Development of an application for bicycle commuters to reduce exposure to air pollution

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Abstract
The purpose of the following Master Thesis was to answer the question of how to develop an application for bicycle commuters to reduce their exposure to air pollution. The thesis explores the problem area related to the topic including air pollution in relation to bicycling, as well as the classification of levels of air pollution. Furthermore, there is presented some related research, that includes some research related to the influence of the route choice on exposure to air pollution, as well as a review of existing solutions serving as an inspiration for the application design.

The Research Design chapter handles the overall design of the following Master Thesis project, including the description of how separate parts of the project are connected to each other. Furthermore, it briefly describes the methods and techniques that have been applied throughout the project. From there on, the project is divided into three phases: Survey, Application and Prototype Experiment.

The first phase – the Survey – is devoted to the results of an online questionnaire conducted in order to gather information on the characteristics of the potential application's users, get to know their biking habits and interest in air pollution topic, as well as to assess whether they would be interested in using the app. The chapter includes the description of the results of the questionnaire, as well as the summary of the results. The results of the survey indicate that the potential user group consists of both males and females that are between 15 and 66 years old with the vast majority of the group being students, but also including employed and unemployed people, as well as few pensioners. The majority of the potential user group uses biking as a mean of commuting and bikes regularly, i.e. either every day or a couple of times a week. Furthermore, the results of the questionnaire indicate that the potential user group is concerned with the air pollution topic and would use the application.

The second phase – the Application – is devoted to the design of the application and activities related to the design. The chapter includes a sub-chapter trying to investigate the users of the application through such activities as conducting a PACT analysis, creating Personas and Scenarios. The activities mentioned above originate in the results of the survey. Furthermore, this phase includes the use of some of the notions from Object-Oriented Analysis and Design including the FACTOR system definition, a class diagram, a database model and description of functions. Lastly, this phase is also concerned with the interface design of the application. This sub-chapter includes pictures and descriptions of each of the app screens, as well as the application's navigational flow.

The third phase – the Prototype Experiment – is devoted to the results of the prototype experiment including the analysis of the results. The experiment was recorded with a GoPro camera and there was followed by a short questionnaire. Therefore, the results include both analysis of the videos, which do not indicate any major issues with the use of the prototype, as well as the analysis of the questionnaire answers. The test subjects' answers indicate that the design of the prototype is quite intuitive, as they did not state to have any issues regarding setting the route. The results show,

furthermore, that some of the test subjects interacted with the app not only in the beginning and at the end of the experiment, but also in the middle of the experiment. Moreover, the test subjects did not report any issues that would be related directly to the prototype. The test subjects offered some useful ideas as to how the app could be improved.

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1 Introduction

Participants of urban traffic are exposed to higher concentrations of air pollutants compared to other places in urban area. Even in a short time spent in traffic, a person can greatly increase the amount of air pollutants they have inhaled. Road traffic and the air pollutants it is responsible for, have been identified as one of the factors contributing to many dangerous diseases. For bicycle commuters, just as for the rest of the traffic users, spending time on the bike means in that particular situation, that they are also in danger of developing negative effects of inhaling air pollutants (Kaur et al., 2007).

In order to address the issue of bicycle commuters being exposed to air pollution, we decided to investigate the following research question: *How can we develop an application for bicycle commuters to reduce their exposure to air pollution?* To answer that question, we decided to research the topic of bicycling and air pollution, as well as to develop a prototype of a solution that would offer the bikers a route that omits most polluted point on the map. The scope of our prototype was narrowed down to Aalborg, as there were to be mounted sensors that would measure air pollution levels.

In order to develop the prototype, we designed and conducted an online survey, which would provide information about the potential user group, their biking habits, as well as their interest in air pollution topic. The purpose of the survey was, furthermore, to answer the question whether the respondents would actually use the solution. As a result of the activity, we gained an understanding of the users we would be developing the application for, which contributed to great extent to the way the prototype of the solution was designed. Furthermore, we planned and conducted an experiment with the prototype we developed.

2 Problem Setting

The purpose of the following chapter is to present the problem setting of the following thesis. It is concerned with the problem area including air pollution in regard to bicycling, as well as with the topic of dividing the levels of air pollution. Furthermore, this chapter presents the research question for the thesis.

2.1 Problem Area

The following chapter is devoted to the problem area of the following thesis. It is concerned with the presentation of air pollution in connection with bicycling, as well as with the topic of how air pollution levels can be classified.

2.1.1 Air Pollution and Bicycling

Cycling is becoming more popular as way of commuting instead of being a leisure time activity or a way of exercising. This is partially due to cycling being a more convenient and affordable method of commuting in certain cities and local areas, but several studies also suggest that cycling, as a physical activity, entails significant health benefits as well as environmental and economic benefits, from a macro-level perspective. A recent report from the Cycling Embassy of Denmark suggest that bicyclist in Greater Copenhagen lead to 215 million € in annual savings, and fewer sick days of approximately 1,1 million days (Cycling Embassy of Denmark, 2017).

Denmark is generally perceived as a country, where cycling is seen as popular way of commuting. With its approximately 5,7 million inhabitants in 2016, it was recorded that 9 out of 10 Danes own a bicycle. This resulted in cycling being the preferred choice of commuting for 26% of all trips with a total travelling distance of 5 km or less, and 16% of all trips in general, with various purposes such as commuting to work, school or running errands and for leisure time use. Cycling is more common in Denmark's three largest cities, Copenhagen, Aarhus and Odense, where the average Dane respectively cycles 3,0 km a day, 2,5 km a day and 2,4 km a day, which is relatively higher than the national average of 1,6 km a day (Cycling Embassy of Denmark, 2017).

A further investigation of bicycling in the largest city of Denmark, Copenhagen, shows that bicycling accounts for 41% of all trips to school or work, and traffic from bicycling has increased with 51% from 2007 to 2017 (Københavns Kommune, 2017b). This indicates that the number of bicyclists is increasing significantly, and that bicycling culture is going to increase even more, since the goal for 2025 is to increase the share of commuters travelling to work or school by bicycle to a total of 50% (Københavns Kommune 2017a).

Unfortunately, bicycle commuters in urban areas also have to deal with the increased air pollution and the health issues related to being exposed to air pollution for a longer period of time, as presented in our previous work (Korczak & Hussain, 2019). Multiple studies suggest that despite being exposed to air pollution, bicycle commuting still has its health benefits, and is also healthier than not doing it, concerning most European cities, due to the generally low level of air pollution (Cole et al., 2018; Kumar et al., 2018; Tainio et al., 2016). These studies are primarily concerned with researching, if the air pollution totally negates all benefits of cycling in polluted areas, but they also suggest that bicycle commuters are still at high risk of being exposed to air pollution and the related health risks. The intensity of exposure to air pollution is dependent on multiple factors, such as concentration of pollutants in the air at the time of exposure, frequency and duration of exposure and levels of intake (Kumar et al., 2018). Frequency and duration are determined by travel time and number of trips, but levels of intake can be determined or influenced by intensity of breathing, which is likely to be higher for bicycle commuters considering they perform a higher level of physical activity, enhancing the intensity of their breathing (Kumar et al., 2018).

2.1.2 Air Pollution Levels

Since 2017, there is the European Air Quality Index created by the European Environment Agency and the European Commission. It makes it possible to check current air quality in over 2000 locations in the European Union. The index monitors five common air pollutants, including PM2.5, PM10, nitrogen dioxide, ozone and sulfur dioxide (European Environment Agency, 2017). The levels of pollution are classified into five categories: good, fair, moderate, poor and very poor. For each pollutant and each category there are specified separate values, which are presented in detail in the table below (European Air Quality Index, n.d.). The Air Quality Index is a map with dots. Each dot representing air quality measuring station. The color of the dot represents the pollution level and it reflects the pollutant with highest concentration in a given location (European Environment Agency, 2017).

Pollutant	Index level (based on pollutant concentrations in µg/m3)				
	Good	Fair	Moderate	Poor	Very poor
Particles less than 2.5 µm ($PM_{2.5}$)	0-10	10-20	20-25	25-50	50-800
Particles less than 10 µm (PM_{10})	0-20	20-35	35-50	50-100	100-1200
Nitrogen dioxide (NO_2)	0-40	40-100	100-200	200-400	400-1000
Ozone (O_3)	0-80	80-120	120-180	180-240	240-600
Sulphur dioxide (SO_2)	0-100	100-200	200-350	350-500	500-1250

(The European Air Quality Index, n.d.)

2.2 Research Question

The following subchapter is concerned with the research question for the project. The starting point for our considerations was the outcome of our previous project: *Pollute Aalborg: Monitoring Air Pollution for the Citizens of Aalborg*. The outcome of that project was an initial prototype of a solution that would enable the users to monitor air pollution in Aalborg. Furthermore, through a set of interviews we found out that there is a potential user group interested in using such a solution (Korczak & Hussain, 2019). In order to narrow down the scope of the following thesis, we decided to aim our solution at a specific target group. By investigating the research related to the topic, we decided to target bicycle commuters as our target user group. Therefore, a following research question was decided upon:

How can we develop an application for bicycle commuters to reduce their exposure to air pollution?

3 Related Research

The following chapter explores the research related to the topic. It is concerned with how the choice of route influences the exposure to air pollution. Furthermore, it contains a review of existing solutions for monitoring air pollution.

3.1 The influence of the choice of route on exposure to air pollution

The level of air pollution in cities depends on many factors and can significantly vary in places that are not far apart. The factors influencing air pollution include among other things, traffic congestion and the specific conditions of a particular street such as the width of the street or the height of the buildings surrounding the street. As the amount of traffic is on the rise, so is the air pollution in urban areas. Furthermore, as many people choose biking as a way of commuting, they are also exposed to air pollutants, which has negative effects on their health (Hertel et al., 2007).

A 2007 study in Copenhagen, tried to find the answers to whether the exposure to air pollution of the bicyclists can be reduced by choosing a less polluted route. The study included 3 types of routes: a shortest biking route, a longer but less polluted bike route and a shortest public transportation route. The results of the study have shown that the average exposure to air pollution is lowest when travelling through the longer, less polluted route, despite the route being longer and therefore the participants breathing in more air. The public transportation routes have proven to be more polluted than the shortest bike routes, which were more polluted than the longer bike routes Hertel et al. 2007). According to Hertel et al. (2007) it is therefore, possible to reduce bicyclists' exposure to air pollution by choosing a greener route with less traffic. Furthermore, the air pollutants inhale can be also reduced by changing the travelling time to non-rush hours. Regarding the idea of having an alternative planner that would offer route suggestions that include the least polluted routes the authors of the study from Copenhagen form a following conclusion: "The obtained results from this study indicate that there is a potential for developing a route planner to help the population in choosing the low exposure routes through the city" (Hertel et al., 2007).

Another study in Boston investigated the influence of the bike route choice on air pollution exposure. MacNaughton et al. (2014) investigated air pollution levels found in three types of bike routes: bike paths, bike lanes adjacent to the traffic and bike lanes that are part of the traffic. Designated bike paths that were not part of or adjacent to the traffic were proven to be the least polluted routes (MacNaughton et al., 2014). Choosing a less polluted bike path can, therefore, reduce the exposure to air pollutants (MacNaughton et al., 2014).

