```

Figure 5-52 Retrieving Pollen Data (Code Snippet)

The code snippet shows how the response returned in production is coming from the Ambee API, while, in a debug environment, it is loaded from a local file instead. While the current environment (debug or production) can be obtained in the controller and the querying could have been dependant on the value, it was decided to stick with commenting out the irrelevant code instead. This is because sometimes it is desirable to get data from the API even if in debug environment.

5.5.3 Usability Testing

Usability testing aims to identify problems in the design of the software, get ideas for potential improvements, as well as to gather more information about the target user's behaviour and preferences [130]. The benefits of usability testing are huge, both in non-critical and critical systems. To perform usability testing, testers would usually be given a set of tasks to perform. Then, the behaviour of the testers will be observed and recorded. Feedback is also gathered. The results are analysed and can uncover specific areas of the system which might need a review. For example, if the average time to perform a given task is longer than anticipated, the flow might be reworked or the features related to the task might have to be extracted to a higher level of navigation hierarchy, so to make them accessible with less clicks.

As part of the evaluation of the project, in-person usability testing was performed with few participants. In general, the outcome was positive, however some feedback was gathered. A user has reported that enrolling on the study from the Settings view is not immediately intuitive. This was something which has been well thought out prior the implementation. The thinking behind this decision was that the in-app survey would not be included in the final product, when released on the AppStore. This is also due to the ethics which is granted just for the duration of the project. The ResearchKit integration was entirely done for the purposes of the dissertation project. In an official release, the ResearchKit and the in-ap survey could be replaced with CareKit and features for logging symptoms, getting reminders to take medications and to display trends over time. This would replace the current "Survey" tab.

When it comes to the feedback from the users, few responses identified that the project is easy to use, and navigation is easy to understand. The full analysis of the user evaluation can be found in **Section 6.3 User Evaluation**.

Unfortunately, the usability of the research aspect of the application could not be assessed. An allergist had shown interest in the project but did not respond to the requests to evaluate the application. As part of the project, few organisations who focus on allergies and asthma were contacted for initial inquiry and, while some showed interest in the project, they also did not take part in the evaluation.

5.5.4 Cross-device Testing

Cross-device testing consists of executing the software under test on different devices. This can either be in order to preview how the user interface looks on different screen sizes or to ensure compatibility with the environment in which the product runs on (for example browser in the context of a web app or an operating system in the context of a mobile app). The cross-device testing was achieved via **emulation** (using the Xcode's simulator), as well as using a secondary physical device. The platform was simultaneously developed and tested on iPhone 12 and iPhone 12 Pro Max.

Figure 5-53 ClimaFever on iPhone 12 and 12 Pro Max

Xcode provides an **Environmental Overrides** options. They allow for the appearance to be changed, the text size to be adjusted, as well as to turn on or off various of accessibility options. Using the Xcode simulator, the application developed can be tested on previous SDKs, to ensure backwards compatibility. A screenshot of ClimaFever, running on an iPhone 12 with iOS 14.1, simulated dark appearance, medium-sized text, reduced transparency and bold text is presented below:

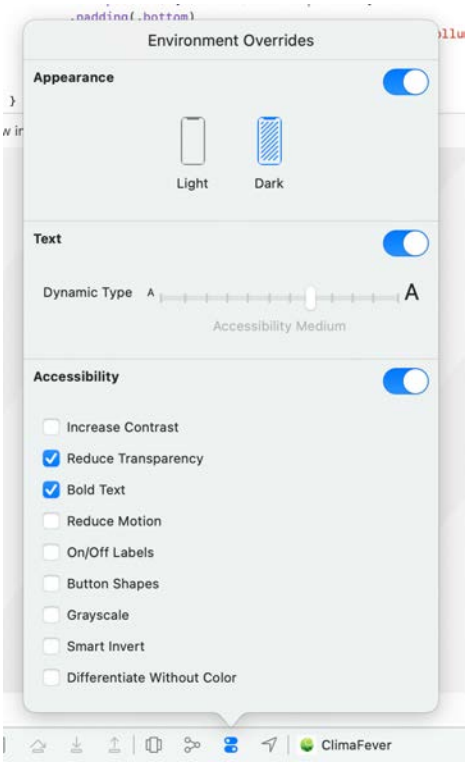

Figure 5-54 Xcode Environment Overrides

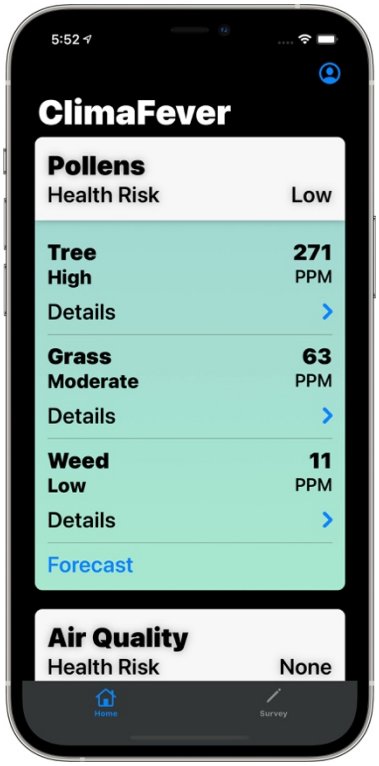

Figure 5-55 ClimaFever under simulated environment

5.5.5 Other Methods

Manual Testing requires tests to be executed manually by the tester. While a formalised set of test scenarios was not produced, manual testing was implicitly performed during the development. The table below demonstrates the strategy used. It also illustrates what a document with test cases could contain.

Test Case	Steps	Expected Result
Inputting a valid Invitation ID with status "Invited"	1. Ensure the current status is "Not Participating" 2. Sign-in to the admin view on the ClimaFever website 3. Generate a new Invitee 4. Copy the new Invitation ID and paste it next to the "Invitation ID", under "Participation Status"	The informed consent view is displayed
Inputting an Invitation ID with more than five characters	1. Ensure the current status is "Not Participating" 2. Copy a string with length bigger than five 3. Paste the string next to the "Invitation ID", under "Participation Status"	An alert stating that Invitation ID cannot be longer than five characters is displayed
Inputting an invalid Invitation ID (random sequence)	1. Ensure the current status is "Not Participating" 2. Type in a random string next to the "Invitation ID", under "Participation Status"	An alert stating that Invitation ID is invalid is displayed
Inputting an Invitation ID with status "Participating"	1. Ensure the current status is "Not Participating" 2. Sign-in to the admin view on the ClimaFever website 3. Copy an Invitation ID with status "Participating" 4. Paste the string next to the "Invitation ID", under "Participation Status"	An alert stating that the Invitation ID is already in use is displayed

Test Case	Steps	Expected Result
Inputting an Invitation ID with status "Withdrawn"	1. Ensure the current status is "Not Participating" 2. Sign-in to the admin view on the ClimaFever website 3. Copy an Invitation ID with status "Withdrawn" Paste the string next to the "Invitation ID", under "Participation Status"	An alert stating that the Invitation ID has been revoked is displayed
Inputting an Invitation ID with status "Restricted"	1. Ensure the current status is "Not Participating" 2. Sign-in to the admin view on the ClimaFever website 3. Copy an Invitation ID with status "Restricted" 4. Paste the string next to the "Invitation ID", under "Participation Status"	An alert, stating that the Invitation ID has been revoked is displayed

Table 5-2 Manual Test Example

If the example above was part of a detailed document with all test cases, the first step, which is common to all cases, could have been extracted as a common *prerequisite*[10] to avoid repetition.

Unit Testing assesses the units produced as a result of the implementation phase of the software development lifecycle model (SDLC). Unit tests for Swift-based application are written using the **XCTest** framework. The framework asserts that conditions are satisfied, helps logging test failures, measures performance and interacts with the user interface [131].

A useful strategy for producing tests is via performing **Input Domain Analysis**. The input domain of a program is the set of the possible values its input parameters can have. The input domain analysis requires partitioning an input domain into *equivalence classes*. Selecting a value from a class is theoretically as good as any other value from the same class. As programmers usually make small mistakes, it is also useful to test with values around the boundaries – also known as **boundary value analysis**.

[10] condition which has to be fulfilled prior to the test execution

```swift
// Shared/Model/Environmental/HealthRisk.swift
import Foundation

enum HealthRisk: String {
    case none = "None"
    case low = "Low"
    case moderate = "Moderate"
    case high = "High"
    case veryhigh = "Very High"
    case hazardous = "Hazardous"
    case unknown = "Unknown"

    ...

    init(aqi: Int) {
        switch aqi {
        case _ where aqi < 50:
            self = .none
        case _ where aqi < 100:
            self = .low
        case _ where aqi < 200:
            self = .moderate
        case _ where aqi < 300:
            self = .high
        case _ where aqi < 400:
            self = .veryhigh
        case _ where aqi < 500:
            self = .hazardous
        default:
            self = .unknown
        }
    }
}
```

Figure 5-56 HealthRisk Enum (Code Snippet)

The code demonstrates a stripped-out version of the **`HealthRisk`** Enum with an initialiser that takes an Air Quality Index value as an Integer. It is used to demonstrate how unit tests can be written. Prior to the identification of the equivalence classes, one should identify a set of *characteristics*. This can be done either using **Interface-Based Input Domain Modelling**, which is simply identifying the parameters to the interface, or **Functionality-Based Input Domain Modelling**, which takes into account the intended functionality of the system. The Functionality-Based Input Domain Modelling is harder and requires strong domain knowledge.

Using the Functionality-Based Input Domain Modelling approach, the characteristics are partitioned into equivalence classes. The obvious choices for the `HealthRisk` example would be based on the risk type – "**None**", "**Low**", "**Moderate**", "**Very High**", "**Hazardous**". While the default value of the Enum is "Unknown", this is an error condition from functionality perspective, so this class can be labelled as "**Invalid**" or "**Error**".

The equivalence classes can then be tweaked further. This will introduce more classes, which in turn would result in more tests and increased likelihood of finding bugs. Apart from the boundary values around each class, one should take care to include negative values as well. This would belong to the "**Invalid**" class. Using this approach, it can immediately be seen that the code contains a bug – if a negative value is passed to the initialiser, the Health Risk will be initialised with value "**None**". However, as the AQI cannot be negative, it should be initialised as "**Unknown**". The "**Invalid**" equivalence class can then be split further to a class that is composed of negative values and a class that is composed of values larger than 500. Using this approach, at least 18 test cases can be generated just for the stripped-out HealthRisk example. Nevertheless, this should be done careful, so to avoid spending too much time on these activities.

When it comes to SwiftUI views, Apple suggests that Xcode previews have to be created for the view states which can then be manually inspected.

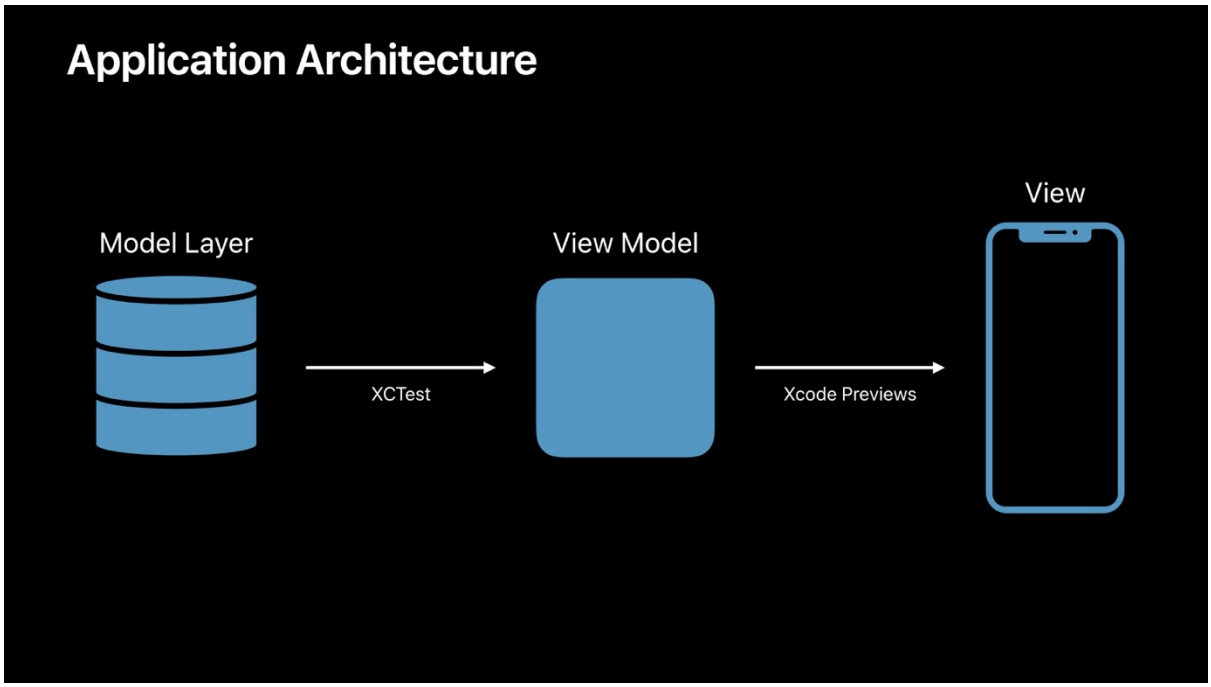

Figure 5-57 Application Architecture
Source: Apple [132]

Manual inspection is error prone. An alternative is **Snapshot Testing**. It is used as a regression testing approach. One would first generate snapshots, also known as *baseline snapshots*. Then testing is performed comparing the output of the test run with these snapshots. A test passes if the current snapshot matches the baseline. As SwiftUI does not provide access to the view tree, snapshot testing is the only way to test SwiftUI views. However, this approach does not replace unit testing in an iOS application, but rather complements it.

Chapter 6

Results and Discussion

The project managed to fulfil its main goals – a website and an iOS application were created. They work together to form the ClimaFever platform which allows the corelation between climate change and hay fever sufferers to be studied. Novel features were implemented, so to add additional value to the product. As planned, the system was developed in two phases. The first one implemented the main features, whereas the second added additional features, based on the user evaluation results, such as a pollen forecast and weather conditions. During development, an unexpectedly high costs, related to using the Ambee API were uncovered (see **Section 6.4.1 Ambee API Pricing**). Unfortunately, this means the project being released on the AppStore might become implausible. However, ClimaFever was made available for the evaluators via TestFlight. While uploading an application to TestFlight does not require a full app review, the submission is still verified and reviewed by Apple, to ensure compliance.

6.1 Revisited Requirements

The requirements have changed during the development. Additional user stories had to be added, to fulfil the requirements of the project. Additionally, some features which were impossible few months ago became possible due to updates of the Ambee API. Other features were replaced with an alternative, which was deemed more suitable within the context of the project and in the available timeframe. As shown in **Chapter 5 Implementation and Testing**, the user interface of the application was reworked, compared to what was presented as a mock-up. This was due to accessibility considerations and with the aim to try to make the feel of the application a bit less stock app like.