3.2 Existing solutions (app review)

As there exist solutions that enable people to monitor air pollution, we decided to investigate a couple of them, as a way to gain insight into what the currently available solutions offer. Furthermore, investigating those solutions could serve as an inspiration while designing our solution. For the purpose of this existing solutions review, we chose five providers of apps or websites that enable air pollution monitoring. The solutions chosen for the review include following:

- AIR by PlumeLabs - https://plumelabs.com/en/flow/
- AirVisual by IQAir - https://www.airvisual.com/air-quality-app
- Polisens - https://polisens.io/#
- PurpleAir - https://www.purpleair.com/
- WAQI (World Air Quality Index) - https://waqi.info/

The solutions chosen for the review can be divided into two groups, i.e. mobile app solutions and web applications. In the following review, there will be presented first the apps for smartphones and then the web solutions.

The first group of the air pollution monitoring solutions – offering mobile apps – include AIR by PlumeLabs and AirVisual by IQAir. Both solutions offer a sensor for collecting the data about air pollution. The PlumeLabs solution offers mobile sensor that can be attached while the users go outside. AirVisual, on the other hand, offers a sensor that can only be used indoors to monitor the air quality in a building, whereas the data for the air pollution levels outdoors is gathered by combining data from various government agencies, the sensors that the AirVisual offers and satellite images. The following table presents which air pollutants are presented in each app:

	PM2.5	PM10	Ozone	NO2	CO2	SO2	VOC
AIR	●	●		●			●
AirVisual	●	●	●	●	●	●	

Table 1: *Comparison of smartphone applications*

The PlumeLabs solution works in such a way, that the sensor that the users have with them collects the air quality data of all the places the user has been to. The data gathered by the sensor can be viewed in the mobile app, presenting a route that the user has been to. The route is presented with colors (from green to red) based on the air quality of each particular place on the route. The user can see the detailed information about air pollution levels of each place. Furthermore, the sensor itself has a button, which if pressed, will cause the sensor to shine LED lights that inform the user about air quality in a given place.

The solution offered by IQAir also offers an app and a sensor, whereas the sensor is not necessary in order to use the app. The app, however, offers not only information about the air pollution, but also about the weather conditions, including a weather forecast. Like the previous solution, AirVisual offers both current, as well as historical data on air pollution. However, AirVisual can also give forecasts on the predicted air quality. Unlike the solution offered by PlumeLabs, this app includes health recommendations and alerts when the outdoor pollution level is too high.

The second group of solutions for monitoring air pollution levels include 3 web applications: Polisens.io, PurpleAir and World Air Quality Index (WAQI). The first two solutions include usage of their own sensors, whereas the World Air Quality Index credits their readings to Environmental Agencies all over the world, and therefore offers readings from all over the world, whereas the areas with most sensor readings include North America, Europe and Asia. The following table presents which air pollutants are covered by each of the above-mentioned web applications:

	PM1.0	PM2.5	PM10	NOx	NO2	CO	CO2	SO2	Ozone
Polisens.io		●	●	●			●		
PurpleAir	●	●	●						
WAQI		●	●		●	●			●

Table 2: *Comparison of web applications*

The first solution – Polisens.io – offers sensors that are to be mounted on vehicles and bikes. The solution offered is divided into three components: the Polipods (the single sensors), the Network of Moving Sensors (NMS) and the Polimonitor (a web platform where the data is presented). The owners of the solution claim, that the coverage of the sensors includes 90% of the city where they are used (Polisens.io, 2018).

The second solution – PurpleAir – also offers their custom sensors. Their sensors are to be mounted on the buildings (for example in the windows) and require power source and WiFi, as they send the data to the map offered by PurpleAir in real time. The sensors are easy to mount, but they only collect data about particulate matter pollution.

The third solution – the World Air Quality Index – is an entirely free solution that includes a world map with real-time pollution data from all over the world. The pollution data comes from national environmental protection agencies. The solution uses Air Quality Scale in order to index air quality in a given location. The scale includes 6 levels describing the air quality: good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, hazardous.

4 Research Design

This chapter includes a description of the project design (see figure 1) and research method applied to this project, including a description of the project's different parts, how they are connected to each other and which techniques and methods are applied throughout the project.

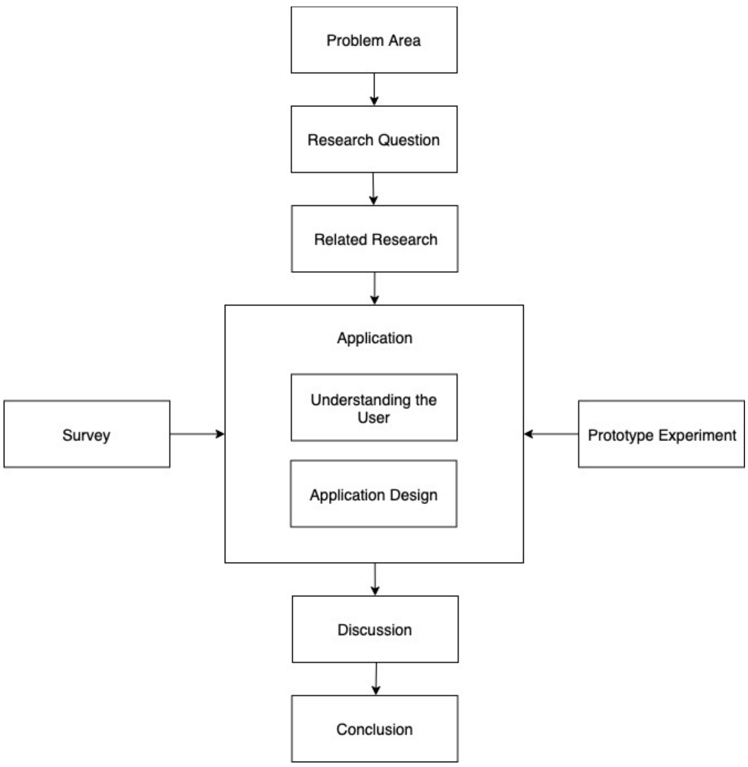

Figure 1: *Project Design*

The project takes its fundamental starting point in the researchers' previous project from the 9th semester, *Pollute Aalborg: Monitoring Air Pollution for the Citizens of Aalborg* (Korczak & Hussain, 2019).

The **Problem Area** is further delimited and specified in this project, and the first chapter contains a description of the project's problem area, which finds its empirical foundation through several scientific articles. A condensation of the problem area will result in formulation of the project's research question that functions as the central point of the project.

The following chapter, **Related Research**, aims to investigate research related to the project's research question, including a study, analysis and comparison of existing solutions. Based on inspiration from this, a solution, related to the project's research question, a smartphone application, is envisioned and expressed through a survey.

We conducted a **Survey** consisting of 13 questions in order to better understand the potential users of the application, their characteristics and habits related to the problem, as well as to verify if the users would be interested in using the envisioned application. Considering the aforementioned purpose, an analysis of the quantitative data from the survey, is carried out, followed by a summary of the most important findings of the analysis.

The comprehension of the application's potential users is presented in the chapter, **Understanding the User**, where it is emphasized through a PACT Analysis, Personas and Scenarios. These activities are carried out as a part of the envisionment process, according to Benyon (2014), and will be used to design an application that is human-centered, by using the results from the survey conducted earlier in the project. Benyon (2014) suggests that the **PACT Analysis** focuses on exploring the potential users and their activities in the context of the potential solution, which is carried out by analyzing people, activities, context and technologies. The PACT analysis is based on data from the survey's results and the with the envisioned application in mind. The **Personas** are constructed with the purpose of emphasizing the potential users' different profiles. The different personas represent characteristics and descriptions of the application's potential users, the target users which the application is developed to. The personas are created according to Benyon (2014), which suggest that the different personas should at least have a name, a background description, some goals, and aspirations and that these characteristics and descriptions should be based on our knowledge of the potential users. The characteristics and descriptions of each persona are inspired by the PACT analysis, which is based on the empirical study, the survey, earlier in the project. The personas are therefore not actual representations of real-life characters, but an envisionment of the potential users. The understanding of the users through personas, is used to develop scenarios, and to advance the design of the application. The **Scenarios** are based on an envisionment of the different personas carrying out their activities. The list of scenarios only consists of scenarios that are relevant to the project's problem and the potential users' activities, which are presented in the PACT analysis. The list of scenarios is therefore not comprehensive.

With the understanding of the users and their activities in the context of the envisioned application, a technical model of the application is created, through **Object-Oriented Analysis and Design** according to Mathiassen et al. (2001). This includes a system definition and an analysis and overview of the application's classes and functions. The following chapter, **User Interfaces**, presents the design of the application's different user interfaces (UI), including an in-depth description of each UI. The design of the UI is based on the technical model created through object-oriented analysis and design, inspiration from the primitive solution presented in the 9^{th} semester project, the existing solutions presented earlier in this project and the Android operating system environment, as the application is developed for this operating system.

For the sake of testing the solution, a prototype based on the application is developed and tested through a designed prototype experiment. The prototype should be considered as an Minimum Viable Product (MVP), meaning that it only has the most essential features that are required for it to function sufficiently and fulfill its purpose, which is to test the solution for the different scenarios presented in this project. The main purpose of testing the prototype is to investigate whether the application is a viable solution for solving the problem presented in the research question, as an extentions to previous research.

The qualitative data material from the prototype experiment is analyzed and subsequently summarized, with the purpose of emphasizing the most important findings from the prototype experiment. The results from the analysis are pursued in a **Discussion**, where these are compared against the project's research question and the existing solutions presented earlier in this project. Finally, a **Conclusion** is given, which answers the project's research question based on the studies carried out.

In this report, the empirical-inductive method is used as the form of conclusion, which is reflected in the project by collecting and processing empirical data material with the purpose of acquiring knowledge and subsequently arriving at a scientific claim; a generalization which constitutes the project's research question. The purpose of the several analysis' is to investigate the project's research question, performed through the deductive method and by investigating through relevant HCI and System Development theories and techniques. This is performed in order to arrive at a possible solution to the problem and a conclusion to the project's research question.

4.1 Survey Design

We conducted a **Survey** consisting of 13 questions. The survey was created with Google Forms and was distributed on the social media platform, Facebook. The entire survey can be found in Appendix 1. There were 95 responses to the survey and the results are presented later in the thesis. The questions from the survey were categorized into 3 groups, as the questions in each group had a related purpose. The first group of questions had the purpose of gathering information about the potential users, which consisted of questions 1-4 in the survey. The second group of questions had the purpose of gathering information about the potential users' biking habits, which consisted of questions 5-9 in the survey.

The third and last group of questions had the purpose of gathering information about the potential users' interest in the air pollution and our proposed potential solution.

4.2 Prototype Experiment Design

To assess the concept of the application, a prototype experiment will be carried out. In order to examine the way the users interact with the prototype, we decided to conduct a prototype experiment with the potential users of the application. Furthermore, the goal of the experiment is to determine general attitude of the potential users towards the proposed solution. The purpose of the experiment is to gather data that would be sufficient enough to perform the analysis of the results. During the experiment the users should:

- experience no performance errors that would make them unable to complete the task
- be able to navigate through the prototype
- complete the tasks they were presented with within 5-10 minutes.

The task of for the test subject is to use the application to find their route, and bike from the starting point to the end point through the route displayed by the application.

The experiment session is expected to last approximately 25-30 minutes. The number of participants is going to be between 9 and 12 people. The experiment will be conducted on a smartphone with the Android operating system and with access to the internet. The experiment session will be video recorded through a GoPro camera mounted on the test subject's head by a headband. The video will focus on the test subject's point of view, primarily following the route and occasionally interacting with the smartphone and will be done in order to see how the participants are going through the task. The experiment will have 3 phases:

1. Introduction
2. Tasks execution
3. Post-test debriefing.

During the introduction phase, the participant will be welcomed and informed about the prototype and the purpose of the experiment. The participants will also be informed how the entire procedure will work. This phase is expected to last less than 5 minutes.