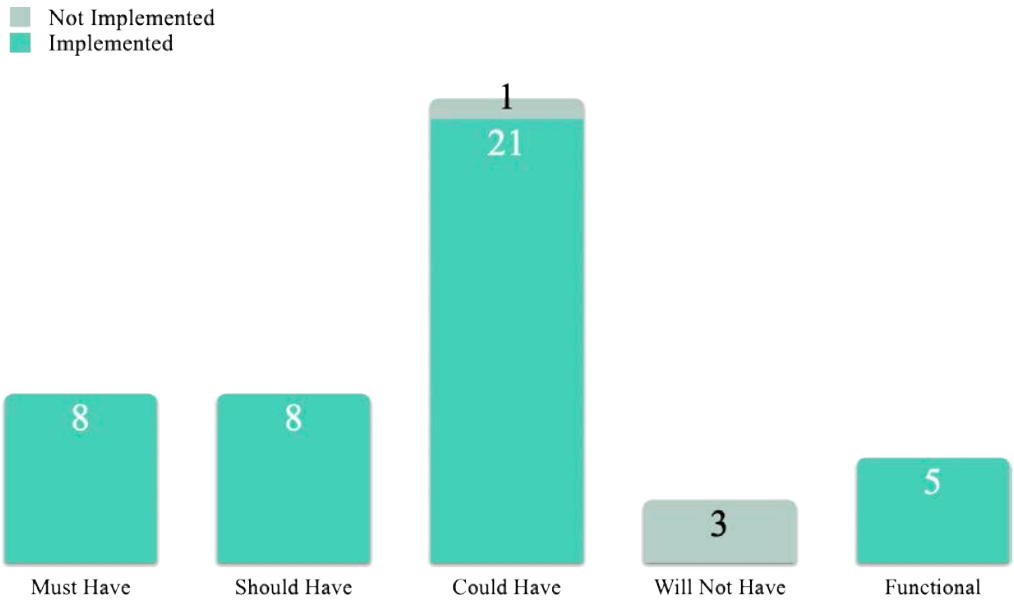

Figure 6-1 Implemented Requirements

As shown in the chart above, all must and should have user stories were implemented. Only one "*could have*" was left out. As expected, "*will not have*" were not included in this iteration of the platform. All functional requirements were met. The results illustrate good planning of the workload prior to the development cycle.

6.2 Implemented Features

The section reassesses the table presented in **Section 2.5 Currently available iOS applications**, with the addition of ClimaFever.

	My Pollen Forecast UK [83]	klarify [84]	ambee [85]	Mask Air [86]	ClimaFever
Pollen count	✓	✓	✗	✗	✓
Pollen count for subcategories	✗	✗	✗	✗	✓
Individualised pollen health risk	✗	✗	✗	✗	✓
Individualised high-risk alerts	✗	✗	✗	✗	+[11]
Pollen forecast	✓	✓	✗	✗	✓
Pollutants count	✗	✗	✓	✗	✓
Weather conditions	✓	✓	✗	✗	✓
AQI	✗	✓	✓	✗	✓
Recommendations	✓	✓	✓	✗	✓
Diary	✓	✓	✗	✓	+
Research-focused questionnaires	✗	✗	✗	✓	-[12]
Treatment options	✗	✓	✗	✗	✓
Test options	✗	✓	✗	✗	✓
Triggers information	✗	✓	✗	✗	✓
Pollutant information	✗	✗	✓	✗	✓
Multi-country data availability	✗	✗	✓	**NA**[13]	✓
iOS widget	✗	✗	✗	✗	+
Apple Watch application	✗	✗	✗	✗	+

Table 6-1 ClimaFever's features comparison

[11] To be added to the official release
[12] To be removed from the official release
[13] Mask Air does not report any environment-related data

Even without the planned future features, ClimaFever is doing more than what all the other popular applications offer to their users. Some features, such as individualised health risk and pollen count information for subcategories, are unique to ClimaFever. Most of what was made as part of the project is because of the tight integration with the Ambee‘s API.

Currently, ClimaFever offers two features which are not found in any other application. However, with the future addition of the individualised high-risk alerts, the iOS widget and the Apple Watch companion application, the number will increase. It should be pointed out that even if many of the features seem common for all applications, they were implemented differently in ClimaFever. For example, while the pollen count can be found in few apps, it is only ClimaFever that provides the information with post code accuracy. Furthermore, it is the only one that shows up to date information outside the pollen season.

6.3 User Evaluation

The user evaluation was conducted using a survey, published on TypeForm. It is a service, similar to Google Forms and Microsoft Forms. However, it provides a much better user experience. The survey was made accessible on the project's website (https://climafever.tech/survey). The user experience of the survey is shown below with a view of a multiple selection type question:

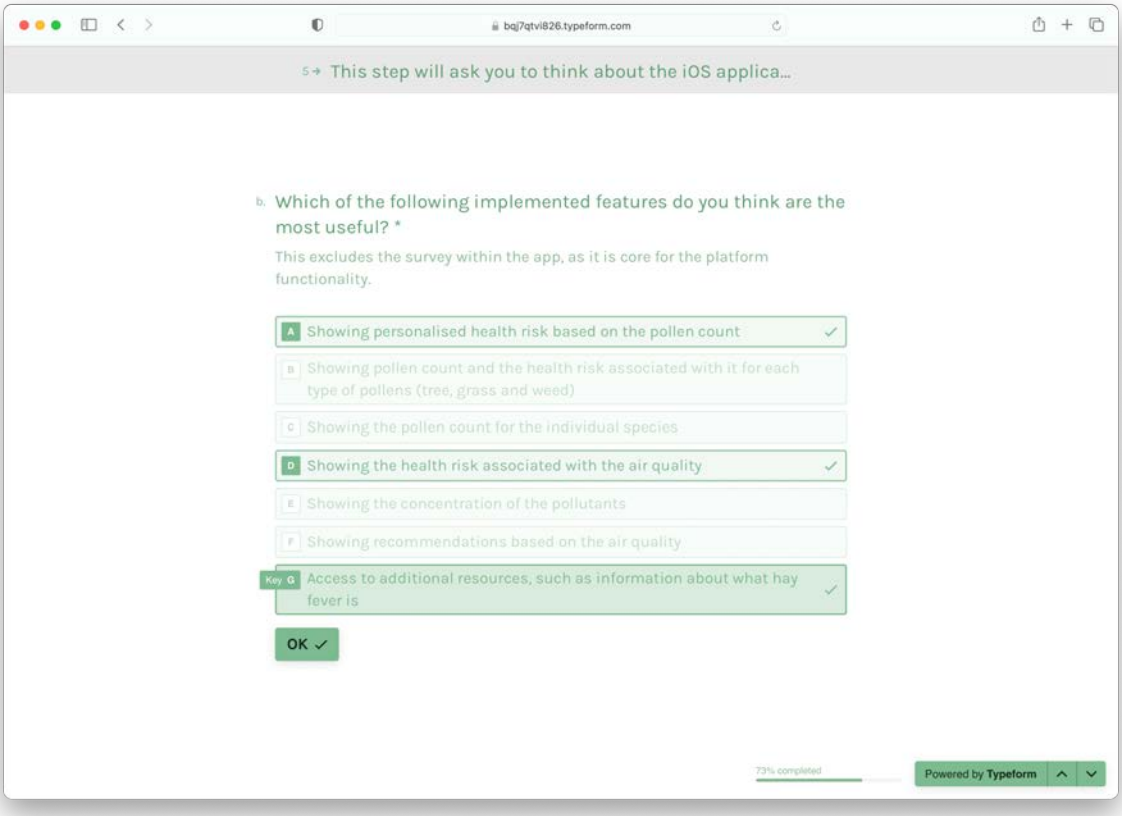

Figure 6-2 Multiple Selection type Question

The user evaluation was done in a way that can provide flexibility and thus ensure more responses. Evaluators were given the opportunity to either test the iOS application, the web application or to watch a demonstration video that covers both. The main goal of the survey was to assess the quality of the produced system. However, it also explored what features users would like to find implemented in the official release. This would ideally have been done at the beginning of the project, however, it is generally hard to accomplish, as people might not want to participate in an evaluation twice. Nevertheless, the collected information was useful for the second iteration and could also aid future development.

The survey was reworked during the evaluation stage. This was based on the feedback received from the evaluators. For example, some had issues skipping the optional questions, so additional information was added at each question view in order to aid the process.

Forty-eight people took part in the evaluation. Six participants have responded that they had not evaluated neither the iOS application, nor the website. These responses were removed, as they do not bring any value. Another response, submitted with an invalid name, was also discarded.

Personal information, apart from the name, which is needed in case participants want to withdraw from the study, was not collected as part of the evaluation. However, as participants were individually recruited, some high-level information of the population is available. It compromises of students, software developers, graphic designers, project managers and others. The ratio of participants in their adulthood and in the middle age is around one. People from Asia, Africa, America, and Europe took part in the study. The diverse study population should ensure that personal biases had been evened out.

6.3.1 Website

Forty people have evaluated the website. It is important to mention that the evaluators only saw the **Researcher** view of the website which contains less information compared to the **Developer** one. The average rating of the design of the website is **4.6 (excellent)**.

One of the questions asked about how needed the interactive map might be in a future release – twenty-five respondents said that it was absolutely needed and ten that it is maybe needed. A user has said that "*I think the aforementioned map would go a long way to helping the data be more readable and interactive for users once implemented*".

Thirteen people in total have left their opinion of the website, some of them praising the design ("***Design looks perfect***", "***Very clean design!***"), while others mentioned the ease of use and the good quality of the features it provides ("***Very easy to navigate and understand. With useful well thought out features***", "***The formatting of the excel sheet the results are extracted to is very nice and intuitive, great work!***").

From the feedback, it becomes clear that people in general enjoy the look of the website. The interactive map seems like a wanted feature, which makes sense, as it would provide an easy way of visualisation of the collected data. However, this feature has to be very well thought of in order to ensure it provides the most important data.

6.3.2 iOS Application

Thirty-five people have evaluated the iOS application. The average rating of its design is **4.7 (excellent)**. As with the website, when it comes to the additional comments left by the evaluators, some have focussed on the design ("***The design is incredibly done.***", "***I loved the design. It is similar to stock applications while also being unique at the same time***."), while others have expressed their opinion about the features the application provides ("***It looks quite useful for users experiencing hay fever and for those who do not***."). Some showed that the project might have good market potential ("***I need this app!***").

One person has suggested that the survey view has to be improved, by adding information about how users could classify their symptoms strength on the scale from low to high. It is suggested within the application that this should be done based on how much the symptoms have impact on the daily activities. Unfortunately, what could be classified as a low interference for someone could be high for someone else. The point made by the evaluator reveals a limitation, which was identified prior to the implementation of the platform. Another evaluator has suggested that the platform should be expanded to Android, however, by design, the project was meant to incorporate ResearchKit and thus focus on iOS solely.

A bug was reported early on the evaluation stage. It was related to applying multiple `.sheet` modifiers to the same view within SwiftUI. The bug was fixed by Apple in iOS 14.6. However, to ensure backwards compatibility with iOS 14.1 and above, as per the requirements, temporary workaround was implemented. This is described in **Section 5.1.5 Additional Resources.**

The survey also tried to find out which of the implemented features users find to be the most useful. To do so, every user was allowed to select their top three out of seven features. The results are presented below:

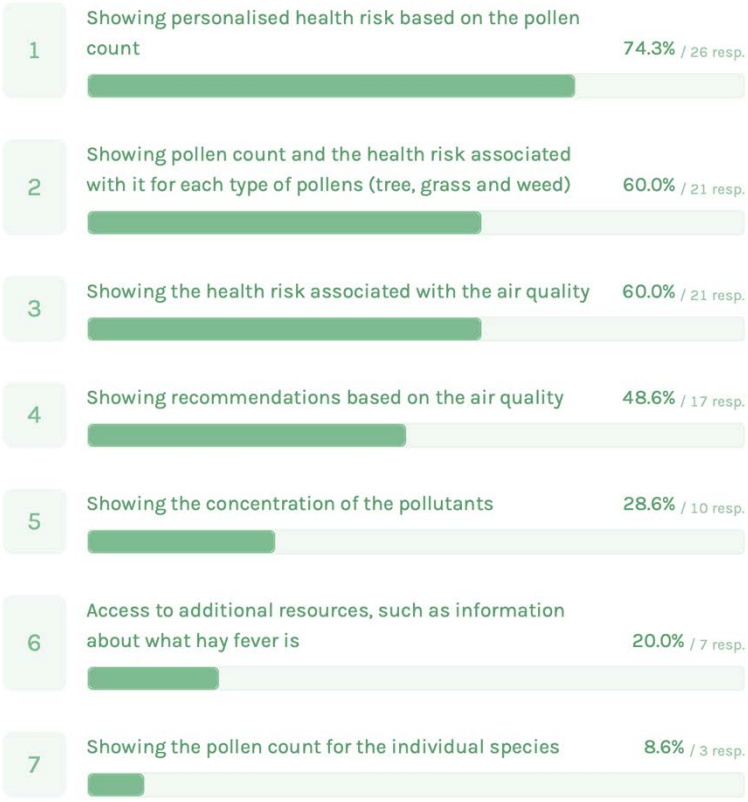

Figure 6-3 Implemented Features Rating

As it can be seen in the figure above, the top three features are the personalised health risk associated with the pollen count, the pollen count for each type of pollens, as well as the health risk associated with the air quality. There are few interesting observations that can be made:

- The most liked feature, displaying the **personalised health risk based on the pollen count**, is exclusive to ClimaFever. It is quite simple to implement, and it is surprising that other vendors have not incorporated it within their applications.
- Showing the **health risk associated with the air quality** is ranked as number three, even if the application is preliminarily focused on hay fever. As there is direct connection between the air quality and the strength of the raspatory-related diseases, this shows that the air quality information is indeed useful for users to have. However, as people who are evaluating the usability of the platform are meant to not suffer from hay fever, it could also be the case that some of them have chosen a feature they can relate to more and might have missed the importance of some of the other features.
- **Showing the pollen count for the individual species** is also exclusive to ClimaFever, however, it was chosen as the least useful one. As mentioned above, it could be due to evaluators not being able to appreciate the additional information provided. Alternatively, people might not be aware which pollen they are exactly allergic to, and thus the aggregated information might be more useful.

The survey also asked the evaluators about their favourite top three planned features, out of five options. The results are presented below:

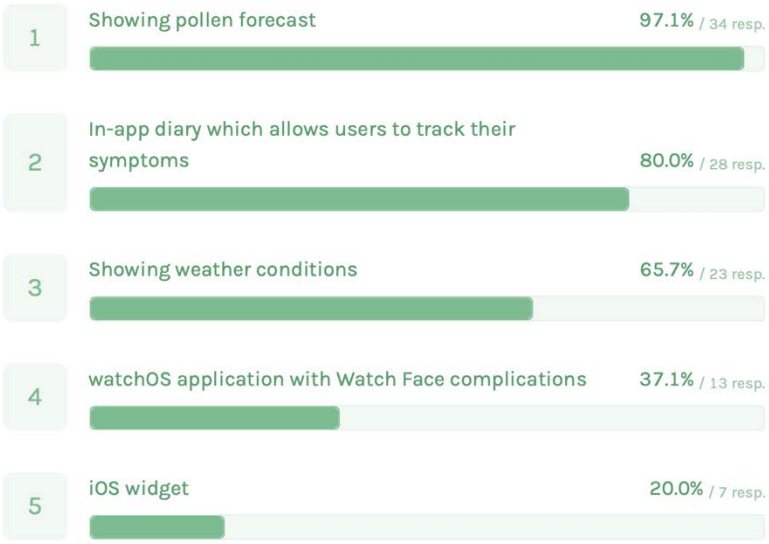

Figure 6-4 Planned Features Rating

As the development was split into two stages, the second one was meant to introduce features, based on the feedback from the users.