During the task's execution phase the users will be given task they will have to do using the prototype. This phase is estimated to last 10 minutes and the participants are expected to complete all tasks. The tasks given to the participants include:

1. Search for a route with following start and end points:
    a. Start point: Jernbanegade 11, 9000 Aalborg
    b. End point: Danmarksgade 9, 9000 Aalborg
2. Commute from the start point to the end point by bike using the route suggested by the application

During the post-test debriefing the participants of the experiment will be asked questions about their experiences while executing the tasks. Furthermore, they will be asked whether they experienced any issues during the testing. The participants will also be asked about their opinion about the proposed solution. This phase is estimated to last between 5 and 10 minutes. The test subject's will be asked the following questions during the post-test debriefing:

1. Did you experience any issues finding the route?
2. Did you experience any issues following the route?
3. When and why did you interact with the application?
4. Was the application easy to understand and use?
5. Did you experience any issues during the test session?
6. Do you have any suggestions for improving the application?

5 Phase 1: Survey

The following chapter is concerned with the survey conducted in order to get to know the potential user group, gain insight into their biking habits, as well as to find out whether they are interested in the topic of air pollution and if they would use the app. It describes the analysis of the answers, as well as summarizes the outcomes of the survey.

5.1 Analysis

The following subchapter is devoted to the analysis of the responses to the online survey. The answers to the questions were divided into three groups: information about the potential user group, information about biking habits and information about interest in air pollution and in using the potential app.

Group 1: Information about the potential user group

Question #	Question
1	Age
2	Gender
3	Occupation
4	Which zip code do you live in?

Table 3: *Survey questions categorized as group 1*

The first 4 questions in the survey were related to the user's characteristics, such as age, gender, occupation and area where they live, see table 1. The respondents were between 15 and 66 years old. Roughly equal number of women and man participated in the survey. In terms of occupation, most of the respondents were students (59%). 26% of the respondents stated that they are employed; 14% of the respondents answered that they are unemployed and 1% were pensioners, see figure 1.

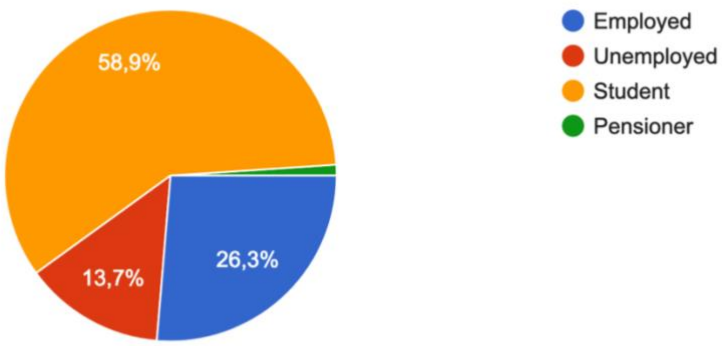

Figure 2: *Answers to question 3 – Occupation*

In terms of areas where the respondents were from, most of the respondents answered that they are from Aalborg (zip code 9000) – 45% of all responses.

Group 2: Information about biking habits

Question #	**Question**
5	How often do you bike?
6	You must often use your bike as… (a way to get to work, a way of exercising, other)
7	What time do you bike most often?
8	On average, how much time do you spend biking a day?
9	How far do you usually bike?

Table 4: *Survey questions categorized as group 2*

Questions 5 to 9 were related to biking habits of the respondents, see table 2. Question 5 was related to how often the respondents bike, see figure 2. It was a closed single-choice question, where the respondents were given 5 answers to choose from. Most of the respondents (35%) stated that they bike every day. Second most popular answer was “a couple of times a week” with 25% of respondents choosing that answer. 24% of the respondents stated that they bike less often than a couple of times a month. 13% of the respondents answered that they bike a couple of times a month and 3% chose the answer “once a week”. The answers to this question show that more than half of the respondents bikes on a regular basis – either every day or a couple of times a week.

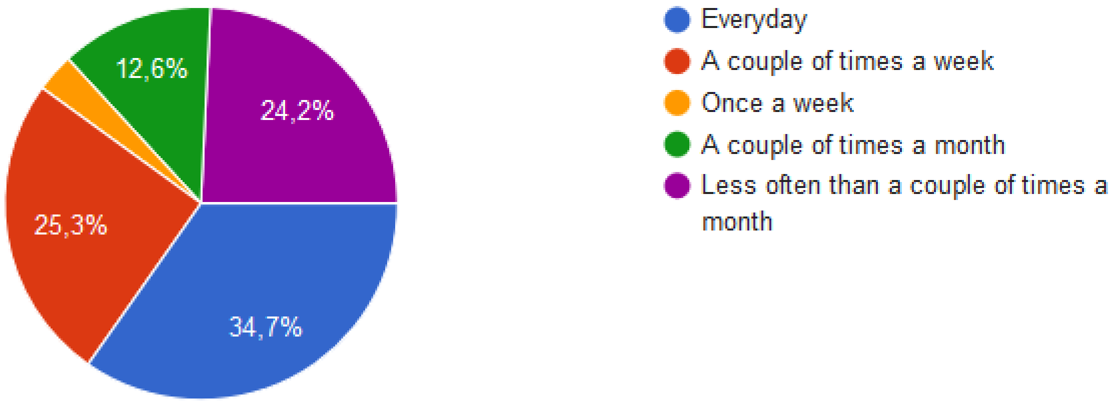

Figure 3: *Answers to question 5 - How often do you bike?*

Question 6 was related to why people are biking most often. It was a single-choice question and the respondents were given 2 options to choose from, as well as an open option where they could give their own responses. The majority of the respondents (71%) chose option "a way to get to work/school". 15% of the respondents answered that they use their bike as a way of exercising. 15% of the respondents provided their own answers and those included: leisure, biking just for the fun of biking or combination of both commuting and exercising.

Question 7 was related to the times of the day when people are biking, see figure 3. It was a closed question with 4 answers to choose from. It was possible for the respondents to choose more than one answer. Most often chosen option was "in the morning" with 60% of the responses. Second most popular time when people are biking was "in the afternoon" with 57% of the responses. Option "in the evening" got 31% responses and option "during working hours" got 22% of the responses.

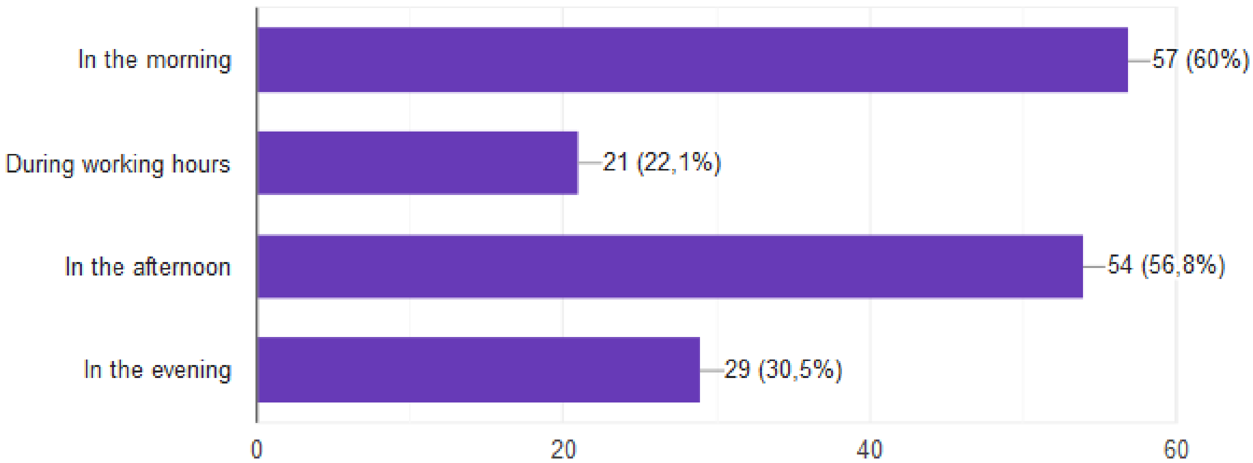

Figure 4: *Answers to question 7 - What time do you bike most often?*

Question 8 was related to how much time people spend biking a day. It was an open question, so the respondents were able to provide their own answers. Based on the answers from the respondents, we created 4 categories of how long the respondents' bike per day. Those categories include:

- less than 15 minutes
- 15 to 30 minutes
- more than 30 minutes to an hour
- more than an hour.

Most of the responses to this question (41%) falls to the category "15 to 30 minutes". 34% of the respondents bikes more than 30 minutes to an hour a day. 19% of the respondent bikes less than 15 minutes daily and only 6% of the respondents bikes more than 1 hour a day.

Question 9 was related to the distance the respondents go by bike, see figure 4. It was a closed single-choice question, where the respondents could choose from 3 answers. Most of the respondents (57%) bikes between 0 and 5 km. 31% of the respondents bikes between 5 and 10 km and only 13% bikes more than 10 km.

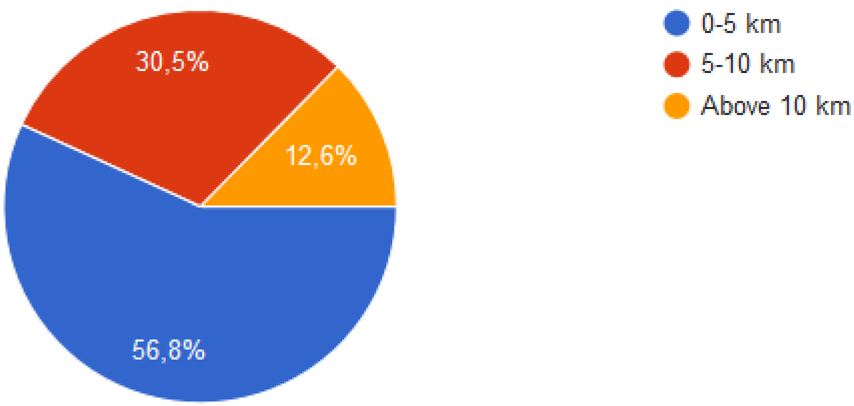

Figure 5: *Answers to question 9 - How far do you usually bike?*

Group 3: Information about interest in air pollution and in using the potential app

Question #	Question
10	The air quality is important to me
11	The noise pollution problem is important to me
12	Would you use an application that would inform you about the current air pollution levels?
13	Would you consider changing your biking route if you knew that the route you've chosen initially includes polluted areas?

Table 5: *Survey questions categorized as group 3*

Questions 10 to 13 were related to air/noise pollution interest among the respondents and the interest in using the potential app, see table 3. Questions 10 and 11 were statements to which the users could agree or disagree choosing one of the answers on a five-point scale (from strongly agree to strongly disagree).

The focus of question 10 was to figure out the importance of air pollution for our respondents, see figure 5. The majority of the respondents chose either “strongly agree” (51%) or “agree” (36%). 14% of the respondents were neutral to the statement. None of the respondents disagreed with the statement. The answers to this question indicate that the issue of air quality is important to the potential users of the app.