Showing the pollen forecast turned out to be the top-rated feature. When the initial requirements were written, this was identified as a possible future extension, however, it was undoable, as the API used did not provide the information. In the course of the project, this feature was added to the API and, as being the most requested one, an hourly pollen forecast for two days was implemented.

The **in-app diary**, ranked as number two, is found in some of the other applications on the market. While useful, it was decided that this would be out of scope for the project. However, it is still a feature useful to have in future.

The **weather conditions** turned out to be among the highly rated features, and, as the time allowed it, it was implemented as part of the second stage of the product development.

Finally, the **iOS widget** and the **watchOS application** would have been exclusive for ClimaFever, if implemented. They were given lower priority in the requirements prioritisation, as they are not key features for achieving the goals of the project. As the survey showed that they are likely to be the least wanted ones, one can conclude the correct decisions were taken during the prioritisation activities. However, people who do not own an iPhone (and thus have evaluated the platform by watching the video) or do not own Apple Watch might have ranked them lower.

6.3.3 Conclusions

In general, it seems that evaluators are happy with the quality of the system produced. One of the ClimaFever-exclusive features being ranked as the most liked one is very promising and shows the potential of user-facing features of the application. Unfortunately, it is harder to evaluate the usefulness of the research aspect of the project (the ResearchKit survey). This would require a consultation with people with better expertise.

The full results from the evaluation can be found in **Appendix L User Evaluation Results.**

6.4 Limitations

As part of the Survey & Analysis stage of the project, as well as during the development, some limitations were identified. The major one is related to the Ambee API pricing. Unfortunately, this is the biggest issue, and the money users will have to pay on a subscription renders the project unsuitable for releasing on the AppStore.

6.4.1 Ambee API Pricing

Using Ambee API is in the core of the project. It is needed both for the user-facing features, such as the pollen count and the air quality data, as well as for submitting responses using the in-app ResearchKit survey.

Initially, there seemed to be some misunderstanding about the way Ambee charges for the API calls.

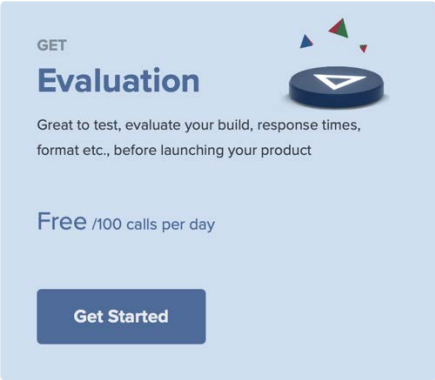

Figure 6-5 Ambee Evaluation Plan Option
Source: Ambee [133]

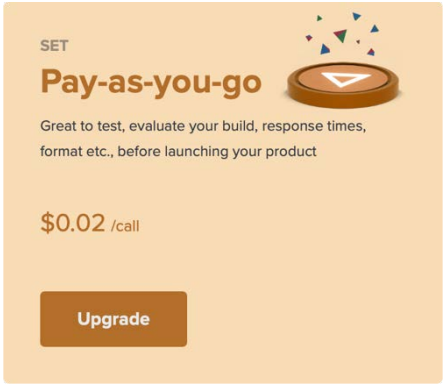

Figure 6-6 Ambee Pay-As-You-Go Plan Option
Source: Ambee [133]

Ambee claims to be offering 100 calls per day, using the free tier. On their pricing page, they also claim that "*You will be notified if you exceed the 100 free API calls with the Evaluation plan.*" [133]. This was understood as if one API request equals to one call. As an example, opening the app once would make a request for the current pollen count, the forecast pollen count, the air quality data, as well as the weather data, so four API calls in total. During the development and testing, in turned out that this was not the case.

The usage is instead determined by the number of data queried, rather than the API calls. For example, the following response would result in two calls, rather than one, as initially anticipated.

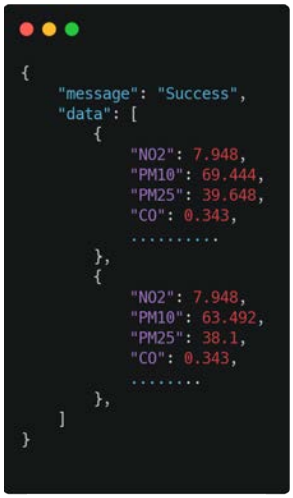

Figure 6-7 Example Ambee API Response

Asking for a two-day hourly pollen forecast, for example, results in 48 calls (2 days x 24 hours), instead of one. Using the pay-as-you-go pricing, which was the only option available prior May 11, 2021, this costs £0.68 ($0.96). It can be seen how using the Ambee API can quickly become quite expensive. A suggestion was made to the developers to change the wording on the website, so instead of "calls", it says "records", to avoid future confusion. Moreover, a suggestion was made to add extra options to the API, so that forecast can be quired for a specific period of time and thus minimise the cost.

As of May 11, 2021, it seems that Ambee is working on an improved pricing system. Now, different plans are available for the different APIs. The Basic Plan for Air Quality API and Pollen AQI costs £85 ($119) each, while the Weather API is £14 ($19).

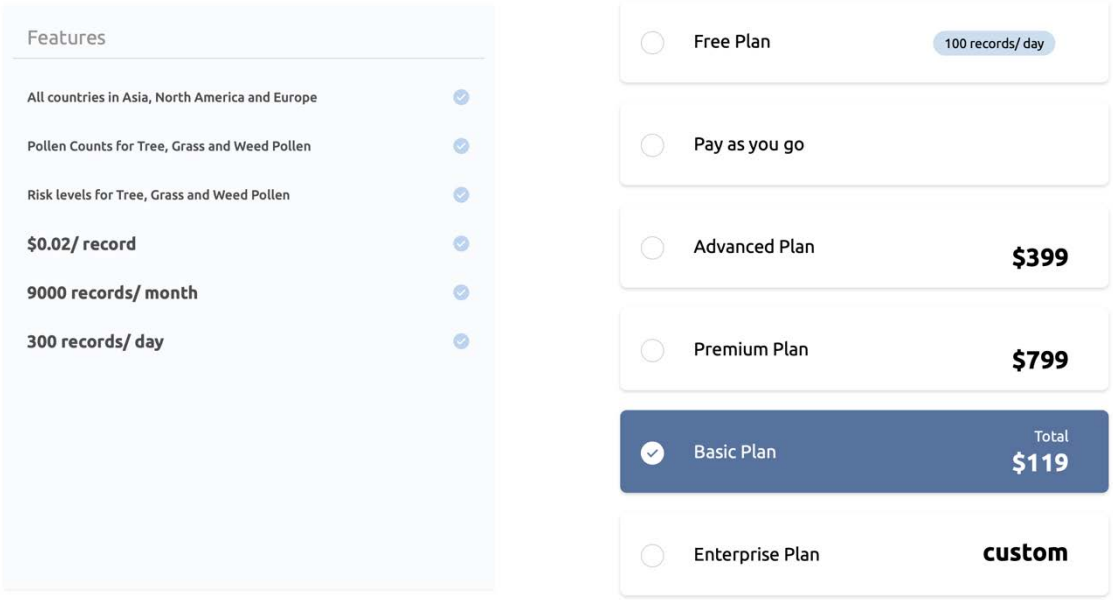

Figure 6-8 Ambee Pollen API Basic Plan

Both basic plans for the Pollen and the Air Quality API offer 300 records a day. It is mentioned that the price per record is $0.02, however, $119/0.02 does not equal to 9000. As it does not become clear how the usage cost should be calculated, it was assumed that the Basic Plan provides 300 records a day. It was already discussed that asking for a pollen forecast results in 48 records. This means that just for

obtaining the pollen forecast, no more than six users can use the ClimaFever app within the same day for the price of $119 per month, under the assumption that each user requests data only once a day. Of course, this will diminish the usability of the application. While certain API call optimisations can be made, the price is too high.

An experiment showed that a single opening of the ClimaFever app results in 54 records. This translates to £0.76 ($1.08) per app launch. As mentioned previously, most of records retrived are because of the pollen forecast. A way to optimise the calls would be to store the pollen forecast locally and display the forecast for the next 24 hours only. This means that the pollen forecast can be obtained once in every two days, and only if requested.

Another issue that arose during development is that the payment system Ambee uses only supports credit cards. Students do not qualify for a credit card and thus pay-as-you-go plan could not be used, despite the willingness to pay.

6.4.2 Other limitations

Some of the other limitations, related to the project, are:

- SwiftUI 2 requires iOS 14 and watchOS 7 or newer. This means that only people running the latest version of the operating systems will be able to take advantage of the app. As of November 19, 2020, iOS 14 adaptation has surpassed 70% [134].
- Currently, Ambee's API provides pollen data for Asia, North America, and Europe only.
- As pollen count information is not publicly available and is very limited in some areas, the API providers apply extrapolation and other techniques which means the data provided is not as accurate and an error rate is expected.

When it comes to the research aspect of ClimaFever, the main limitations are related to how long such research should run for, as well as how many people enrol on the study:

- The project would require a large number or participants in as many countries as possible.
- The project should run for few years, to be able to cover all seasons.
- Data, collected by users, is subjective by its nature. For example, people have different liminal point[14].

Because of the time-constraints, it is not possible to gather enough data, to conclude if climate change is related to the hay fever symptoms onset. However, the project gives a good ground for future research in an area of a high social significance. The platform also illustrates how modern technologies can be used for research purposes.

[14] The point at which a stimulus is strong enough to produce a physiological or psychological response

6.5 Further Work

While what has been implemented covers the main objectives of the project, there is a scope for further work to ensure the software is of a production-quality. Due to the time constraints, some optimisations and security features were left out. Furthermore, some additional features were identified. While they were not planned to be included as part of the minimum viable product, they would make ClimaFever stand out from the competition even more. The features and optimisations needed are prioritised based on importance and are listed in descending order from the most important one:

6.5.1 API Calls Optimisations

The environmental data, received from the Ambee API, is in the core of the user-facing functionality of ClimaFever. For the application to be usable, as well as for the survey responses to be reliable, it must be ensured that the environmental data is always up to date. Currently, the environmental data is updated when the significant location (500 meters or more) of the user changes. The data is also requested again if the user force-closes the application, however, this is a limitation rather than a desired behaviour (see **Section 6.5.2 Client Database**).

To enhance user experience, Background Fetch API can be used. It ensures that the application always displays up-to-date data while minimizing the impact on the battery life. It is part of the Background Modes services and lets the system decides when it is the best time for the data to be updated [135]. It uses machine learning and learns the usage patterns. For example, if the user interacts with the specific app at a certain time of the day, the background fetch is likely to happen shortly before that. Making use of the Background Fetch API will ensure that the application is not too greedy on system and network resources, while still being up to date enough to provide useful information.

6.5.2 Client Database

Currently, the iOS application uses UserDefaults for storing user settings. UserDefaults is a storage option, only appropriate for data of a small size. It is also an insecure store and data can easily be extracted. To optimise how the application works and to be able to expand its features, another storage solution should be implemented alongside UserDefaults. Possible options are CoreData and CloudKit. CloudKit is built on top of CoreData and allows for the data to be synchronised using iCloud. This means that users will be able to access all their data on all devices they own provided they have signed in with the same Apple ID.

There will be numerous benefits of implementing a better client storage:

- Currently, the environmental data is stored in memory only. This means that upon force closing and reopening the application, the data must be requested again. This is inefficient (creates multiple requests), expensive (API calls are charged) and unreliable (requires internet connection). If a database solution is implemented, the fetched data can be stored there and used until there is a genuine need to request new data (a certain amount of time has passed, or the user location has changed significantly).
- Users will be able to see a history of their survey responses. With the current implementation, only the latest response is available to the user. As it is too big to store in UserDefaults, it is requested from the server, when needed. This again creates unnecessary requests and makes the data unavailable if the user is offline.

6.5.3 Apple Watch Application

With over 100 million Apple Watches sold around the world, it is a device that becomes almost as important as the iPhone itself. Due to its nature, users interact with the device all the time – even without realising it. Building an Apple Watch companion app for ClimaFever will allow users to see the most important information at a glance. With the development of the application, Apple Watch widgets can also be developed. This is quite simple to do, once the application is available. By having the complications, users can place them on their Watch Face and make use of the latest data at any time. The application can also notify the users should the high-risk alerts are implemented (see **Section 6.5.6 High Risk Alerts**).

6.5.4 iOS Widget

iOS Widgets have been revamped in iOS 14. Now they can be placed anywhere on the Home screen. What is more, iOS Widgets are now exclusively built with SwiftUI. As SwiftUI promotes reusability, most of the code for the widget and the Apple Watch application could be shared between both. In iOS 14, Widgets can be built in different sizes, each one showing a different level of detail. The user is then free to choose the one that suits their needs the best.

6.5.5 CareKit Integration

The ResearchKit survey would be replaced with CareKit instead. This will bring new functionality to ClimaFever, such as symptoms tracking and following daily care plan. Users can be given a reminder to take antihistamines. The collected information over time can then be shared with a healthcare professional in order to aid the diagnosis and treatment.

6.5.6 High Risk Alerts

As ClimaFever has access to an hourly pollen forecast, as well as a way for users to choose their pollen sensitivity, the application can alert users about an upcoming elevated health risk. Getting the personalised health risk is already the users' favourite feature, so receiving customised alerts is also expected to be a popular one. This can be done on the night before or at the beginning of the day. Having this notification can remind the user to take their medications before the symptoms have unfolded, or to change their plans for the day.

6.5.7 SwiftUI 3 Support

SwiftUI 3 is expected to be unveiled on WWDC 2021, which is going to be held on June 7th, 2021. While it is hard to speculate what changes the new version could bring, SwiftUI 2 introduced new components, as well as new property wrappers which improve the semantics and lead to shorter code. Prior to the official release, CliamFever will be reworked to introduce the changes mentioned above, while also taking benefit from the changes introduced in SwiftUI 3. Furthermore, the evaluation testing revealed a bug which was subsequentially fixed in iOS 14.6. However, to preserve compatibility with earlier iOS versions, it was decided to use workarounds. When ClimaFever is updated to support SwiftUI 3, the minimum iOS target version will have to be incremented to 15, meaning that these temporary workarounds can be reverted to the original implementation.

6.5.8 Disabling Features

Users can be given the opportunity to disable certain features, such as displaying air quality or weather data. This would again optimise the number of requests needed, which saves resources. It can also lead to a less cluttered user interface, allowing users to focus only on what they really need to see. Access to the additional resources is one of the least liked features, based on the user evaluation, and users might want to remove it from the UI.

Chapter 7

Conclusions

Hay fever is among the most common medical conditions. Millions are suffering every year. With its symptoms, such as itchy eyes and runny nose, it can greatly affect the everyday life. While some are self-managing their symptoms, other are either misdiagnosed or not being diagnosed at all. This is partially due to the symptoms being similar with those of many other conditions. However, possibly the biggest issue is that the hay fever season is known to be from March to October. Patients, showing symptoms at other times of the year, would most probably not even be sent for allergy sensitivity testing.

Climate change is a change in the average weather patterns. This includes changes in precipitation and more intense heatwaves. As a result, seasonal shifting has been observed – spring arrives earlier, and winter is getting shorter. This changes the timing of when flowers and trees bloom. The early onset of spring prolongs the pollen exposure, whereas late spring leads to people being exposed to multiple pollens at once. This is especially dangerous for those who suffer from raspatory diseases, such as asthma. It has been shown that increased concentrations of CO_2 lead to increased ragweed pollen production. However, all studies made on the topic are performed in lab. As being in a controlled environment, many factors, such as the ambient temperature and rainfall, are excluded. Furthermore, in lab studies are hard to extrapolate to the whole world – as pollen concentration and air pollution differs based on the geographical location.

While the limited in lab experiments give the ground for future work, there has not been anything developed that can be used to collect quantitative information. What is more, none of the studies that have been conducted already can be directly translated in how the climate change affects the hay fever sufferers. ClimaFever consists of an iOS application with an in-app survey, implemented using Apple's ResearchKit framework. The survey has been designed to be as short as possible and takes just a few seconds to complete. The collected information can reveal when people start experiencing symptoms and what their strength is. The application also collects location, pollen, and air quality data. The results can be easily exported from the project's website and analysed with tool such as Excel. ClimaFever gives everything needed to build on top of the lab experiments and provide definite answers. As the location of the users is stored as well, conclusions can be made for each country or region individually.

Currently, only one research-based application related to hay fever is available. It allows users to track and report their symptoms for a number of days. The application is purely for research purposes, so it lacks symptoms self-management features that can be found in other apps.

ClimaFever is the first platform that combines the research-based aspect with additional features, such as displaying pollen and air quality data, allowing self-management of symptoms. ClimaFever makes use of Ambee's proprietary technology – AIONN-MetNet – which combines a model trained on historical weather data, radar data, satellite information and Gaussian interpolation. The technology demonstrates a great application of Machine Learning. With the available information, ClimaFever was designed to be fundamentally different to what is currently available on the market:

- It is the first application that displays **pollen count information throughout the whole year**. The others are showing data between March and October and assume low pollen count at all other times. As one of the main purposes of ClimaFever is to change the established perceptions about when the hay fever season starts and how long it lasts, displaying pollen count information in real time is of a vital importance.
- It is the first that provides **pollen count with post code accuracy**.
- It is also the first one that provides the actual concentration of pollens as a number.

ClimaFever also introduces few new features which are exclusive to the platform – these include **pollen count for subcategories**, as well as **individualised pollen health risk**. As a future development, an iOS widget and an Apple Watch application can be developed. These will also be unique to ClimaFever.

An extensive evaluation of the developed platform was performed with a varied population of participants. The project received very positive feedback. The personalised health risk, which is a ClimaFever exclusive feature, was identified as the users' favourite. Some of the most wanted features, such as pollen forecast, were also implemented based on the feedback.

One of the main limitations of the project is the high pricing of the Ambee's API. With the current features and the way they are implemented, a single launch of the application costs £0.76 ($1.08). While some optimisations can be made, users would have to pay a costly monthly subscription if the app is made available on the App Store. Nevertheless, the project will be finished, so that it can be used as a portfolio item. Whether it is going to be officially released will depend on what the costs of running it can be reduced to. A balance between showing up to date data, features and cost effectiveness will have to be achieved. The published version will slightly differ from the one presented in this report – the research-based survey will be replaced with a diary.

In its current implementation, the ClimaFever iOS application contains fourteen core features, which is with five more than what the current best app on the market offers. With its research aspect, the dynamic web application, and the possible addition of four more extra features, ClimaFever provides everything needed to hay fever researchers and sufferers. The project also shows how modern-day technologies can be used to investigate and resolve problems of high importance.

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Appendices

Appendix A User Stories

Tag	No.	Story	Status	Remarks
Must Have	1	As a user I can enrol on the study so that I can take part in the research. **Acceptance Criteria:** 1. Open ClimaFever **either** 2. Go to "Settings" view by clicking the user icon on the upper right corner **or alternatively** 2.1 Go to "Survey" 2.2 Click "Open Settings" 3. Type in the "Invitation ID" you have been provided with under the "Participating Status" section 4. Follow the on-screen instructions 5. Informed consent is displayed and can be electronically signed 6. The informed consent with the signature can be exported or emailed 7. Participation status changes to "Participating" 8. The Daily Survey appears under the "Survey tab"	Implemented	The user story has been rewritten to introduce the two different ways the user can enrol. Some of the steps were modified.

Tag	No.	Story	Status	Remarks
Must Have	2	As an enrolled user I can unenroll from participating in the study. **Acceptance Criteria:** 1. Open ClimaFever 2. Go to "Settings" view by clicking the user icon on the upper right corner 3. Click "Opt-out" under "Status" 4. A success message alert appears 5. The participation status changes to "Withdrawn" 6. Introductory content appears on the "Survey" view	**Implemented**	The user story was changed, as the stored survey response is not associated with the user. The data cannot be removed, as it is not identifiable. "Unenroll" was changed to "Opt-out".
Must Have	3	As an enrolled user I can fill in the questionnaire so that I can contribute to the research. **Acceptance Criteria:** 1. Open ClimaFever 2. Go to "Survey" view 3. Click on "Get Started" 4. Follow the on-screen instructions and click "Done" 5. A "Response Summary" view appears with the submitted data	**Implemented**	The user story was updated to introduce the extra step which is displaying the Response Summary.
Must Have	4	As a user I can see information whether I can access the in-app survey, as well as how to sign up. **Acceptance Criteria:** 1. Open ClimaFever 2. Go to "Survey" view 3. Information about how to participate in the study is displayed.	**Implemented**	A new user story.

Tag	No.	Story	Status	Remarks
Must Have	5	As a user/enrolled user I can see my current participation status. **Acceptance Criteria:** 1. Open ClimaFever 2. Go to "Survey" view 3. Go to "Settings" view by clicking the user icon on the upper right corner 4. The current status appears under "Participation Status"	**Implemented**	A new user story.
~~Must Have~~	6	As a researcher/developer I can access the data, collected by users, on a website so that I can access the data gathered from the participants. **Acceptance Criteria:** 1. Open the website 2. Login 3. Dashboard with summative data appears	**Replaced**	This user story was replaced with user story #7.
Must Have	7	As a researcher/developer I can see and export the data, collected from the users, as an Excel spreadsheet file, so to be able to perform data analysis. **Acceptance Criteria:** 1. Open the website 2. Login 3. Select "Responses" 4. Responses appear 5. Click "Export" 6. An Excel spreadsheet with the following sheets gets generated and downloaded: - Responses Summary - Pollen Count Data - Air Quality Data - Reported Symptoms	**Implemented**	New user story which replaces user story #6.

Tag	No.	Story	Status	Remarks
Must Have	8	As a researcher I can create new Invitation IDs so that every participant can have its own ID. **Acceptance Criteria:** 1. Open the website 2. Login 3. Select "Invitees" 4. Select "Create Invitee" 5. A new random Invitation ID appears on the page with status "Invited"	**Implemented**	This was deemed necessary so to ensure that evaluation can happen following the and complying with the ethics procedures. The tag was changed from "Will not have" to "Must have"
Must Have	9	As a researcher I can restrict Invitation IDs so that I can prevent multiple users enrolling with the same Invitation ID. or alternatively As a researcher I want Invitation IDs to auto-expire when used for the first time, so that I can prevent multiple users enrolling with the same Invitation ID. **Acceptance Criteria:** 1. Open the website 2. Login 3. Select "Invitees" 4. Select "Restrict" next to the invitee you want to restrict 5. Invitation Status changes to "Restricted"	**Implemented**	This was deemed necessary so to ensure that evaluation can happen following the and complying with the ethics procedures. The tag was changed from "Will not have" to "Must have"

Tag	No.	Story	Status	Remarks
~~Should Have~~	10	As a user/enrolled user I can view the localised risk levels associated with the PM_{10}, O_3 and CO pollutants so that I am aware of what the current risk level associated with each pollutant is. **Acceptance Criteria:** 1. Open the ClimaApp 2. Accept location sharing 3. Pollutant risk levels for PM_{10}, O_3 and CO appear on the "Home" view (can be "Low", "Medium" or "High")	**Dropped**	The requirement is infeasible, as the data is not easily available. Potentially, it can be displayed if the values are within a certain range or not, however, the health risk cannot be directly calculated.
Should Have	11	As a user/enrolled user I can view the localised pollen count for each of the three types of pollens (trees, grass, weed) so that I am aware of how much pollen is present in the air. **Acceptance Criteria:** 1. Open ClimaFever 2. Accept location sharing 3. Pollen count for trees, grass and weeds appears on the "Home" view on the Pollens card	**Implemented**	
Should Have	12	As a user/enrolled user I can view the health risk associated with the localised pollen count for each of the three types of pollens (trees, grass, weed) so that I am aware of how much pollen is present in the air. **Acceptance Criteria:** 1. Open ClimaFever 2. Accept location sharing 3. The health risk for trees, grass and weeds appears on the "Home" view on the Pollens card	**Implemented**	A new user story.

Tag	No.	Story	Status	Remarks
Should Have	13	As a user/enrolled user I can view the personalised risk associated with the localised pollen count of either tree, grass or weed pollens, based on my sensitivity, so that I can get the essential information as easy as possible. **Acceptance Criteria:** 1. Open ClimaFever 2. Accept location sharing 3. The personalised pollen risk appears on the "Home" view (can be "Low", "Medium" or "High") on the top of the Pollens card	**Implemented**	"Overall" replaced with "Personalised"
Should Have	14	As a user/enrolled user I can set what I am allergic to, so that the personalised health risk associated with the pollens can be updated accordingly. **Acceptance Criteria:** 1. Open ClimaFever 2. Go to "Settings" view by clicking the user icon on the upper right corner 3. Tap "Pollen Sensitivity" 4. Select the type of pollen 5. Tap "Done" 6. The health risk is updated to reflect the new selection	**Implemented**	A new user story.

Tag	No.	Story	Status	Remarks
Should Have	15	As a user I can view an hourly 2-day pollen forecast so that so that I am aware of what the risk level associated with each pollen will be in the following days. **Acceptance Criteria:** 1. Open ClimaFever 2. Accept location sharing 3. Tap "Forecast" on the Pollens card 4. A view with the pollen forecast appears	**Implemented**	This requirement was infeasible in the past as the Ambee API did not provide this information. However, it was eventually made available. It was also the most required feature based on the user evaluation. The tag was changed from "Will not have" to "Should Have"
Should Have	16	As a user/enrolled user I can view the localised air quality index (AQI) so that I am aware of how polluted the air is. **Acceptance Criteria:** 1. Open ClimaFever 2. Accept location sharing 3. AQI index appears on the "Home" view under the Air Quality card	**Implemented**	
Should Have	17	As a user/enrolled user I can view the risk associated with the air quality index (AQI) so that I can get the essential information as easy as possible. **Acceptance Criteria:** 1. Open ClimaFever 2. Accept location sharing 3. The health risk associated with the AQI appears on the "Home" view on the top of the Air Quality Card	**Implemented**	A new user story

Tag	No.	Story	Status	Remarks
Should Have	18	As a user/enrolled user I can view the localised PM_{10}, PM_{25}, SO_2, NO_2, Ozone and CO levels so that I am aware of how much the concentration of each of the pollutants is. **Acceptance Criteria:** 1. Open ClimaFever 2. Accept location sharing 3. Tap "Details" under the Air Quality card 4. PM_{10}, PM_{25}, SO_2, NO_2, Ozone and CO concentrations appear	**Implemented**	Additional pollutants added (PM25, SO2, Ozone) Additional step (#3) added.
Could Have	19	As a user I can see an onboarding screen outlining all main features of ClimaFever and allowing me to set my pollen sensitivity, as well as the unit system I prefer to be used for the weather data. **Acceptance Criteria:** 1. Open ClimaFever for the first time 2. On-boarding screen with features outline appears 3. Tap "Continue" 4. A screen with settings appear	**Implemented**	A new user story.
Could Have	20	As an enrolled user I can see my latest survey submission. **Acceptance Criteria:** 1. Open ClimaFever 2. Submit a new survey response 3. Tap on "Survey" 4. The latest response with the pollen, air quality, reported symptoms and location data is displayed	**Implemented**	A new user story.

Tag	No.	Story	Status	Remarks
Could Have	21	As a user/enrolled user I can view recommendations based on the AQI so that I can get additional information about what the recommendations are in the current environment. **Acceptance Criteria:** 1. Open ClimaFever 2. Accept location sharing 3. Recommendations appear on the "Home" view on the Air Quality card	**Implemented**	The recommendations are based on the AQI only and do not consider the pollen count, as previously planned.
Could Have	22	As a user/enrolled user I can view the localised pollen count for each subcategory of the three types of pollens (trees, grass, weed) so that I am aware of how much pollen is present in the air. **Acceptance Criteria:** 1. Open ClimaFever 2. Accept location sharing 3. Pollen count for trees, grass and weeds appears on the "Home" view 4. Select "Details" under "Tree", "Grass" and "Weed" 5. Subcategory data appears	**Implemented**	A new user story.
Could Have	23	As a user/enrolled user I can view the weather data (current temperature, humidity, cloud cover and wind speed), so to know what the likelihood of experiencing hay fever symptoms is. **Acceptance Criteria:** 1. Open ClimaFever 2. Accept location sharing 3. Scroll down to the Weather card 4. The current temperature, humidity, cloud cover and wind speed appear on the card	**Implemented**	New user story which replaces user story #46

Tag	No.	Story	Status	Remarks
Could Have	24	As a user/enrolled user I can set if I want to use metric or imperial unit system, so that the current temperature and the wind speed can be displayed accordingly. **Acceptance Criteria:** 1. Open ClimaFever 2. Go to "Settings" view by clicking the user icon on the upper right corner 3. Tap "Unit System" 4. Select "Metric" or "Imperial" 5. Tap "Done" 6. The current temperature and the wind speed are updated to use the selected units.	**Implemented**	A new user story.
~~Could Have~~	25	As a user/enrolled used I can view information about different treatment options so that I can get informed about methods I might not have been aware of. **Acceptance Criteria:** 1. Open the ClimaFever app 2. Scroll to "Additional Information" on the "Home" view 3. Select "Treatment" 4. A new view with information about treatment options appears	**Replaced**	This user story was replaced with user story #27.

Tag	No.	Story	Status	Remarks
~~Could Have~~	26	As a user I can view information about different testing options so that I can get informed about methods I might not have been aware of. **Acceptance Criteria:** 1. Open the ClimaFever app 2. Scroll to "Additional Information" on the "Home" view 3. Select "Diagnosis" 4. A new view with information about diagnosis appears	**Replaced**	This user story was replaced with user story #27.