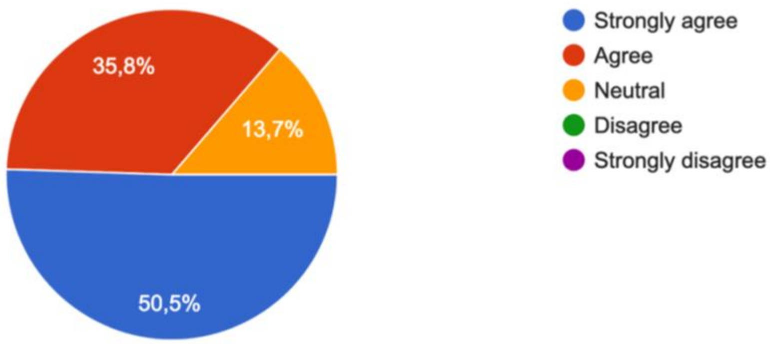

Figure 6: *Answers to question 10 – The air quality is important to me*

The statement in question 11 was related to the issue of noise pollution and it was the following statement: the noise pollution problem is important to me. The option with most responses was the agree option with 47% of the respondents choosing it. 26% of the respondents were neutral to the statement. 17% of the respondents strongly agreed with the sentence. 7% disagreed with the statement and only 2% of the respondents stated that they strongly disagree with the statement.

Question 12 was related to whether the potential users would use the app at all. It was a closed single-choice question where the respondents could pick one out of 3 available answers. The majority of the respondents answered that they either would use the app (35%) or that they would maybe use the app (39%). 26% of the respondents answered that they would not use the app. The responses to these questions indicate that there is interest in using such an app, as more than 70% of the respondents would potentially use the app.

Question 13 was related to whether the respondents would consider changing their biking route if they knew that the one, they have chosen was polluted, see figure 6. 47% of the respondents said yes. 37% of the respondents answered maybe and only 16% of the respondents said no.

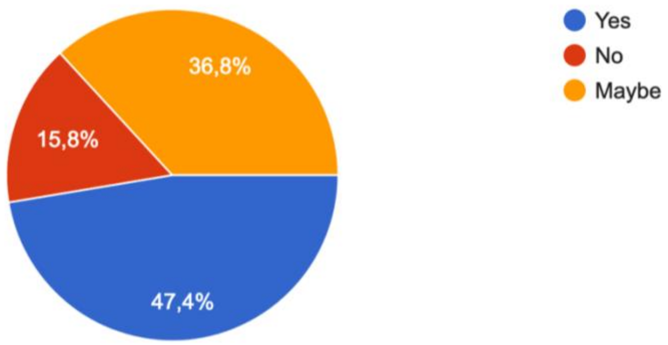

Figure 7: *Answer to question 13 - Would you consider changing your biking route if you knew that the route you've chosen initially includes polluted areas?*

5.2 Summary

This section includes a summary of the results from the analysis of the survey data, in the previous section. The summary does not necessarily include all results from the analysis but only the most significant results, selected by the researchers.

The results from questions 1-4 provide us with information about our respondents and their characteristics. This is significant because it gives us an insight into the potential users of the application. Based on the results from the survey and the respondents, we can deduce that our potential users have a wide age group of 15-66 years and that they equally consist of males and females. They are most commonly students but there are also a fair share of employed and unemployed people and very few pensioners.

The results from questions 5-9 provide us with information about our respondents biking habits, which once again gives us an insight into our potential users biking habits, but it also provides us with clear details about the scenarios that they experience. We can deduce that most of our potential users' bike frequently as our respondents bike every day and a couple of times a week even though there is also a fair share that seldomly use their bike. This also enhanced by the fact that most of our respondents use their bike as a way to get to work, school or similar, as these are daily life activities. This is significant as our potential users often perform the activity, that increases their chance of experiencing the problem and therefore also increasing the relevance of the application.

The results from questions 10-13 provides us with information about the respondents' concern for air pollution and interest for a potential solution, an application, that would help them avoid polluted routes and areas. We can deduce that our potential users are concerned about air pollution and that they are willing to use a solution, an application, that would help them investigate and avoid polluted routes and areas, as this is applicable to most of the respondents.

These significant results along with other less significant results from the survey will be pursued later in this project to form an understanding of the application's potential users and to create and design a solution, an application, that is centered around these users.

6 Phase 2: Application

The following chapter is devoted to the application. It is concerned with getting to know the potential users of the application. In order to do that, there was made a PACT analysis, there were created Personas and Scenarios. Furthermore, this chapter includes the outcomes of some of the Object-Oriented Analysis & Design activities, including FACTOR system definition, class diagram, database modelling and functions. The following chapter is also concerned with the application design, including pictures and descriptions of each screens in the application, as well as the description of application's navigational flow.

6.1 Understanding the user

The purpose of the following subchapter is to better understand the potential user of the application. This can help to imagine what kind of people will be using the application, how they are going to interact with it and what scenarios of use should be taken into consideration during the design process. This can help design a better solution that will be targeted at a specific group of people with specific needs, which will be reflected in the application design.

6.1.1 PACT Analysis

"People use technologies to undertake activities in contexts" (Benyon, 2014). In order to design an appropriate solution, we decided to make a PACT analysis that would help us envision what kind of people the application would be targeted, what kind of activities would the users perform, what contexts would the app be used in and what kinds of technologies should be considered while designing the solution.

People

The application will be targeted at male and female bicycle commuters in ages between 15 and 66 as this was the age group represented in the survey. Demographically, the application will be targeted at commuters in Aalborg due to the pollution data being available for the city, but the application could also work elsewhere, if the necessary pollution data was made available, e.g. the Greater Copenhagen area, as most of Denmark's bicycle commuters exist in this area and this geographic area was heavily represented in the survey . In terms of their occupation, most of the respondents from the survey were students, a fair share of them were employed or unemployed, and a few of them were pensioners. This could most likely also be the case for our potential users.

Activities

The application will primarily be used by bicycle commuters before they begin their trip to identify polluted areas in their route. The commuters will not actively use the application during the trip as it will require the commuter to stop and therefore will not be appropriate. The user can mount and set up the device, that runs the application, on their bicycle in order to continuously monitor the user's interference with polluted areas. This not mandatory or necessary as the application provides notification in case the user should be near a polluted area. The commuters are not expected to physically interact with the application during their trip, as this will require them to stop and perform the different actions. They are not allowed to use the application while bicycling. The commutes primarily consist of trips up to 5 km long to work, school or similar and usually with a time duration of 15-30 minutes, which is suggested by the respondent's answers to the survey questions. The trips mostly occur during the morning and the afternoon, as respondents respectively arrive to and leave from the beforementioned locations. The survey suggests that the trips could also be longer and for different purposes, such as exercising and leisure. The activities are carried with the purpose of allowing the user the opportunity to get an overview of the pollution level in the different areas of Aalborg and to avoid these polluted areas.

Context

The activities will be carried out in the context of users preparing a bicycle commute in the city of Aalborg, and they will be carried out by users who find air quality important and are aware of the possible consequences related to environmental pollution.

Some of the activities could be carried out by the users separately in a different context for other purposes than the primary intended purpose of the applications. Such activities and purposes could be carried out in contexts, where the user, for example, would like to use the application and investigate the map and data to gain an insight into the current level of pollution in different areas of the city.

Technologies

The applications will have to be installed onto a portable or mobile device as the bicycle commuters will have to be equipped with the device during their trip for notification about exposure to air pollution. It is also required that the device has a GPS chip to provide the application with the user's current location, which is necessary for the user to properly carry out the different activities.

6.1.2 Personas

We have created four different personas primarily based on the different occupations discovered in the survey. The discovered occupations were student, employed, unemployed and pensioner. Furthermore, we have arbitrarily related to the different habits and routines discovered in the survey, to each individual persona.

The first persona is Kristian Lorentzen, see figure 8. His profile is based on the occupation as a student, which was the most common occupation (out of four) in our group of respondents. The age is an arbitrary number in the age group of the potential users, defined by the survey results, which would be suitable for a student.

(Dissolve)

Name	**Kristian Lorentzen**
Age	**22**
Gender	**Male**
Occupation	**Student**
Description	Kristian is a full-time law student at Aalborg University and is currently close to finishing his bachelor. His preferred method of commuting is bicycle, which he primarily uses to get to the University or when running errands in the city. Kristian’s ride to the university consists of a 6-7-kilometer-long trip. Besides that, he mostly does short trips to the grocery store or when has to go for football practice. Most of his commutes revolve around the city and he is sometimes bothered by the noise and exhaust from cars during rush hours. He tries to avoid heavily trafficked roads as much as possible.

Figure 8: *Persona for Kristian Lorentzen*

The second persona is Sara Kirkeby, see figure 9. Her profile is based on the occupation as an employed person, which was the second most common (out of four) occupation in our group of respondents. Once again, age is an arbitrary number in the age group of the potential users, defined by the survey results, which would also be suitable for Sara's occupation and habits.

(Stockunlimited)

Name	Sara Kirkeby
Age	31
Gender	Female
Occupation	Employed
Description	Sara is living in the northern part of Aalborg, Nørresundby, with her boyfriend of 3-years. She works as a stewardess for SAS and regularly departs from Aalborg Airport. Sara commutes to the airport multiple times a week by bicycle, which is around 2 kilometers away from her house. Her commutes are usually in the early morning or late at night. Her travel route involves contact with trafficked roads and bicycling through industrial areas close to the airport, which makes her likely to be exposed to air pollution.

Figure 9: *Persona for Sara Kirkeby*

The third persona is Hans Kristensen, see figure 10. His profile is based on the occupation as an unemployed person, which was the third most common (out of four) in our group of respondents. The age is an arbitrary number in the age group of the potential users, defined by the survey results, which would also be suitable for the Hans' occupation and habits.

(Saris)

Name	**Hans Kristensen**
Age	**44**
Gender	**Female**
Occupation	**Unemployed**
Description	Hans Kristensen has been unemployed since he lost his job a couple of months ago. He is living in a suburban area in Aalborg with his wife and his 2-year-old son. His wife is working full-time, so he takes care of things at home, including getting his son to and from kindergarten and doing grocery shopping. His wife takes the car to work, which means that he uses his bicycle for a lot of his chores. He uses his bicycle 3-4 days during the week and commutes 2-3 kilometers daily. Sometimes he prefers to leave his bicycle at home and walk instead. His daily routine usually consists of him getting his son to kindergarten by bicycle, which is a 1 kilometer away from their house. On his way back he drops by the gym for an hour and does some grocery shopping, if necessary. When he is at home, he spends a lot of his time looking at job posts and searching for jobs. Hans is very environmentally conscious is always trying to figure out new ways to be "greener" and implement these in their daily lives. He just installed a new system for sorting their recyclable waste last month.

Figure 10: *Persona for Hans Kristensen*

The fourth persona is Birgitte Nørgaard, see figure 11. Her profile is based on the occupation as a pensioner, which was the least common (out of four) occupation in our group of respondents. The age is, once again, an arbitrary number in the age group of the potential users, defined by the survey results, which would also be suitable for the Birgitte's occupation and habits.

(Alstrom)

Name	**Birgitte Nørgaard**
Age	**63**
Gender	**Female**
Occupation	**Pensioner**
Description	Birgitte is retired and living in the outskirts of the city of Aalborg with her husband. Her kids have grown into adults and have been living for themselves for years. She enjoys most of her days with her husband, going for walks and visiting family. Occasionally, she gets together with some of her friends and plays bingo almost every Friday at the local bingo club. She lives around 4-5 kilometers outside the city center. Birgitte owns a bicycle which she uses a couple of times a month to get from her home to the bus stop a kilometer from her house. From there she takes the bus into the city when she has some errands to run. She has asthma which leads to her being easily affected by the polluted air originated from the industrial area close to her home and her route. Birgitte does not always when to avoid the area since there is no specific pattern that she can identify.