Could Have	27	As a user/enrolled user I can view information about what hay fever is, what its symptoms are, how it is diagnosed and what treatment options are available. **Acceptance Criteria:** 1. Open ClimaFever 2. Tap on the "What is hay fever" card 3 A new view with information about hay fever appears	**Implemented**	New user story which replaces user stories #25 and #26.
Could Have	28	As a user/enrolled user I can view information about the different triggers (trees, grass, weeds) so that I know what risk is associated with each of them. **Acceptance Criteria:** 1. Open ClimaFever 2. Tap on the "Pollens" card 3 A new view with information about pollens appears	**Implemented**	

Tag	No.	Story	Status	Remarks
Could Have	29	As a user/enrolled user I can view information about the different air pollutants so that I know what risk is associated with each of them. **Acceptance Criteria:** 1. Open ClimaFever 2. Tap on the "Pollutants" card 3. A new view with information about pollutants appears	**Implemented**	
Could Have	30	As a user/enrolled user I can see if the app is showing an outdated information because I am offline or using low power mode. **Acceptance Criteria:** 1. Open ClimaFever 2. Go to "Settings" view by clicking the user icon on the upper right corner 3. The network status with an informative description appears under "Network Status"	**Implemented**	A new user story.
Could Have	31	As a researcher/developer I can see individual responses. **Acceptance Criteria:** 1. Open the website 2. Login 3. Select "Responses" 4. Responses page appear 5. Click "Preview" next to the response 6. A page with the following data appears: - Pollen Count - Air Quality - Reported Symptoms - Location	**Implemented**	A new user story.

Tag	No.	Story	Status	Remarks
Could Have	32	As a developer I can delete invitees, so that I can clean the database, if needed. **Acceptance Criteria:** 1. Open the website 2. Login with a developer account 3. Select “Invitees” 4. Invitees appear 5. Click “Delete” next to the invitee you want to delete 6. Confirm your action 7. The invitee is deleted	**Implemented**	A new user story.
Could Have	33	As a developer I can edit invitees, so that I can make a change, if a researcher has made a mistake, or for debugging purposes. **Acceptance Criteria:** 1. Open the website 2. Login with a developer account 3. Select “Invitees” 4. Invitees appear 5. Click “Edit” next to the invitee you want to edit 6. Change the ID or the status 7. Select “Update” 8. The Invitee is updated	**Implemented**	A new user story.

Tag	No.	Story	Status	Remarks
Could Have	34	As a developer I can create new statuses which can be assigned to Invitees. **Acceptance Criteria:** 1. Open the website 2. Login with a developer account 3. Select “Invitees” 4. Invitees page appears 5. Scroll to the “Statuses” section 6. Type the status value in the field and press “Create Status” 7. The Status is created	**Implemented**	A new user story.
Could Have	35	As a developer I can delete statuses. **Acceptance Criteria:** 1. Open the website 2. Login with a developer account 3. Select “Invitees” 4. Invitees page appears 5. Scroll to the “Statuses” section 6. Click “Delete” next to the status you want to delete 7. The Status is deleted	**Implemented**	A new user story. The iOS application is dependent on the statuses in the database matching the prespecified requirements. Deleting a status will cause runtime crashes! Should only be used for development and debugging purposes.

Tag	No.	Story	Status	Remarks
Could Have	36	As a developer I can create user roles so that users can be given different privileges. **Acceptance Criteria:** 1. Open the website 2. Login with a developer account 3. Select “Users” 4. “Users” page appears 5. Select “New Role” 6. “New Role” page appears 7. Fill in the name and the description of the role 8. Press “Submit” 9. The new role with no associated users is displayed on the “Users” page	**Implemented**	A new user story.
Could Have	37	As a developer I can edit user roles so that mistakes can be fixed. **Acceptance Criteria:** 1. Open the website 2. Login with a developer account 3. Select “Users” 4. “Users” page appears 5. Select “Edit” next to the role you want to edit 6. “Editing Role” page appears 7. Fill in the updated name and the description of the role 8. Press “Submit” 9. The updated role is displayed on the “Users” page	**Implemented**	A new user story.

Tag	No.	Story	Status	Remarks
Could Have	38	As a developer I can delete user roles so that the database can be cleaned. **Acceptance Criteria:** 1. Open the website 2. Login with a developer account 3. Select "Users" 4. "Users" page appears 5. "Delete" appears only for roles which have no associated users with it 6. Select "Delete" next to the role you want to delete 7. Confirm your action 8. The role is deleted	**Implemented**	A new user story.
Could Have	39	As a developer I can create users so that more people can use the system. **Acceptance Criteria:** 1. Open the website 2. Login with a developer account 3. Select "Users" 4. "Users" page appear 5. Select "New User" 6. "New User" page appears 7. Fill in the username, the email, the password, and the role of the user 8. Press "Submit" 9. The new user is displayed under the associated Role on the "Users" page	**Implemented**	A new user story.

Tag	No.	Story	Status	Remarks
Could Have	40	As a developer I can edit users so that mistakes can be fixed. **Acceptance Criteria:** 1. Open the website 2. Login with a developer account 3. Select "Users" 4. "Users" page appear 5. Select "Edit" next to the user you want to edit 6. "Editing User" page appears 7. Fill in the updated information 8. Press "Submit" 9. The "Users" page is displayed without errors	**Implemented**	A new user story.
Could Have	41	As a developer I can delete users so that the database can be cleaned, or people can be restricted from accessing the system. **Acceptance Criteria:** 1. Open the website 2. Login with a developer account 3. Select "Users" 4. "Users" page appear 5. Select "Delete" next to the user you want to delete 6. Confirm your action 7. The user is deleted	**Implemented**	A new user story.

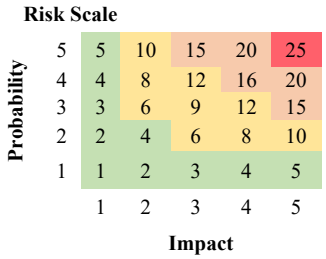
Tag	No.	Story	Status	Remarks
Could Have	42	As a user/enrolled user I can view the overall risk associated with the pollen count of tree, grass, and weed pollens, on my Apple Watch so that I can get the essential information with a glance. **Acceptance Criteria:** 1.1 Choose a Watch Face that allows adding complications 1.2 Press and hold on the Apple Watch screen until settings appear 1.3 Click “Edit” 1.4 Select a complication to be replaced with the ClimaFever one 1.5 Find the ClimaFever complication from the scroll list and select it 1.6 Click the digital crown to return to the Watch Face 1.7 The complication is on the screen or alternatively 2.1 Open the Watch app on the iPhone 2.1 Under “My Faces”, select the Watch Face you want to add the complication to 2.3 Under “Complications”, select the location name 2.4 Find the ClimaFever Pollen complication in the form and select it 2.5 Ensure the complication is applied to the Watch Face on the Watch	**Not Implemented**	

Tag	No.	Story	Status	Remarks
Will not have	43	As a user/enrolled user I want to have a choice of multiple iOS Widgets sizes so that I can get as much information as possible without opening the application.	**Not Implemented**	
Will not have	44	As a user/enrolled user I can view the overall risk associated with the AQI, on my Apple Watch so that I can get the essential information with a glance.	**Not Implemented**	
Will not have	45	As a user/enrolled user I can get daily log my symptoms so that I can get a better awareness of how they develop over time / share them with my healthcare provider.	**Not Implemented**	
~~Will not have~~	46	As a user/enrolled user I can see the weather forecast so that I can decide what the chance of experiencing hay fever symptoms might be.	**Replaced**	This user story was replaced with user story #23.
Non-functional	47	As a user/enrolled user I want the application to be available on the TestFlight.	**Satisfied**	Updated to say TestFlight instead of AppStore.
Non-functional	48	As a user/enrolled user I want the application to be compatible with iOS 14.1.	**Satisfied**	Updated to say iOS 14.1 and newer, instead of 14. watchOS requirement removed.
Non-functional	49	As a user/enrolled user I want the application to follow Apple Human Interface Guidelines and be accessible.	**Satisfied**	
Non-functional	50	As a researcher/developer I want the website to be deployed on Heroku and being accessible on www.climafever.tech	**Satisfied**	URL added
Non-functional	51	As a researcher/developer I want the website to be W3C-compliant.	**Satisfied**	

Appendix B Risk Register

Probability	Description
5	Very likely
4	Likely
3	Possible
2	Unlikely
1	Very unlikely

Impact	Description
5	Catastrophic damage
4	Major damage
3	Serious damage
2	Minimal damage
1	Very minor damage



Rank	Description	Impact	Rating			Mitigation	Remaining Rating		
			Probability	Impact	Risk		Probability	Impact	Rrisk
1	IDE or SDKs have bugs	May lead to project delay or impossibility to complete a task or the whole project	4	5	20	Use the most up-to-date versions, in order to ensure bug fixes are applied as soon as they are made available Attempt using an earlier or a newer version	3	5	15
2	Incompatible tool / framework required for implementing requirement(s)	May lead to extra time needed to find an alternative or some requirements might be impossible to implement in the way they are set	4	5	20	Investigate requirements carefully before finalisation Ensure compatibility by producing a prototype Be prepared with an alternative if an incompatibility is found late during the development	3	5	15

APPENDIX B RISK REGISTER

Rank	Description	Impact	Rating			Mitigation	Remaining Rating		
			Probability	Impact	Risk		Probability	Impact	Rrisk
3	Insufficient time to complete the project	May lead to missed deadlines, unfinished product or delivering the product in a non-working state	5	5	25	Use Gantt chart to track progress Prioritise requirements Always have a working version ready to deliver Utilise Christmas and Easter breaks to work on the project Work on the project regularly to ensure being up to date	3	5	15
4	Inability to evaluate the usability of the project	May lead to lack of confidence that the project is fit for purpose	4	5	20	Propose sensible and easy verifiable acceptance criteria for each requirement	3	5	15
5	Unfamiliarity with a tool / framework	May lead to extra time needed to obtain the skills or some requirements might be impossible to implement in the way they are set	4	4	16	Use familiar technologies where possible, familiarise with tools / frameworks before finalising requirements	3	4	12

APPENDIX B RISK REGISTER

Rank	Description	Impact	Rating			Mitigation	Remaining Rating		
			Probability	Impact	Risk		Probability	Impact	Rrisk
6	Final product contains bugs	May lead to bad user experience, or unusable product, as well as negative impact on the reputation of the developer	5	4	20	Produce unit and manual tests Make early version available for beta testing Act on the feedback gathered during the evaluation stage Use good software engineering practices to mitigate risks related to down-time of databases or APIs	3	4	12
7	Inadequately defined requirements	May lead to unpredicted extra work, the project might be unsuccessful due to missing core features needed to achieve the aims	4	5	20	Ensure requirements are well-defined Allow extra time for development, in case an unforeseeable situation occurs	2	5	10
8	Project might not get approved on the App Store	May lead to delays making the app available for testing, as well as not meeting one of main goals of the project	3	5	15	Ensure familiarity with the App Store Review Guidelines Design the app following the Apple Human Interface Guidelines	2	5	10
9	API(s) needed for the project becomes unavailable	May lead to inability to deliver core feature(s)	4	5	20	Be prepared to use an alternative option	2	5	10

APPENDIX B RISK REGISTER

Rank	Description	Impact	Rating			Mitigation	Remaining Rating		
			Probability	Impact	Risk		Probability	Impact	Rrisk
10	API(s) might provide low-quality on unreliable data This is not a major concern for this project, as an experimental platform is developed and the evaluation is on the software built, rather than the outcome of the potential day-to-day use of the platform.	May lead to non-definite / wrong results from the research	5	3	15	Make it clear that monitoring the type of data needed for the project is a challenging task and is expected that it will not be perfect	5	2	10
11	Hardware equipment becomes faulty	May lead to loss of data and project delay due to the servicing time	3	5	15	Data backup on a secondary device Have project stored in the cloud (using iCloud) Use of version control (GitHub) Two iPhones are available for development Use Xcode simulator for development and testing the app	1	5	5
12	Confidential user data leaks	May lead to negative impact on the reputation of the developer, possible legal actions	2	5	10	Use secure database Use encrypted connection when sharing data with APIs and databases Only collect the data absolutely necessary for taking part of the evaluation	1	5	5

APPENDIX B RISK REGISTER

Rank	Description	Impact	Rating			Mitigation	Remaining Rating		
			Probability	Impact	Risk		Probability	Impact	Rrisk
13	Product misleads users with wrong / invalid information or data	May lead to bad user experience, or unusable product, as well as negative impact on the reputation of the developer	4	4	16	Use information and data from trusted sources Make it clear that the data reported by the API is based on ML approaches and perfect data is not expected as not possible	1	4	4
14	Usage of copyrighted content	May lead to legal actions and negative impact on the reputation of the developer / University	2	4	8	Asking the owner of the copyrights for permission before using the content over relying on fair use Buy content, if needed Use royalty-free content Contribute creators	1	4	4
15	Lack of on-time feedback from the supervisor	May lead to bad project quality	3	4	12	Submit drafts two weeks before deadlines and arrange regular meetings with the supervisor	1	4	4
16	Illness	May lead to a delay	3	3	9	Take extra precautions to stay safe and healthy	1	3	3

Appendix C Ethics Application

The University Of Sheffield.

Application 037025

Section A: Applicant details

Date application started:
Thu 29 October 2020 at 20:02

First name:
Norton

Last name:
Andreev

Email:
aastrigachev1@sheffield.ac.uk

Programme name:
BEng Software Engineering

Module name:
Dissertation Project
Last updated:
11/05/2021

Department:
Computer Science

Applying as:
Undergraduate / Postgraduate taught

Research project title:
ClimaFever - iOS app to research the impact of climate change on hay fever sufferers

Has your research project undergone academic review, in accordance with the appropriate process?
Yes

Similar applications:
- not entered -

Section B: Basic information

Supervisor

Name	Email
Maria-Cruz Villa-Uriol	m.villa-uriol@sheffield.ac.uk

Proposed project duration

Start date (of data collection):
Sun 9 May 2021

Anticipated end date (of project)
Thu 10 June 2021

3: Project code (where applicable)

Project externally funded?
No

Project code
- not entered -

Suitability

Takes place outside UK?
No

Involves NHS?
No

Health and/or social care human-interventional study?
No

ESRC funded?
No

Likely to lead to publication in a peer-reviewed journal?
No

Led by another UK institution?
No

Involves human tissue?
No

Clinical trial or a medical device study?
No

Involves social care services provided by a local authority?
No

Is social care research requiring review via the University Research Ethics Procedure
No

Involves adults who lack the capacity to consent?
No

Involves research on groups that are on the Home Office list of 'Proscribed terrorist groups or organisations?
No

Indicators of risk

Involves potentially vulnerable participants?
No
Involves potentially highly sensitive topics?