Figure 11: *Persona for Birgitte Nørgaard*

6.1.3 Scenarios

To enhance our understanding of how and when the users will be performing the activities presented in the PACT analysis to solve the problem, we have envisioned the different relevant scenarios related to the activities. Furthermore, the scenarios are envisioned based on the personas performing the different activities. The envisioned scenarios are listed and described, which will be used to further develop the application's functions and design. The list of scenarios is not exhaustive.

Commute without being exposed to high level of air pollution: Kristian wants to commute to the university by bicycle. To ensure that Kristian follows a route with a low level of air pollution, he opens the application on his smartphone, inputs his current location as the starting point and the address of the university as the endpoint. The application generates a route and displays it to Kristian. He follows the route all the way to the university and ends the navigation from the application when he has reached his destination.

Investigate the air pollution level: Birgitte lives in an area close to some industrial plants. Before she leaves her house, to run errands, go for a walk, etc., she likes to have an idea of the air pollution level for the area where the industrial plants are, as she always passes by it on her route. To investigate the current level of air pollution in her area, Birgitte opens the application on her smartphone. The application displays an overview of her area and she can quickly get an understanding of the air pollution level in that area if it is low, medium or high. She can also investigate further, and view more specific data related to the measurement of air pollution in that given area and for each specific sensor, as the pollution data is received from sensors mounted in and around the area.

Monitor and be prepared against high level of air pollution: Hans always wants to be prepared against wandering into areas that have a high level of air pollution. In case he is within 50 meters of a polluted area, Hans receives a notification on his smartphone, warning him that he is close to an area with air pollution level higher than the one he is willing to accept. The application is always monitoring Hans' locations and makes sure that he is warned, if necessary. Eventually, Hans can open the application by clicking on the notification or clicking on the application's icon and investigate which exact area is highly polluted and see the data from the sensor in that area.

6.2 Object Oriented Analysis & Design

The following chapter is devoted to some of the Object-Oriented Analysis and Design activities. There is presented a FACTOR system definition, a class diagram and a database model, as well as functions for the application.

6.2.1 System Definition

A system definition is „a concise description of a computerized system expressed in a natural language" (Mathiassen et al., 2001). The purpose of a system definition is to keep track of what system is actually being developed. Furthermore, it also helps when the developers and designers want to compare the current idea of what the system should be to new ideas arising throughout the development process. A FACTOR system definition covers six crucial system elements that should be taken into consideration while developing a system: its functionality, the application domain, conditions under which the system would be developed and used, technologies used for implementing the system, what objects are to be considered, as well as the responsibility the system will have (Mathiassen et al., 2001). During the work on the project, the following FACTOR system definition was developed:

Functionality	Support bicycle commuters in Aalborg in commuting through routes with less air pollution.
Application domain	Bicycle commuters in Aalborg.
Conditions	The bicycle commuters will use the application voluntarily.
Technology	The application will be for we available for smartphones running on the Android operating system.
Objects	Users, sensors, locations and routes.
Responsibility	Providing routes with low level of air pollution for bicycle commuters and providing data representing the current air pollution level.

Table 6: *FACTOR Criterion*

6.2.2 Class Diagram

This chapter contains a depiction of the application's objects and the structures between them, which will be described and illustrated through a class diagram, see figure 11.

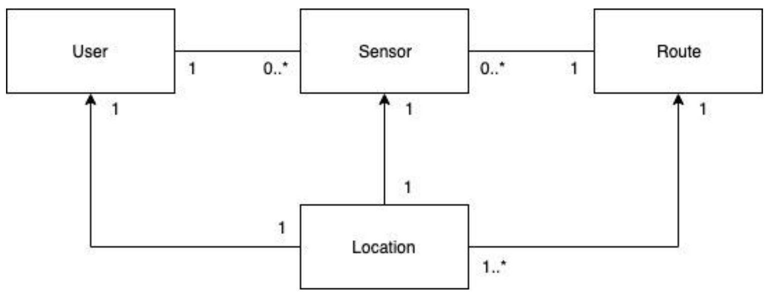

Figure 12: *Class diagram*

Concerning the application's problem domain, we have discovered the following objects: user, sensor, route, and location. The user class symbolizes the user of the application and is used to register the name and e-mail of each user. The sensor class symbolizes the various sensors mounted throughout the city of Aalborg and is used to register air pollution data from these. The route class symbolizes the routes displayed to navigate the user through their commute and is used to calculate and generate the most appropriate route primarily based on air pollution level and thereafter distance. There is no requirement that the application should register this information. The location class symbolizes the different objects' locations, as these are relevant. The user's location is identified and displayed to the user and is continuously updated as the user's location changes. The sensor's location is registered and used to place the sensor on the map. The route has multiple locations, which is the location for the route's starting point, end point and the location points between the starting point and end point. There is an association structure between the objects' user, sensor and route, as these can exist independently without each other and they are therefore parallel and peers to each other. A user has a location, a sensor has a location and a route has one or more location. Location is, therefore, a subclass to the user, sensor, and route class and has multiple inheritances as it inherits characteristics and behavior patterns from these classes. In terms of cardinality, there is one-to-one relationship between user and location, which implies that one user has one location. User also has an optional one-to-many relationship to the sensor object, as one user can experience none or many sensors. Furthermore, sensor has a one-to-one relationship to location, as one sensor has one location. Sensor is also associated to route, and there is an optional one-to-many relationship between them, as a route can include none or many sensors. Lastly, the relationship between route and location can be described as one-to many as well, since one route has many locations.

Database model

This chapter contains a description of the database model for the application. The database model is presented by an entity-relationship (ER) diagram, see appendix 2. The database of the application consists of three entities, which are users, sensors and sensor data. The user entity will be used to store data about the user's account, which is the user's e-mail and password. Each user will be given a unique id number, which will be used to identify the user by the application. The sensor entity will be used to store general information concerning the different sensors, which is the name of the sensor, the address and location coordinates for where it is mounted. Each sensor will also be given a unique id number, which will be used to identify the sensor by the application. The sensor data entity, which is a sub-entity of the sensor entity, is used to store data from all sensors. Each input of data is given an id number, which is used to identify that specific input and the sensor that the data concerns are identified by the foreign key, sensor id, which is the id from the sensor entity.

6.2.3 Functions

This chapter includes an overview of the different functions of the application and a description of the functions. The functions are also evaluated according to Mathiassen et al. (2001). They suggest that the functions should be evaluated with a focus on two factors, which are complexity related to the development and the type of the function. Evaluation of a function's complexity is subjective and based on the evaluating developer's skill and experience. The evaluation may, therefore, differ from developer to developer. The functions are evaluated based on the following range: simple, medium, complex and very complex (Mathiassen et al., 2001). Evaluation of the function's type is on the other hand objective and can be categorized as one of the following four types of functions: update, signal, read and compute (Mathiassen et al., 2001).

#	Function	Complexity	Type
1	User registration	Simple	Update
2	User login	Simple	Read
3	Display map	Simple	Read
4	Display sensors	Medium	Read
5	Get and display user’s GPS location	Simple	Read
6	Generate and display route	Medium	Compute
7	Display sensor data	Simple	Read
8	Display exposure notification	Medium	Signal
9	Edit user’s name	Simple	Update
10	Edit user’s e-mail address	Simple	Update
11	Edit user’s password	Simple	Update
12	Edit exposure willingness	Simple	Update
13	Turn on/off exposure notification	Simple	Update

Table 7: *Evaluation of functions*

A prioritization of the functions in relation development of the application, is made through the MoSCoW rules, and can be found in Appendix 3.

6.3 Application Design

The following chapter is devoted to the application design, which is the outcome of the activities undertaken in the previous parts of the report. It describes the user interfaces, as well as the application’s navigational flow.

6.3.1 User Interfaces

This chapter includes a presentation of the application’s various views and the design of the user interfaces. A description of the interface design and the elements used and presented on each view.

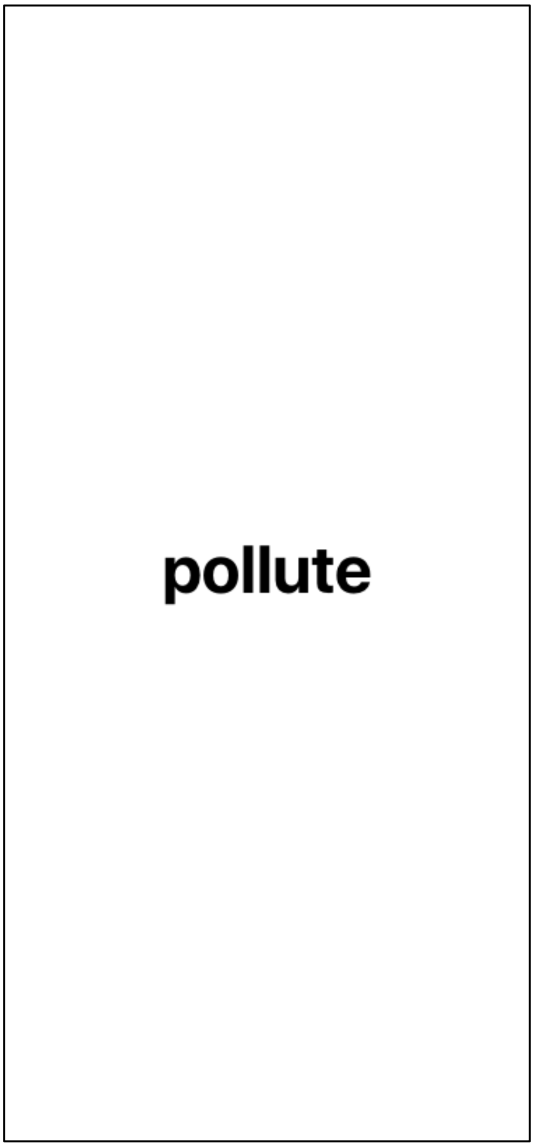

Figure 13: *User Interface for the application's splash view*

The very first screen of the application is the splash screen, see figure 13. The user interface (UI) of the splash view is simple and consist of displaying the logo. The purpose of the splash view is to display that the application is starting and loading. Once the application has been loaded and it is ready for the user, the user will automatically be forwarded to the login/register view. In case the user is already signed in, the user will instead be forwarded to the map view, which is the main of the application.

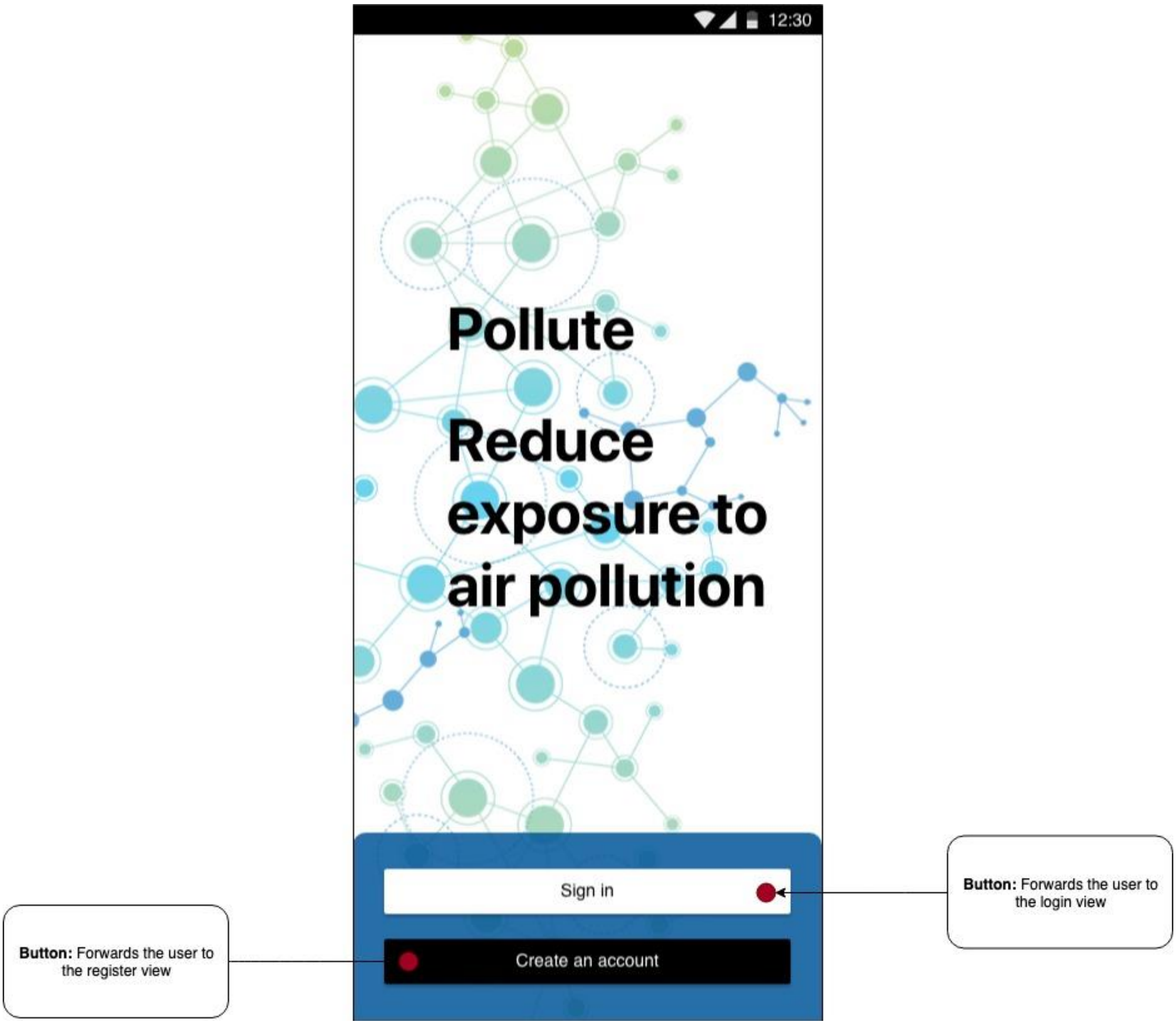

Figure 14: *User Interface for the application's login/register view*

The login/register view allows the user to either log in with an existing account or to create an account, which can be used to login into the application, see figure 14. The view has two components, which are both buttons. They each respectively have the text “sign in” and “create an account”. The sign in button forwards to the user to the login view and the create an account button forwards the user to the register view.

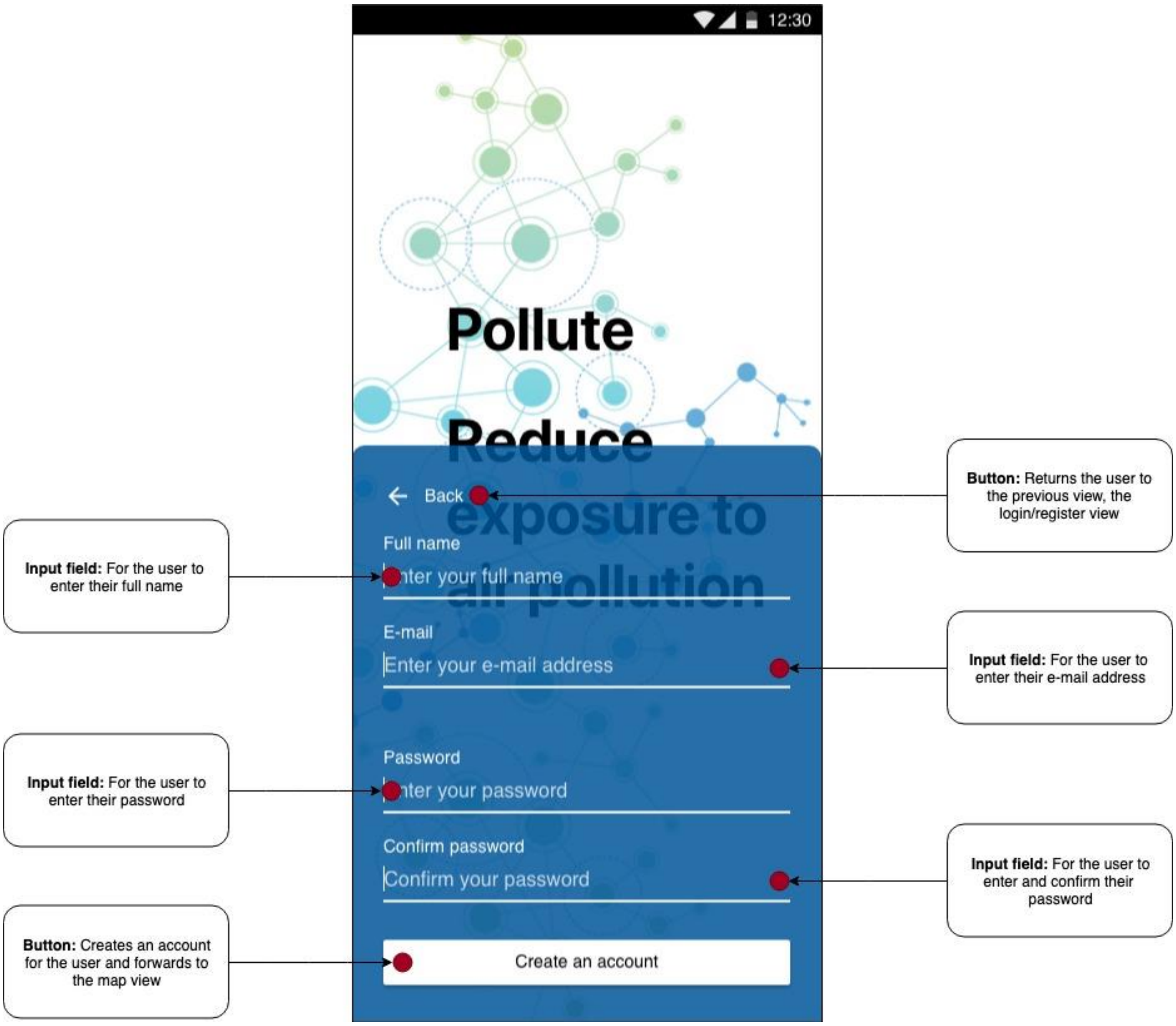

Figure 15: *User Interface for the application's register view*

The register view allows the user to the create an account, see figure 15. The view has four input fields, which are for entering full name, e-mail, password and confirming the entered password. Each input field has a label above it, to give the user direct and constant indication of which information is to put in the specific field. The view also has button at the bottom with the text "create an account", which sends the user's information from the input fields to the database and creates the account. If all input fields are filled out by the user and the information provided fulfills the necessary requirements, the user will be forwarded to the map view. Otherwise the user will be prompted with an error message, requiring the user to fill out the input field correctly. Following are the requirements for the different input fields: e-mail has to be a valid e-mail address with an at sign (@), and password has to have at least 6 characters. Lastly, the view has a button in the middle left of the view with a left arrow icon and the text "back", which sends the user back to the previous view, the login/register view.

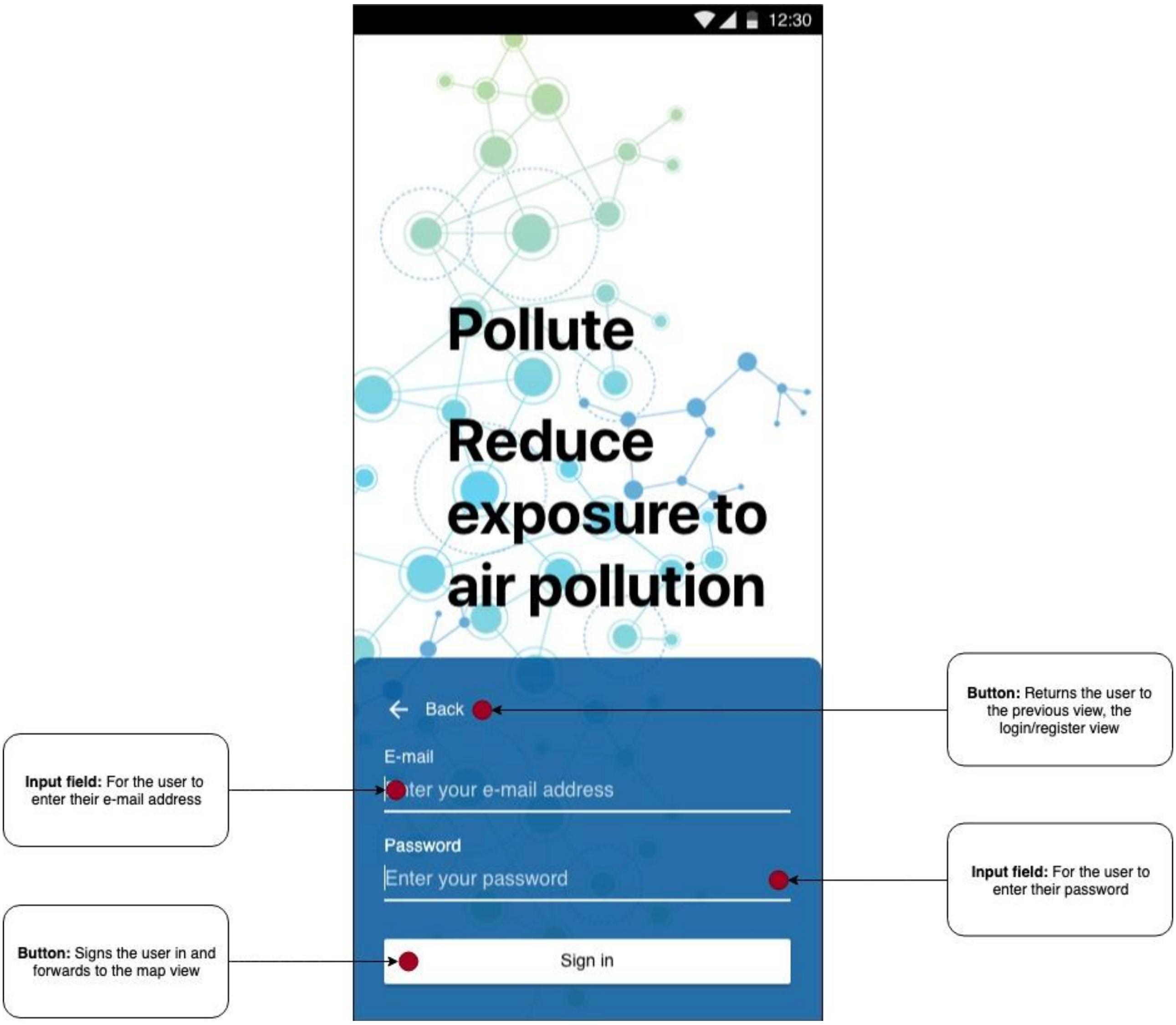

Figure 16: *User Interface for the application's login view*

The login view allows the user to login with an existing account, see figure 16. The view has two input fields with labels, which are for entering e-mail and password. There is a button at the bottom of the view with the text "sign in". The sign in button is used to sign in to the user account with entered account information. If the information matches an account in the database, the user is signed in and forwarded to the map view. Otherwise the user will be prompted with an error message, requiring correct information that matches an existing account. Lastly, the view has a button in the middle left of the view with a left arrow icon and the text "back", which sends the user back to the previous view, the login/register view.