No

Section C: Summary of research

1. Aims & Objectives

ClimaFever is an experimental platform for researching how climate changes affects hay fever sufferers. As part of it, an iOS and a Web application will be built. The dissertation project is not concerned with collecting actual data to be used for studying the correlation between climate change and hay fever, but rather an experimental platform, showing what can be done using novel technologies. Therefore, the ethical approval sought is focused on evaluating the usability of the system, for the purposes of completing the dissertation project and including the results in the report.

The goal is to have the iOS app available on TestFlight and, eventually, on the AppStore. For people who download it, only a subset of features, such as getting pollen count and air quality index information, will be available. This is publicly available information. Following the medical device regulation (MDR), an app that provides general information on a disease, does not diagnose, and does not prescribe a treatment, is not classify as a medical device. MDR states that the way the description of a given application is worded also influences if it is regulated or not. Therefore, it will be stated clearly that the application only provides general data about the current environment and hay fever. It will not be advertised as a medical application and an on-boarding screen will make users aware that it is not suited for medical

purposes.

The application will contain a research-based questionnaire. This will be available only to people who have been invited to test the usability of the project, meaning that people who download the application from the AppStore will not have access to this functionality. This part of the project will not be used after 10th of June, when is the official end date of data collection. The questionnaire will ask the users to select what fever symptoms they are experiencing on the current day, as well as what their severity is. Again, as users will only be evaluating the app, their input to the survey will be irrelevant and will be not used for any other purposes, apart from displaying the information on the website (accessible only with authentication), to show that the functionality works as expected. Apart from the questionnaire's response, the user location will also be stored, as it is core to the project requirements, so additional security measures will be taken to ensure secure transmission and storage of this data. Users will be given the opportunity to allow or deny location sharing, and privacy description will be provided describing why the information is required. iOS 14 lets users decide if they want to share precise or approximate location. Only significant-change location service will be used for the application. This service relies on lower-power alternatives to determine location. It does not make use of the GPS and thus the location received is not as accurate. This should be enough to fulfil the purpose of the project, while protecting the user's privacy.

Ethical approval is sought to cover the following aspects of the project:

1. People who are going to evaluate the usability of the platform (both the iOS application and the website). This consists of few elements. Testers will give their feedback using an online form. The data collected will be used to improve the app, as well as to aid the completion of the dissertation report. It is important to note that participants will be allowed to choose if they want to test either the iOS app, the website or both. This is useful, as some might not have iPhone, but might still want to test the web application. Testing the iOS app will include filling in the integrated questionnaire within the iOS application which aims at researching a common condition (hay fever). People who agree to test the application will be informed that they only evaluate its usability, not the content of the questionnaire, nor its suitability for medical use. An information sheet will be sent out to each potential participant. Once they have agreed to take part in the evaluation, and have agreed to test the questionnaire as well, they will be given a unique Invitation ID which will unlock the in-app survey. On-boarding screens will summarise the most important points of the information sheet for the specific feature the user is about to evaluate. In all stages – filling in the integrated questionnaire, as well as the evaluation surveys for the iOS and the web app – will rely on implicit consent upon progressing to the questions.

To ensure higher number of participants, and thus better evaluation, an alternative option of evaluating ClimaFever will be provided. This consists of a demonstration video, which introduces the project and gives a walkthrough the system. The users will then be able to answer the survey as if they have done direct evaluation of the platform.

Please see the attached file (ClimaFever_Evaluation_Survey.pdf) for the questions which will be asked as part of the evaluation survey.

Additional to the people who will be needed to test the planform, some third parties are expected to participate in the project.

2. An allergist, who has over 17 years of professional experience, will be interviewed on the main points that the project is researching. He will also be asked to provide a feedback on the questions which are part of the in-app questionnaire, in order to make it as realistic as possible. Any suggestions will be accommodated. His will also be questioned on the final product. His responses will be useful for the dissertation report. He is based in Bulgaria, has a private clinic, and is not tied with the NHS. An information sheet and consent form will be available for his participation.

3. A provider (Ambee) for pollen count and air quality data has been chosen. The integration with the company's API will play a vital role in the project, as it provides air quality and pollen count data. The company has agreed to answer questions and provide support, if needed. An interview will be conducted on the approaches they take to collect and provide the data. Ambee will also be asked for a feedback on the finished product.

Each of these groups take important part of the different stage of the project. Their input will be useful for ensuring that the application and the idea behind it is good for real-world application, as well as that the software requirements have been successfully met. The information gathered will also be useful to identify limitations and critique the work completed, which is an essential part of the dissertation project.

2. Methodology

The data will be gathered and analysed in different ways.

People who are going to evaluate the usability of the application will usually have to do the evaluation in their own time. The results will be recorded using the Typefrom service (similar to Google Forms and Microsoft Forms) which provides beautifully designed survey templates, as well as easy means for summarising the data collected. The form will contain two sections. One related to the iOS app and one related to the web application. Participants will be able to answer either of them, depending on the time they are willing to spent.

If possible, some in-person testing will be performed. This would be following all COVID-guidelines and is planned to only happen with friends, relatives, and course mates who I would usually meet regardless of the evaluation of the software (subject to the current government restrictions). By having in-person testing, additional parameters, such as how long it

takes for an action to be performed, can be gathered.

The allergist will be interviewed via email.

The conversations with Ambee will be both via email and over online meetings. The online meetings will be voice recorded. Ambee's team will be made aware of that as part of the information sheet and the consent form.

Any artifacts will be kept locally, for the shortest amount of time possible

3. Personal Safety

Have you completed your departmental risk assessment procedures, if appropriate?

Not applicable

Raises personal safety issues?

No

Most parts of the research are conducted online (via email, online meetings or online surveys). Where in-person testing is to be performed, it will be with close friends or relatives, which does not pose additional risks.

Section D: About the participants

1. Potential Participants

People who will evaluate the usability of the platform should be able to use smartphone and/or computer without any assistance, have good knowledge of English and be over 18 to be able to give consent. The participants will be healthy adults who do not suffer from hay fever or an asthma. People with software engineering or medical background, in order to ensure high-quality feedback.

2. Recruiting Potential Participants

The evaluation is planned in two stages:

During the first one, potential participants will be friends, relatives, and fellow students. They will be approached using email or social media. Special care will be taken to ensure potential participants are not coerced.

Second stage will include posting the survey publicly on Facebook, LinkedIn, and the project website. This will give the opportunity to whoever is interested to familiarise themselves with the project and to contribute by filling in the evaluation survey. During this stage, the survey will also be sent to some of the University staff, who could provide beneficial feedback of the project, as well as to suggest future improvements.

2.1. Advertising methods

Will the study be advertised using the volunteer lists for staff or students maintained by CiCS? No

- not entered -

3. Consent

Will informed consent be obtained from the participants? (i.e. the proposed process) Yes

The consent will be obtained in different ways for the different participants:

1) Information sheet will be displayed prior to starting the survey and the in-app questionnaire. The platform evaluators will give implicit consent by agreeing with the information sheet and proceeding to the next step.

Evaluators will be given the opportunity to save/download the information sheet for future reference. This is valid for both the in-app survey evaluation, as well as the project evaluation survey.

2) For the allergist and Ambee, separate information sheets and consent forms will be sent as an email prior to the interviews.

4. Payment

Will financial/in kind payments be offered to participants? No

5. Potential Harm to Participants

What is the potential for physical and/or psychological harm/distress to the participants?

There is a little to none risk for the participants.

As the usability of the application is to be evaluated, users should not have hay fever or asthma to take the in-app questionnaire. This would ensure that the platform is not perceived as a medical device or used as self-diagnosis or treatment tool.

Participants will have good English, so that they can understand the provided Information Sheets and Informed Consent documents.

The preferred group of people who will test the application will be with software engineering background, so they will be aware of what software testing and evaluation is, thus minimising the risk of being confused about what is expected from them.

The third parties (the allergist and Ambee) will be contacted online. Questions asked will be based on already available public information or general trends, based on experience.

How will this be managed to ensure appropriate protection and well-being of the participants?

All participants will be made aware that they can stop participating and withdraw at any given point, without having to justify their decision.

All participants will be made aware that they do not have to answer to a question, if they do not want to. Special care will be taken to ensure that delicate questions are not asked.

All questions and guidance will be written in an easy-understandable language, so that participants are not intimidated at any point.

6. Potential harm to others who may be affected by the research activities

Which other people, if any, may be affected by the research activities, beyond the participants and the research team?

None

What is the potential for harm to these people?

N/A

How will this be managed to ensure appropriate safeguarding of these people?

N/A

7. Reporting of safeguarding concerns or incidents

What arrangements will be in place for participants, and any other people external to the University who are involved in, or affected by, the research, to enable reporting of incidents or concerns?

The information sheet, provided to the participants, includes detailed information about the steps they could perform in case an incident or a concern occurs.

Who will be the Designated Safeguarding Contact(s)?

Norton Andreev (aastrigachev1@sheffield.ac.uk)

How will reported incidents or concerns be handled and escalated?

Initially, the participants will be encouraged to raise any concerns with the project leader. Alternatively, as part of the informed consent, they will be provided with the contact details of the project supervisor. If they have received an unsatisfactory outcome from both the project lead and the project supervisor, they will be advised to contact the Head of Department.

Section E: About the data

1. Data Processing

Will you be processing (i.e. collecting, recording, storing, or otherwise using) personal data as part of this project? (Personal data is any information relating to an identified or identifiable living person).
Yes

Which organisation(s) will act as Data Controller?

University of Sheffield only

2. Legal basis for processing of personal data

The University considers that for the vast majority of research, 'a task in the public interest' (6(1)(e)) will be the most appropriate legal basis. If, following discussion with the UREC, you wish to use an alternative legal basis, please provide details of the legal basis, and the reasons for applying it, below:

- not entered -

Will you be processing (i.e. collecting, recording, storing, or otherwise using) 'Special Category' personal data?
No

3. Data Confidentiality

What measures will be put in place to ensure confidentiality of personal data, where appropriate?

For the most part of the project, the data will be pseudonymised.

People who evaluate the usability of the platform will have to provide their feedback using a survey created with Typeform. The form will require the participant's name, so that they can digitally sign the informed consent. Furthermore, the name is required, so that the answer can be removed, should the evaluator decide they want to withdraw from the project prior to the end date of data collection.

People who evaluate the iOS application will be given a randomised ID which will be used for filling in the in-app questionnaire. This will ensure that only a random ID is stored in the database. User will not be required to create personal accounts. The response from the in app-survey is submitted will not be submitted alongside the ID that the user has used for joining the study, so the responses will not be directly identifiable.

All of the information collected, both from the in-app survey and the project evaluation survey, will be summarised in the final report and no names or other personal details will be present.

Where interviews with third parties are conducted, participants will be made aware that their names and the information they share will be made publicly available as part of the Dissertation report (on the University and the researcher's website). Prior to submitting the report, an opportunity will be given to the third parties to double-check the content, to ensure they are happy with it.

4. Data Storage and Security

In general terms, who will have access to the data generated at each stage of the research, and in what form

Most of the raw data will be available to the researcher only. Potentially, the supervisor will have access to some of it, to provide a feedback on what might be important to be included in the final report.

Summarised, anonymous data will be made available within the report. Where interviews with third parties are conducted, the identifiable responses will be made available within the report, after the interviewees have given their consent.

In terms of software, the data collected will be stored on systems provided by Apple, Microsoft and Typeform. Furthermore, the web application and the backend will be deployed on Heroku. This will host the application's database.

What steps will be taken to ensure the security of data processed during the project, including any identifiable personal data, other than those already described earlier in this form?

While working on the project, the data will be stored on secure systems. All services store the data encrypted and make the data accessible only to a pre-specified individual.

The responses from the research-based survey will be stored on a secure database with an encrypted end-to-end connection. Sending information over secure connection is a requirement of iOS which cannot be bypassed.

Where voice recordings are to be made, this will be done using the Voice Memos app on iOS. iCloud will be disabled on the devices used for the audio recordings. This will ensure that the data is available only locally and not stored in the cloud. Recordings will be transcribed as soon as possible, and recordings will be deleted. This will ensure that the recordings are kept only for the absolute necessary amount of time.

When the project finishes, all collected data, apart from what is submitted as part of the report, will be deleted.

Will all identifiable personal data be destroyed once the project has ended?
No

Please outline your plans for retention of the data, including a justification for holding personal data beyond the end of the project, and data security arrangements.

The only personal data that will be kept indefinitely (as the report will be available online) is the responses from people who will be interviewed as part of the project (the allergist and the Ambee's team). They will be made aware that what they share, including their names, will be publicly available.

Section F: Supporting documentation

Information & Consent

Participant information sheets relevant to project?
Yes

Document 1086550 (Version 2) — All versions

Document 1086551 (Version 2) — All versions

Document 1086552 (Version 2) — All versions
This is the main information sheet for the participants who are going to test the usability of the application. It will be available prior to filling in the online survey.

Document 1086553 (Version 1) — All versions
This is the extension to the evaluator IS. As testers will be given access to the questionnaire after agreeing to the first IS, this only covers the in-app questionnaire which will be displayed prior to staring the questionnaire within the application.

Consent forms relevant to project?
Yes

Document 1091376 (Version 1) — All versions
This is the document which will be displayed within the ResearchKit onboarding experience.

Document 1086555 (Version 2) — All versions

Document 1086554 (Version 2) — All versions

Additional Documentation

Document 1091377 (Version 1) — All versions
This shows the questions which will be asked in regards evaluating the ClimaFever platform. The survey is available on: http://www.climafever.tech/survey

External Documentation

- not entered -

Section G: Declaration

Signed by:
Norton Andreev
Date signed:
Sat 8 May 2021 at 04:58

Offical notes

- not entered -

Appendix D Ambee Information Sheet

UREC – July 2020

Participant Information Sheet

1. Research Project Title:

ClimaFever – iOS app to research the impact of climate change on hay fever sufferers

2. Invitation

You are being invited to take part in a research project. Before you decide whether or not to participate, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

3. What is the project's purpose?

ClimaFever is an experimental platform, aiming to showcase how the correlation between climate change and hay fever symptoms' onset, strength and duration can be studied using novel technologies. While the project is not going to do the actual research on that, it aims at developing a system which can be of a real-world use and will hopefully inspire similar projects in the future.

The project is part of my Bachelor's degree in Software Engineering. The focus is on the usability of the platform developed, rather than its suitability as a medical device

4. Why have I been chosen?

The iOS application will utilise Ambee's Air Quality and Pollen APIs. Your participation in the project will help explore new use cases for the APIs provided. Information about how the data provided is gathered will be useful in order to clearly explain how the system works within the project report, as well as to identify and discuss potential limitations.

5. Do I have to take part?

It is up to you to decide whether to take part. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a consent form. You can still withdraw at any time without any negative consequences. You do not have to give a reason. Keep in mind that already published information cannot be deleted if you withdraw after 01/06/2021. If you wish to withdraw from the research, please contact Norton Andreev (aastrigachev1@sheffield.ac.uk).

Please note that by choosing to participate in this research, this will not create a legally binding agreement, nor is it intended to create an employment relationship between you and the University of Sheffield.

6. What will happen to me if I take part? What do I have to do?

If you agree to participate, you will be briefed on the current progress of the project, including how Ambee APIs are going to be used, as well as how the final platform is expected to work. You will be questioned on the current platform idea. The way Ambee APIs work will be discussed. Finally, when the project has been completed, you will be asked to provide your feedback on the finished product. This will be useful for discussing the outcome of the project within the report. The communication will be via email and online meetings. Special care will be taken in preserving the privacy of the communications.

7. What are the possible disadvantages and risks of taking part?

The only possible foreseeable disadvantage is the time you will have to spend in order to familiarise yourself with the project and to participate in the interview(s).

8. What are the possible benefits of taking part?

Whilst there are no immediate benefits for those people participating in the project, it is hoped that this work will help me develop a good-quality project.

9. Will my taking part in this project be kept confidential?

The information you agree to provide, including the company name, will be made publicly available as part of the project report, on the University, the researcher, and the project website. You will be given the opportunity to read the information which has been included in the report, prior to the report being uploaded online.

10. Will I be recorded, and how will the recorded media be used?

The audio recordings of online meetings will be used to be able to quote you in the project report. No other use will be made of them, and no one outside the project will be allowed access to the original recordings.

11. What is the legal basis for processing my personal data?

According to data protection legislation, we are required to inform you that the legal basis we are applying in order to process your personal data is that 'processing is necessary for the performance of a task carried out in the public interest' (Article 6(1)(e)). Further information can be found in the University's Privacy Notice https://www.sheffield.ac.uk/govern/data-protection/privacy/general.

12. What will happen to the data collected, and the results of the research project?

As stated in section 9., the information you have agreed to provide will be made publicly available, as part of the project report, unless you withdraw from the project before 01/06/2021. Interim data, such as email communications and voice recordings, will be deleted once it has been processed by the end date of the project (01/06/2021).

13. Who is the Data Controller?

The University of Sheffield will act as the Data Controller for this study. This means that the University is responsible for looking after your information and using it properly.

14. Who has ethically reviewed the project?

This project has been ethically approved via the University of Sheffield's Ethics Review Procedure, as administered by 'Computer Science' department.

15. What if something goes wrong and I wish to complain about the research?

If you wish to complain about the research, you can do so by contacting the project supervisor — Dr. Maria-Cruz Villa-Uriol (email: m.villa-uriol@sheffield.ac.uk). If you feel your complaint has not been handled to your satisfaction, you can contact the Head of Department — Prof Guy Brown (email: g.j.brown@sheffield.ac.uk).

If the complaint relates to how your personal data has been handled, information about how to raise a complaint can be found in the University's Privacy Notice: https://www.sheffield.ac.uk/govern/data-protection/privacy/general.

UREC – July 2020

16. Contact for further information

If you require more information about the project, you can contact the researcher — Norton Andreev (email: aastrigachev1@sheffield.ac.uk). If unavailable, you can contact the project supervisor — Dr. Maria-Cruz Villa-Uriol (email: m.villa-uriol@sheffield.ac.uk).

Keep this information sheet for your reference.

Thank you for going through this sheet and considering whether to participate in the project.

Appendix E Ambee Consent Form

ClimaFever – iOS app to research the impact of climate change on hay fever sufferers

Consent Form

Please tick the appropriate boxes	**Yes**	**No**
Taking Part in the Project		
I have read and understood the project information sheet dated 01/12/2020 or the project has been fully explained to me. (If you will answer No to this question, please do not proceed with this consent form until you are fully aware of what your participation in the project will mean.)		
I have been given the opportunity to ask questions about the project.		
I agree to take part in the project. I understand that taking part in the project will include online interviews, conducted via email and/or meetings.		
I agree that whilst I am participating in this interview audio recordings will be made. I agree to being audio recorded and for transcripts of these anonymised audio recordings to be used in the research. The audio recordings will only be stored locally. Audio recordings will be transcribed as soon as possible and will be deleted immediately afterwards.		
I understand that by choosing to participate as a volunteer in this research, this does not create a legally binding agreement nor is it intended to create an employment relationship with the University of Sheffield.		
I understand that my taking part is voluntary and that I can withdraw from the study at any time before 01/06/2021. I do not have to give any reasons for why I no longer want to take part and there will be no adverse consequences if I choose to withdraw. I understand that the information I provide will potentially be available indefinitely, if I do not withdraw before 01/06/2021, as it will be made available in a report, published online.		
How my information will be used during and after the project		
I understand the company name and information our team provides will be made publicly available as part of the project's final report.		
I understand and agree that our words may be quoted in the project report, the researcher's website, as well as the project's official website.		

Name of participant: Signature Date

Name of Researcher: Norton Andreev Signature Date

Project contact details for further information:
Lead Researcher: Norton Andreev
email: aastrigachev1@sheffield.ac.uk
+44 747 976 0854

Project Supervisor: Dr. Maria-Cruz Villa-Uriol
email: m.villa-uriol@sheffield.ac.uk
+44 114 222 1870

For complaints:
Head of Department: Prof Guy Brown
email: g.j.brown@sheffield.ac.uk

The template of this consent form has been approved by the University of Sheffield Research Ethics Committee and is available to view here: https://www.sheffield.ac.uk/rs/ethicsandintegrity/ethicspolicy/further-guidance/homepage

Appendix F Allergist Information Sheet

UREC – July 2020

Participant Information Sheet

1. Research Project Title:

ClimaFever – iOS app to research the impact of climate change on hay fever sufferers

2. Invitation

You are being invited to take part in a research project. Before you decide whether or not to participate, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

3. What is the project's purpose?

ClimaFever is an experimental platform, aiming to showcase how the correlation between climate change and hay fever symptoms' onset, strength and duration can be studied using novel technologies. While the project is not going to do the actual research on that, it aims at developing a system which can be of a real-world use and will hopefully inspire similar projects in the future.

The project is part of my Bachelor's degree in Software Engineering. The focus is on the usability of the platform developed, rather than its suitability as a medical device

4. Why have I been chosen?

As a health professional with over 17 years of experience, you can provide information of a vital importance for verifying the project's aims and goals, as well as to discuss if the planned way to achieve them seems reasonable.

5. Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. You can still withdraw at any time without any negative consequences. You do not have to give a reason. Keep in mind that already published information cannot be deleted if you withdraw after 01/06/2021. If you wish to withdraw from the research, please contact Norton Andreev (aastrigachev1@sheffield.ac.uk).

Please note that by choosing to participate in this research, this will not create a legally binding agreement, nor is it intended to create an employment relationship between you and the University of Sheffield.

6. What will happen to me if I take part? What do I have to do?

If you agree to participate, you will be briefed on the current progress of the project, including what research has been done to date, as well as how the final platform is expected to work. You will then be asked general questions, based on your experience as an allergist, related to the main findings. Furthermore, you will be questioned on the current platform idea. This will include questions such as if you think the platform can have real-world use and, if not, what could be changed or improved. Based on your responses, potentially additional research will be conducted or/and software requirements might be amended. This will be of a great help during the development process. Finally, when the project has been completed, you will be asked to provide your feedback on the finished product. This will be useful for discussing the outcome of the project within the report. The communication will be via email or phone calls, depending on your preference.

7. What are the possible disadvantages and risks of taking part?

The only possible foreseeable disadvantage is the time you will have to spend in order to familiarise yourself with the project and to participate in the interview(s).

8. What are the possible benefits of taking part?

Whilst there are no immediate benefits for those people participating in the project, it is hoped that this work will help me develop a good-quality project.

9. Will my taking part in this project be kept confidential?

The information you agree to provide, including your name and job title, will be made publicly available as part of the project report, on the University, the researcher and the project website. You will be given the opportunity to read the information which has been included in the report, prior to the report being uploaded online.

10. What is the legal basis for processing my personal data?

According to data protection legislation, we are required to inform you that the legal basis we are applying in order to process your personal data is that 'processing is necessary for the performance of a task carried out in the public interest' (Article 6(1)(e)). Further information can be found in the University's Privacy Notice https://www.sheffield.ac.uk/govern/data-protection/privacy/general.

11. What will happen to the data collected, and the results of the research project?

As stated in section 9., the information you have agreed to provide will be made publicly available, as part of the project report, unless you withdraw from the project before 01/06/2021. Interim data, such as email communications, will be deleted once it has been processed by the end date of the project (01/06/2021).

12. Who is the Data Controller?

The University of Sheffield will act as the Data Controller for this study. This means that the University is responsible for looking after your information and using it properly.

13. Who has ethically reviewed the project?

This project has been ethically approved via the University of Sheffield's Ethics Review Procedure, as administered by 'Computer Science' department.

14. What if something goes wrong and I wish to complain about the research?

If you wish to complain about the research, you can do so by contacting the project supervisor — Dr. Maria-Cruz Villa-Uriol (email: m.villa-uriol@sheffield.ac.uk). If you feel your complaint has not been handled to your satisfaction, you can contact the Head of Department — Prof Guy Brown (email: g.j.brown@sheffield.ac.uk).

If the complaint relates to how your personal data has been handled, information about how to raise a complaint can be found in the University's Privacy Notice: https://www.sheffield.ac.uk/govern/data-protection/privacy/general.

15. Contact for further information

If you require more information about the project, you can contact the researcher — Norton Andreev (email: aastrigachev1@sheffield.ac.uk). If unavailable, you can contact the project supervisor — Dr. Maria-Cruz Villa-Uriol (email: m.villa-uriol@sheffield.ac.uk).

Keep this information sheet for your reference.

Appendix G Allergist Consent Form

ClimaFever – iOS app to research the impact of climate change on hay fever sufferers

Consent Form

Please tick the appropriate boxes	**Yes**	**No**
Taking Part in the Project		
I have read and understood the project information sheet dated 01/12/2020 or the project has been fully explained to me. (If you will answer No to this question, please do not proceed with this consent form until you are fully aware of what your participation in the project will mean.)		
I have been given the opportunity to ask questions about the project.		
I agree to take part in the project. I understand that taking part in the project will include online interviews, conducted via email. I understand that some of the questions asked will be related to my professional experience as an allergist.		
I understand that by choosing to participate as a volunteer in this research, this does not create a legally binding agreement nor is it intended to create an employment relationship with the University of Sheffield.		
I understand that my taking part is voluntary and that I can withdraw from the study at any time before 01/06/2021. I do not have to give any reasons for why I no longer want to take part and there will be no adverse consequences if I choose to withdraw. I understand that the information I provide will potentially be available indefinitely, if I do not withdraw before 01/06/2021, as it will be made available in a report, published online.		
How my information will be used during and after the project		
I understand my name, job title and information I provide will be made publicly available as part of the project's final report.		
I understand and agree that my words may be quoted in the project report, the researcher's website, as well as the project's official website.		

Name of participant: Signature Date

Name of Researcher: Norton Andreev Signature Date

Project contact details for further information:
Lead Researcher: Norton Andreev
email: aastrigachev1@sheffield.ac.uk
+44 747 976 0854

Project Supervisor: Dr. Maria-Cruz Villa-Uriol
email: m.villa-uriol@sheffield.ac.uk
+44 114 222 1870

For complaints:
Head of Department: Prof Guy Brown
email: g.j.brown@sheffield.ac.uk

The template of this consent form has been approved by the University of Sheffield Research Ethics Committee and is available to view here: https://www.sheffield.ac.uk/rs/ethicsandintegrity/ethicspolicy/further-guidance/homepage

Appendix H Evaluation Survey Information Sheet

UREC – July 2020

Participant Information Sheet

1. Research Project Title:

ClimaFever – iOS app to research the impact of climate change on hay fever sufferers

2. Invitation

You are being invited to take part in a research project. Before you decide whether to participate, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether you wish to take part. Thank you for reading this.

3. What is the project's purpose?

ClimaFever is an experimental platform, aiming to showcase how the correlation between climate change and hay fever symptoms' onset, strength and duration can be studied using novel technologies. While the project is not going to do an actual research on that, it aims at developing a system which can be of a real-world use and will hopefully inspire similar projects in the future. The focus is on the usability of the platform developed, rather than its suitability as a medical device.

The project is part of Norton Andreev's dissertation project as part of his Bachelor's degree in Software Engineering.

This app is not to approved or to be used for medical purposes!

4. Why have I been chosen?

Due to your skill set / educational background you have been identified as suitable for evaluating the usability and the features of the ClimaFever platform. Furthermore, you are a healthy adult who is not suffering from a respiratory condition.

5. Do I have to take part?

It is up to you to decide whether to take part. If you do decide to take part, you will be given this information sheet to keep. By progressing with the survey, you are giving implicit consent to participate. You can still withdraw at any time before the 1st of June without any negative consequences. You do not have to give a reason. If you wish to withdraw from the research, please contact Norton Andreev (aastrigachev1@sheffield.ac.com).

Please note that by choosing to participate in this research, this will not create a legally binding agreement, nor is it intended to create an employment relationship between you and the University of Sheffield.

6. What will happen to me if I take part? What do I have to do?

You can either evaluate the usability of the iOS application or the website (or both). If you wish to evaluate the usability of the iOS application, you will be required to download it on your iPhone first (requires iOS 14.1 or newer). You will also be provided with an anonymous ID which you can use to unlock all features of the application. You will then be required to spend some time playing around with the application. Finally, you will be asked to complete this survey about the experience (skipping the questions about the website).

If evaluating the website, you will be provided with a username and password you have to use to sign in. You will then be required to spend some time playing around with the website. Finally, you will be asked to complete this survey about the experience (skipping the questions about the iOS app).

If you are evaluating both the iOS and the web app, you will be required to do everything described in the previous two paragraphs. When completing the survey, please answer both the questions about the iOS and the web app.

Alternatively, you can complete the evaluation by watching a demonstration video which covers the main aspects of the system. In that case, please answer the questions which are related to both the website and the iOS application.

7. What are the possible disadvantages and risks of taking part?

The only possible foreseeable disadvantage is the time you will have to spend in order to play around with the system and to fill in the survey.

8. What are the possible benefits of taking part?

Whilst there are no immediate benefits for those people participating in the project, it is hoped that this work will help me develop a good-quality project.

9. Will my taking part in this project be kept confidential?

Yes. You will be given random Invitation ID. Therefore, the data you provide is pseudonymised. The results from the survey will be analysed as a whole, meaning individual answers will not be part of the project report. Answers to the in-app questionnaire will be summarised on the project website and, similarly, individual responses are not presented. You are not required to create a user account, to provide a name or an email for any of the evaluation.

10. What is the legal basis for processing my personal data?

According to data protection legislation, we are required to inform you that the legal basis we are applying in order to process your personal data is that 'processing is necessary for the performance of a task carried out in the public interest' (Article 6(1)(e)). Further information can be found in the University's Privacy Notice https://www.sheffield.ac.uk/govern/data-protection/privacy/general.

11. What will happen to the data collected, and the results of the research project?

As stated in section 9., the information you have agreed to provide will be made publicly available, as part of the project report, only summarised with other responses and thus it will not be directly identifiable.