Figure 17: *User Interface for the application's map view*

The map view allows the user to get an overview of the air pollution level in their current area, see figure 17. The view also allows the user to discover and investigate the air pollution level in other areas by swiping and pinching the map, respectively allowing the user to move and zoom in/out of the map. The map view displays a map with circles at each sensor location and the size of the circle represent the coverage of the sensor data. The circle can be of the colors green, yellow and red, which respectively indicates the air pollution level on low, medium and high, for the area surrounding the sensor. Touching a circle forwards the user to the sensor data view. There is a blue and white dot with point, which displays the user's current location and where the user is headed. At the bottom left corner of the view, there is a circular button with a nut icon, which forwards to the user to the settings view. At the bottom left corner of the view, there is a circular button with a right arrow icon, which forwards the user to the route view.

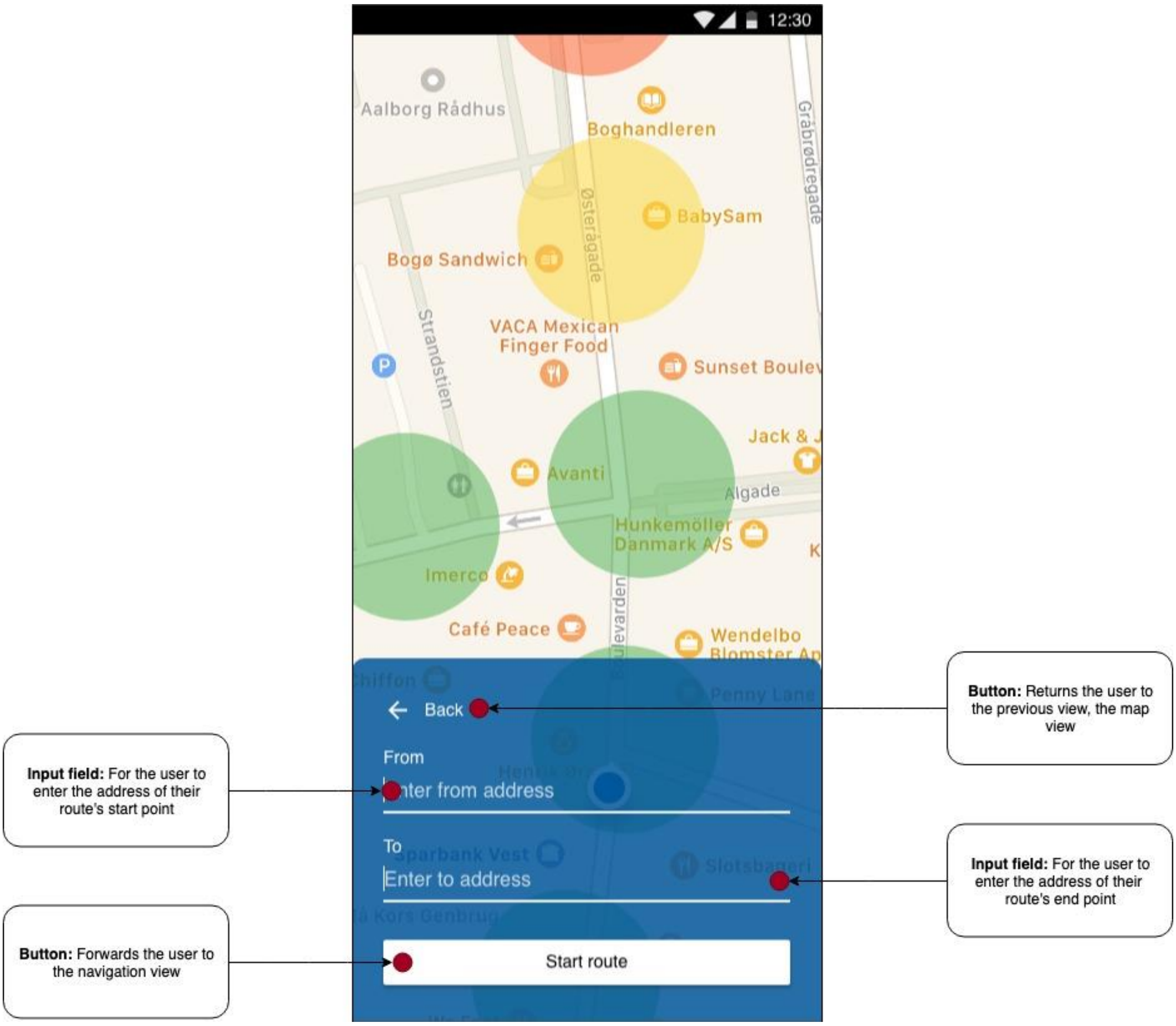

Figure 18: *User Interface for the application's route view*

The route view allows the user to inform the application about where the user would like to commute from and to, see figure 18. The view has two input fields with labels, which are for entering the address of the user's current location, or a location that the user would like to commute from, and the address of the location, which the user would like to commute to. At the bottom of the view there is a button with the text "start route", which makes the application generate a route based on the addresses entered by the user and forwards the user to the navigation view. Lastly, the view has a button in the middle left of the view with a left arrow icon and the text "back", which sends the user back to the previous view, the map view.

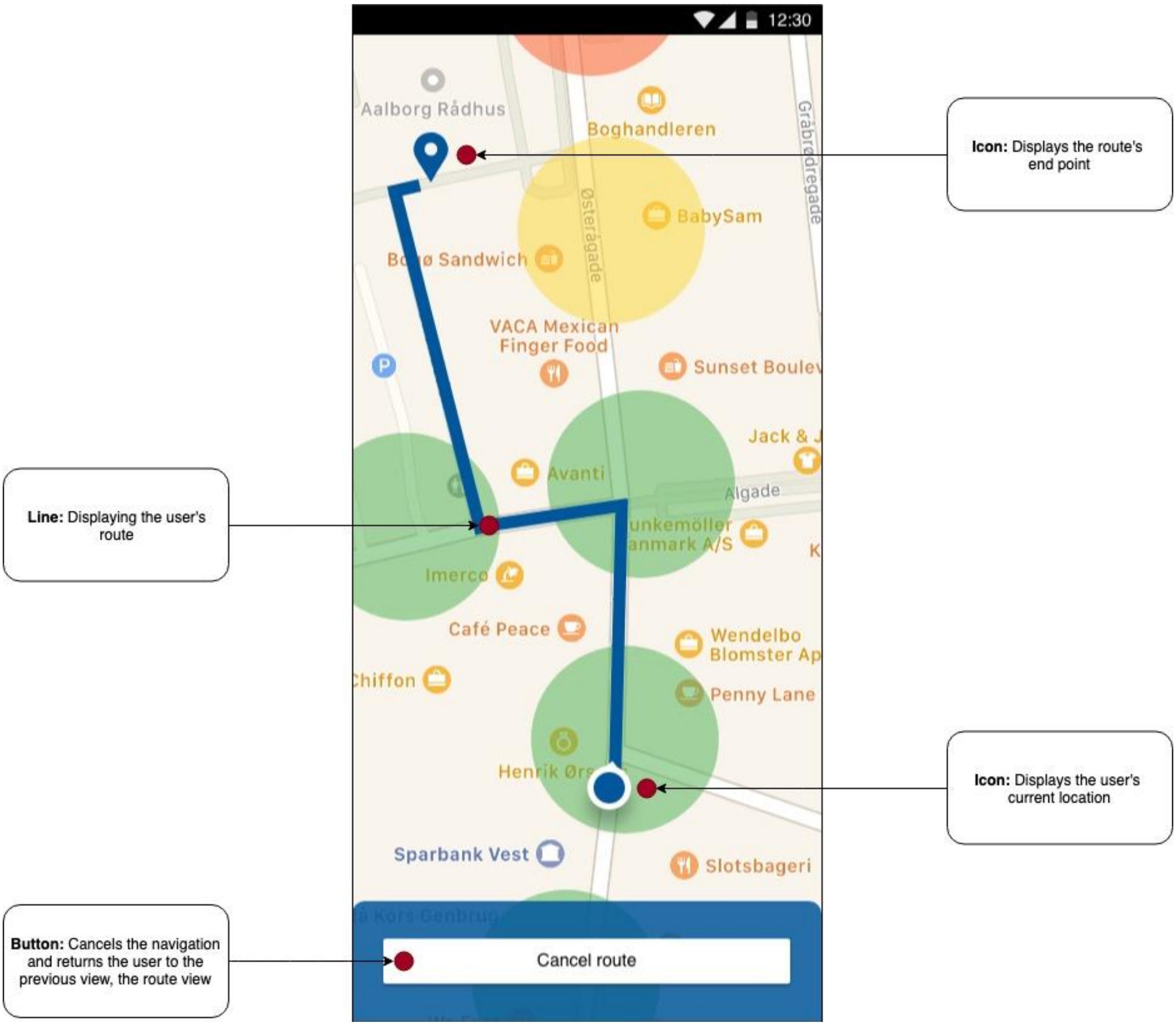

Figure 19: *User Interface for the application's navigation view*

The navigation view provides the user with a route based on their entries in the previous view, the route view, and their current location in relation to the route, see figure 19. Besides the elements of the map view, the navigation view displays a blue line, which is the route that the user should follow. There is a blue pin icon at the end of the route, indicating the finish point of the route. At the bottom of the view there is a button with the text "cancel route", which stops the navigation and sends the user back to the previous view, the route view.