12. Who is the Data Controller?

The University of Sheffield will act as the Data Controller for this study. This means that the University is responsible for looking after your information and using it properly.

13. Who has ethically reviewed the project?

This project has been ethically approved via the University of Sheffield's Ethics Review Procedure, as administered by 'Computer Science' department.

14. What if something goes wrong and I wish to complain about the research?

If you wish to complain about the research, you can do so by contacting the project supervisor — Dr. Maria-Cruz Villa-Uriol (email: m.villa-uriol@sheffield.ac.uk). If you feel your complaint has not been handled to your satisfaction, you can contact the Head of Department — Prof Guy Brown (email: g.j.brown@sheffield.ac.uk).

If the complaint relates to how your personal data has been handled, information about how to raise a complaint can be found in the University's Privacy Notice: https://www.sheffield.ac.uk/govern/data-protection/privacy/general.

15. Contact for further information

If you require more information about the project, you can contact the researcher — Norton Andreev (email: aastrigachev1@sheffield.ac.uk). If unavailable, you can contact the project supervisor — Dr. Maria-Cruz Villa-Uriol (email: m.villa-uriol@sheffield.ac.uk).

Keep this information sheet for your reference.

Thank you for going through this sheet and considering whether to participate in the project.

Appendix I In-app questionnaire Information Sheet

UREC – July 2020

In-app questionnaire Information Sheet

1. Invitation

You have agreed to test the functionality of the iOS ClimaFever application. Therefore, you have agreed to the original information sheet. This should be seen as an extension, covering the in-app questionnaire you are about to be granted access to.

2. Do I have to take part?

It is up to you to decide whether or not to take part. Filling in the questionnaire is not required for finishing the evaluation of the platform (you can skip the questions about the questionnaire on the survey). However, it is a major feature of the iOS app, so your contribution will be appreciated.

3. What will happen to me if I take part? What do I have to do?

You will be required to answer simple questions, which a person, suffering from hay fever, would have to answer. You can put random response — you are free to put a completely random response.

4. Will my taking part in this project be kept confidential?

Yes. The responses given are associated with the Invitation ID you have been given, which makes them non-directly identifiable. Answers to the in-app questionnaire will be summarised on the project website.

5. What will happen to the data collected, and the results of the research project?

The summarised data collected from all responses will be visible on the admin area on the project website (password-protected).

6. Contact for further information

If you require more information about the project, you can contact the researcher — Norton Andreev (email: aastrigachev1@sheffield.ac.uk). If unavailable, you can contact the project supervisor — Dr. Maria-Cruz Villa-Uriol (email: m.villa-uriol@sheffield.ac.uk).

Keep this information sheet for your reference.

Thank you for going through this sheet and considering whether to participate in the project.

Appendix J In-app questionnaire Consent Form

ClimaFever Consent

Overview

ClimaFever is an experimental platform, aiming to showcase how the correlation between climate change and hay fever symptoms' onset, strength and duration can be studied using novel technologies. While the project is not going to do an actual research on that, it aims at developing a system which can be of a real-world use and will hopefully inspire similar projects in the future. The focus is on the usability of the platform developed. The application is not approved or to be used as a medical device.

The project is part of Norton Andreev's dissertation project as part of his Bachelor's degree in Software Engineering.

Data Use

The data collected from all survey responses will be visible on the admin area (password-protected) on the project website. The admin area is accessible only by people who have been invited to test the system, as well as the developer, and the project supervisor. Snippets of the collected data might appear on the final report.

The data that gets stored is the your current approximate location and the responses provided to the survey.

Privacy

You have been given a random Invitation ID which is used for verification purposes. The Invitation ID does not get stored alongside the survey response, meaning that the response records cannot be traced back to the users who have submitted them.

The data collected is stored on a server over a secure connection. Access to the collected data is limited to those, who have access to the password-protected section of the website.

Study Survey

The survey contains four questions related to the symptoms a hay fever suffered might be experiencing. Answering the questions takes a few second.

Time Commitement

The survey can be submitted only once per day. You are not required to submit more than one response. However, submitting more responses will be beneficial for generating more data which can then be used for system presentation purposes.

Withdrawing

You can Withdraw from the research at any time. To do so, you can just uninstall the application. As no personal account has been created, no further actions are needed.

However, the preferred way of withdrawing would be to opt-out from the study (from the Settings section of the application). This will change your Invitation ID to “Withdrawn” which can then be used for analysis the retention and the usability of the project.

Keep in mind that the data you have submitted prior to the withdrawing will not be deleted. This is because the data is not associated with you in any way, so there is no way to know which are the responses you have submitted.

Consent

I confirm that I have read and understand the previous steps explaining the research project.

I confirm that I have had the opportunity to ask questions about the project.

I understand that the taking part in the research is completely voluntary.

I understand I can withdraw at any time without any negative consequences.

I understand that by choosing to participate in this research, this will not create a legally binding agreement, nor is it intended to create an employment relationship between you and the University of Sheffield.

I understand that my responses are anonymised, as well as that they will be stored on a secured server and will only be accessible from a limited number of people, related to the research project.

I understand that ClimaFever is not aproved or to be used as a medical device.

Appendix K Ethics Approval Letter

Downloaded: 28/05/2021
Approved: 11/05/2021

Norton Andreev
Registration number: 170164919
Computer Science
Programme: BEng Software Engineering

Dear Norton

PROJECT TITLE: ClimaFever iOS app to research the impact of climate change on hay fever sufferers
APPLICATION: Reference Number 037025

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 11/05/2021 the above-named project was **approved** on ethics grounds, on the basis that you will adhere to the following documentation that you submitted for ethics review:

- University research ethics application form 037025 (form submission date: 08/05/2021); (expected project end date: 10/06/2021).
- Participant information sheet 1086550 version 2 (08/05/2021).
- Participant information sheet 1086551 version 2 (08/05/2021).
- Participant information sheet 1086552 version 2 (08/05/2021).
- Participant information sheet 1086553 version 1 (21/01/2021).
- Participant consent form 1091376 version 1 (08/05/2021).
- Participant consent form 1086555 version 2 (08/05/2021).
- Participant consent form 1086554 version 2 (08/05/2021).

If during the course of the project you need to deviate significantly from the above-approved documentation please inform me since written approval will be required.

Your responsibilities in delivering this research project are set out at the end of this letter.

Yours sincerely

Com Ethics
Ethics Administrator
Computer Science

Please note the following responsibilities of the researcher in delivering the research project:

- The project must abide by the University's Research Ethics Policy: https://www.sheffield.ac.uk/rs/ethicsandintegrity/ethicspolicy/approval-procedure
- The project must abide by the University's Good Research & Innovation Practices Policy: https://www.sheffield.ac.uk/polopoly_fs/1.671066!/file/GRIPPolicy.pdf
- The researcher must inform their supervisor (in the case of a student) or Ethics Administrator (in the case of a member of staff) of any significant changes to the project or the approved documentation.
- The researcher must comply with the requirements of the law and relevant guidelines relating to security and confidentiality of personal data.
- The researcher is responsible for effectively managing the data collected both during and after the end of the project in line with best practice, and any relevant legislative, regulatory or contractual requirements.

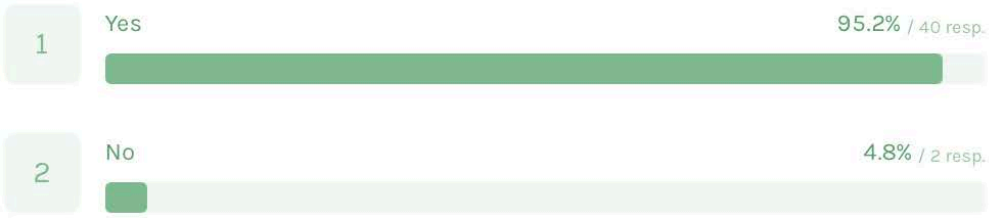
Appendix L User Evaluation Results

ClimaFever

42 responses

Have you evaluated the website?

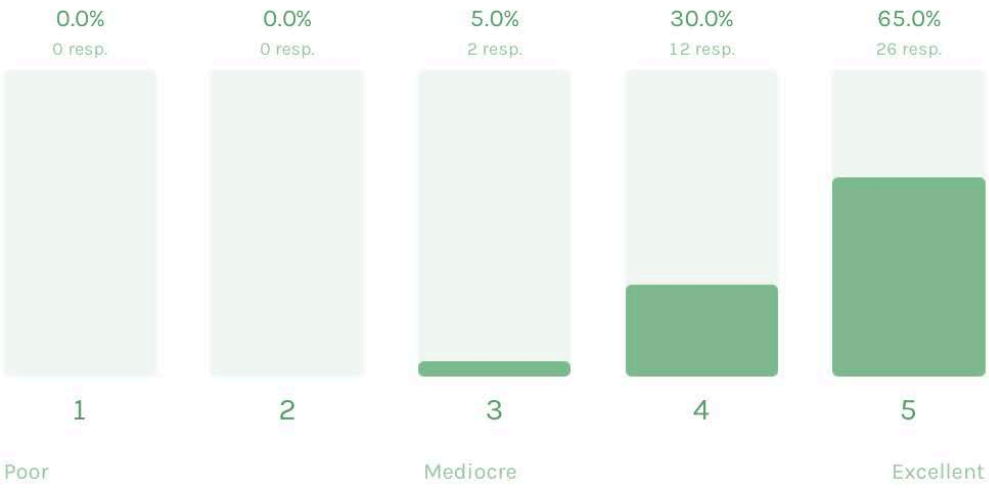
42 out of 42 answered



How would you rate the design of the website?

40 out of 42 answered

4.6 Average rating



One of the features planned for the future is an interactive map on the admin panel of the website. This would provide less information than the exported Excel file, however, it will allow visualisaion of the most important data. In the context of the platform, how needed do you think this feature is?

40 out of 42 answered

4.4 Average rating

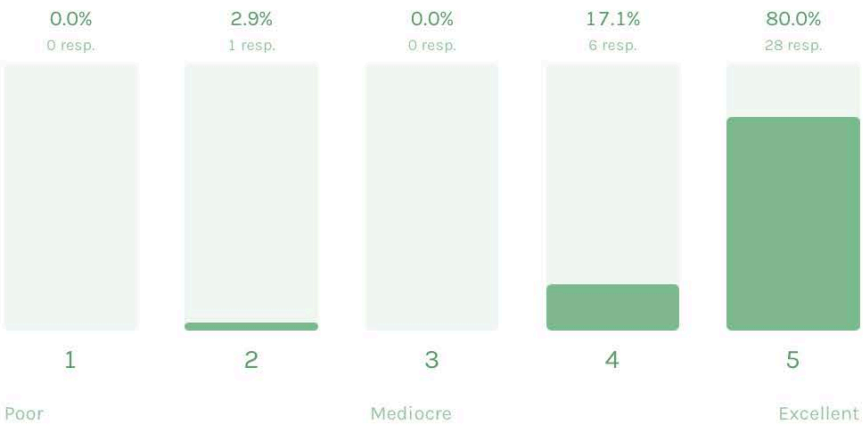
Have you evaluated the iOS application?

42 out of 42 answered

How would you rate the design of the iOS application?

35 out of 42 answered

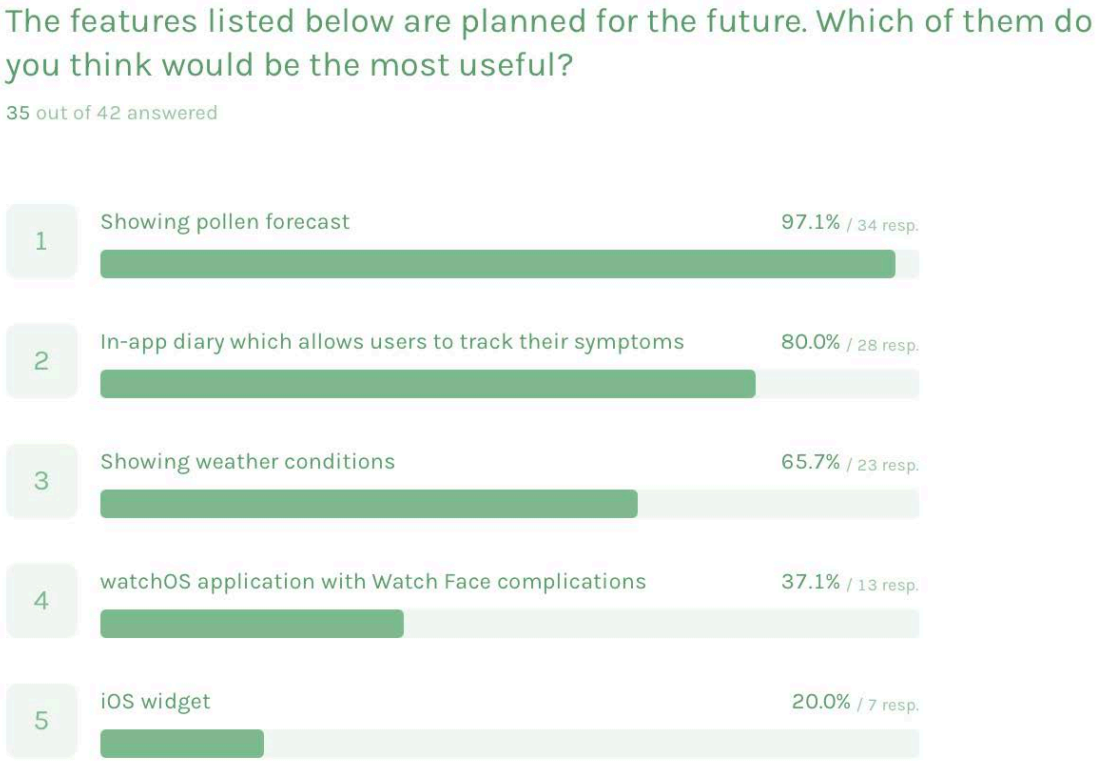
4.7 Average rating



Which of the following implemented features do you think are the most useful?

35 out of 42 answered

1	Showing personalised health risk based on the pollen count	74.3% / 26 resp.
2	Showing pollen count and the health risk associated with it for each type of pollens (tree, grass and weed)	60.0% / 21 resp.
3	Showing the health risk associated with the air quality	60.0% / 21 resp.
4	Showing recommendations based on the air quality	48.6% / 17 resp.
5	Showing the concentration of the pollutants	28.6% / 10 resp.
6	Access to additional resources, such as information about what hay fever is	20.0% / 7 resp.
7	Showing the pollen count for the individual species	8.6% / 3 resp.


The features listed below are planned for the future. Which of them do you think would be the most useful?
35 out of 42 answered
1
Showing pollen forecast
97.1% / 34 resp.
2
In-app diary which allows users to track their symptoms
80.0% / 28 resp.
3
Showing weather conditions
65.7% / 23 resp.
4
watchOS application with Watch Face complications
37.1% / 13 resp.
5
iOS widget
20.0% / 7 resp.