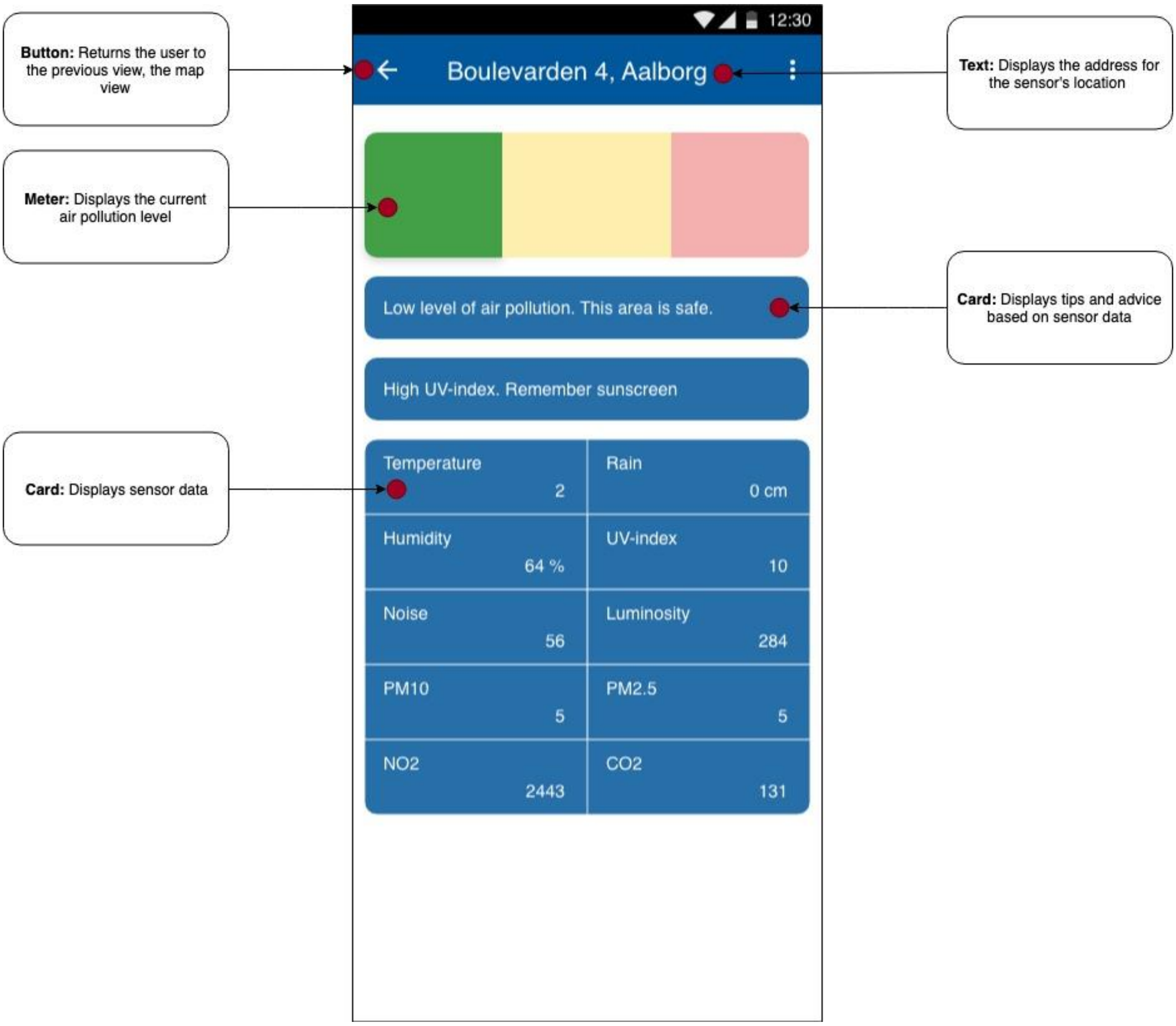

Figure 20: *User Interface for the application's sensor data view*

The sensor data view allows the user to see all data gathered by the sensor in the selected area, see figure 20. The view has a meter at the top, which goes from green to yellow to red, indicating the air pollution level for the specific area. The application provides tips and advice based on the sensor data, which are displaying in cards with text. The view displays the data from the sensor in a collection of cards, where each measuring point is given a card. The application displays the following sensor data: temperature, rain, humidity, UV index, noise, luminosity, PM10, PM2.5, NO2 and CO2.

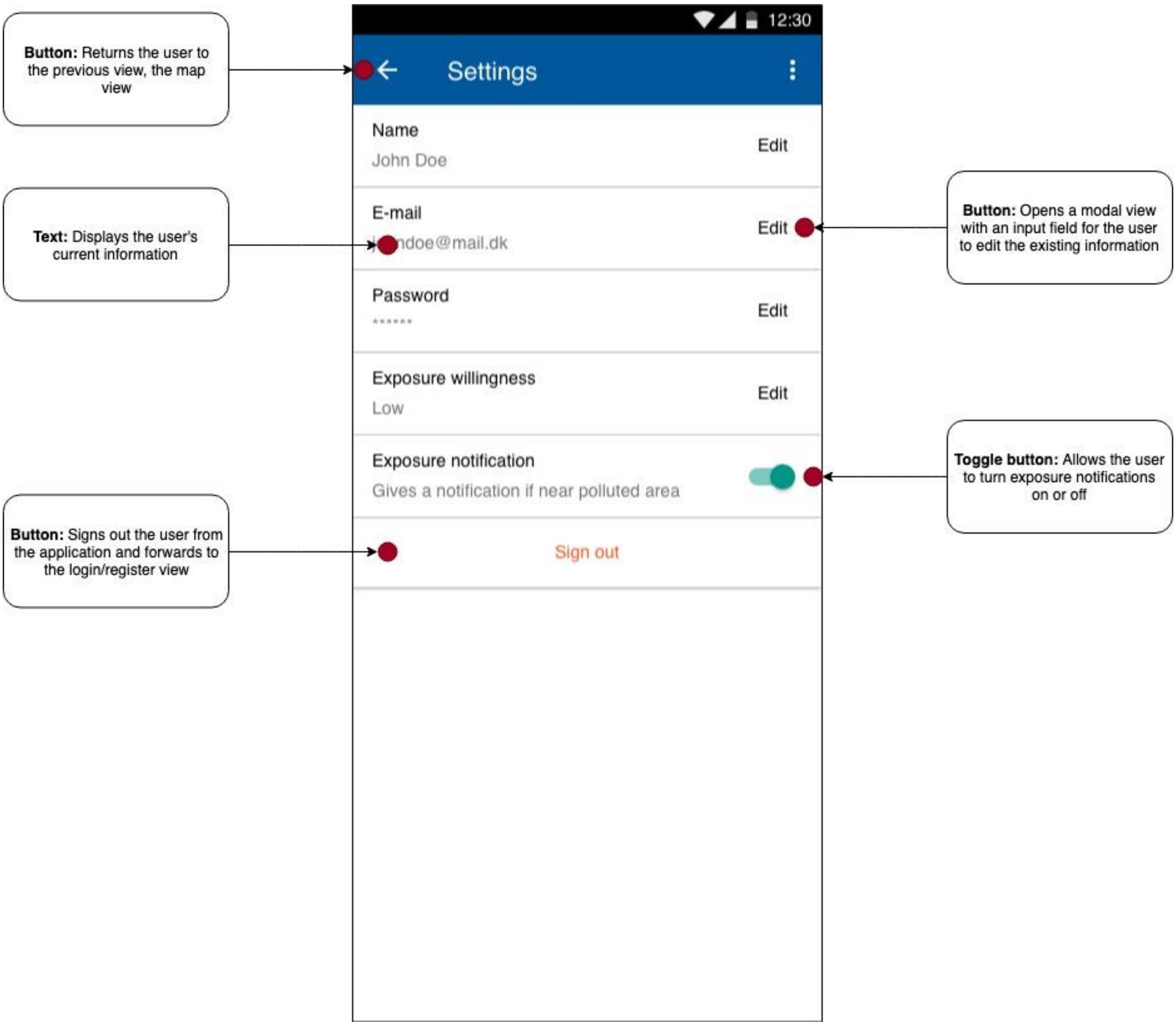

Figure 21: *User Interface for the application's settings view*

The settings view allows the user to control different setting related to the user's account, see figure 21. The view has four rows, which is for each possible setting. The first row displays the name registered to the user account and a button with the text "edit". Touching the edit results in a pop-up being displayed, with an input field, allowing the user to edit the current name to a new one. The same description applies to the next two rows, which respectively displays the user's e-mail address and password and allowing the user to edit these by touching the edit button. The password is never really displayed but just represented as an arbitrary number of asterix signs (*). The fourth row has the text "exposure willingness", which lets the user set their willing exposure level, with the following options: low, medium and high. The fifth row has the text "exposure notification" and toggle button. The toggle button allows the user to control the notification settings by turning notification on/off. The application displays notification, whenever the user is close to area with a sensor that indicates medium or high level of air pollution. The sixth and the last row consists of a button with the text “sign out”, which signs the user out of the application and forwards the user to the login/register view.

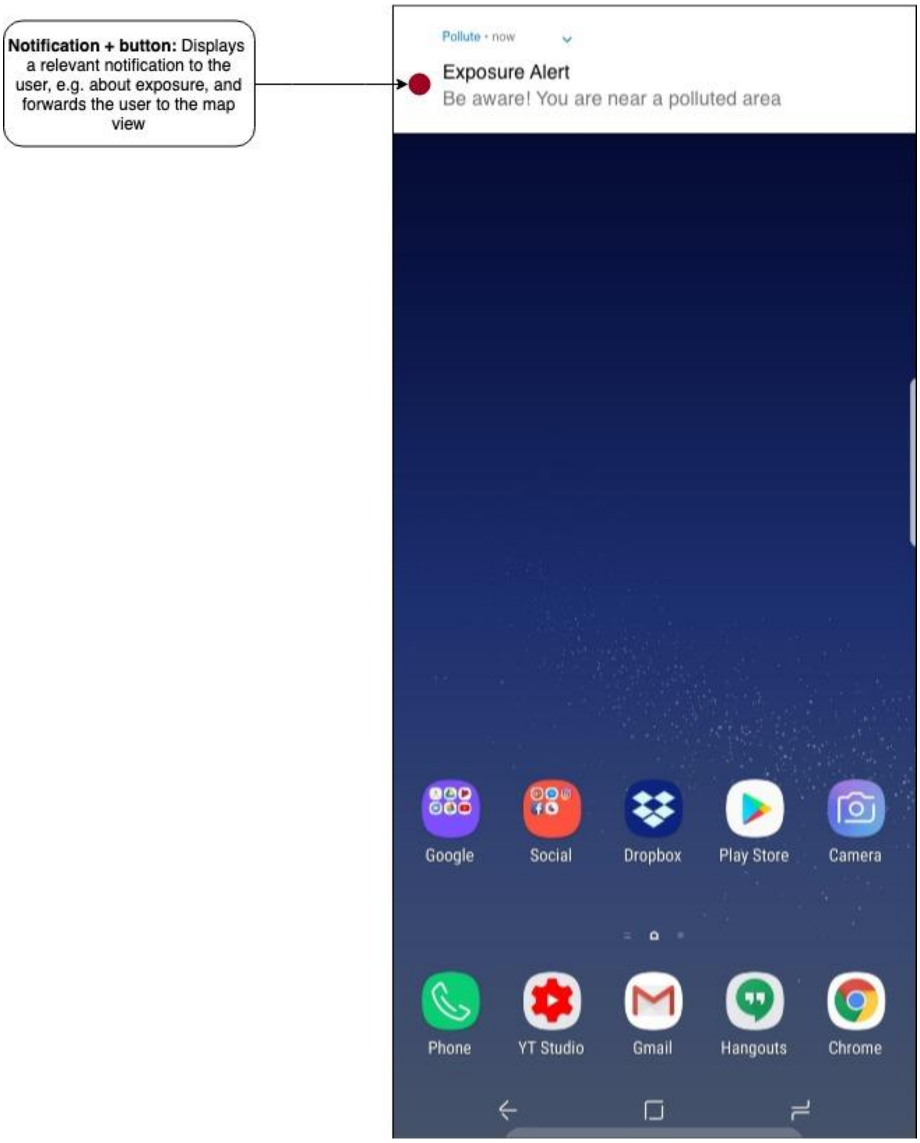

Figure 22: *User Interface for the application's notification view*

The notification view represents how notifications from the application is displayed to the user, see figure 22. Notifications are displayed according to the standard of the operating system of the smartphone, and therefore displayed with the name of the application, time of the notification, a notification title and message. As mentioned earlier, the application displays notifications whenever the user is close to area with a sensor that indicates medium or high level of air pollution.

6.3.2 Navigation

This chapter provides a description of the application’s navigational flow, see figure 23. The figure represents the navigation for the time usage of the application, as to when the user is not signed in. If the user's is signed in at further usage, the application will go straight from splash view to the map view, skipping the views related to signing in or creating an account.

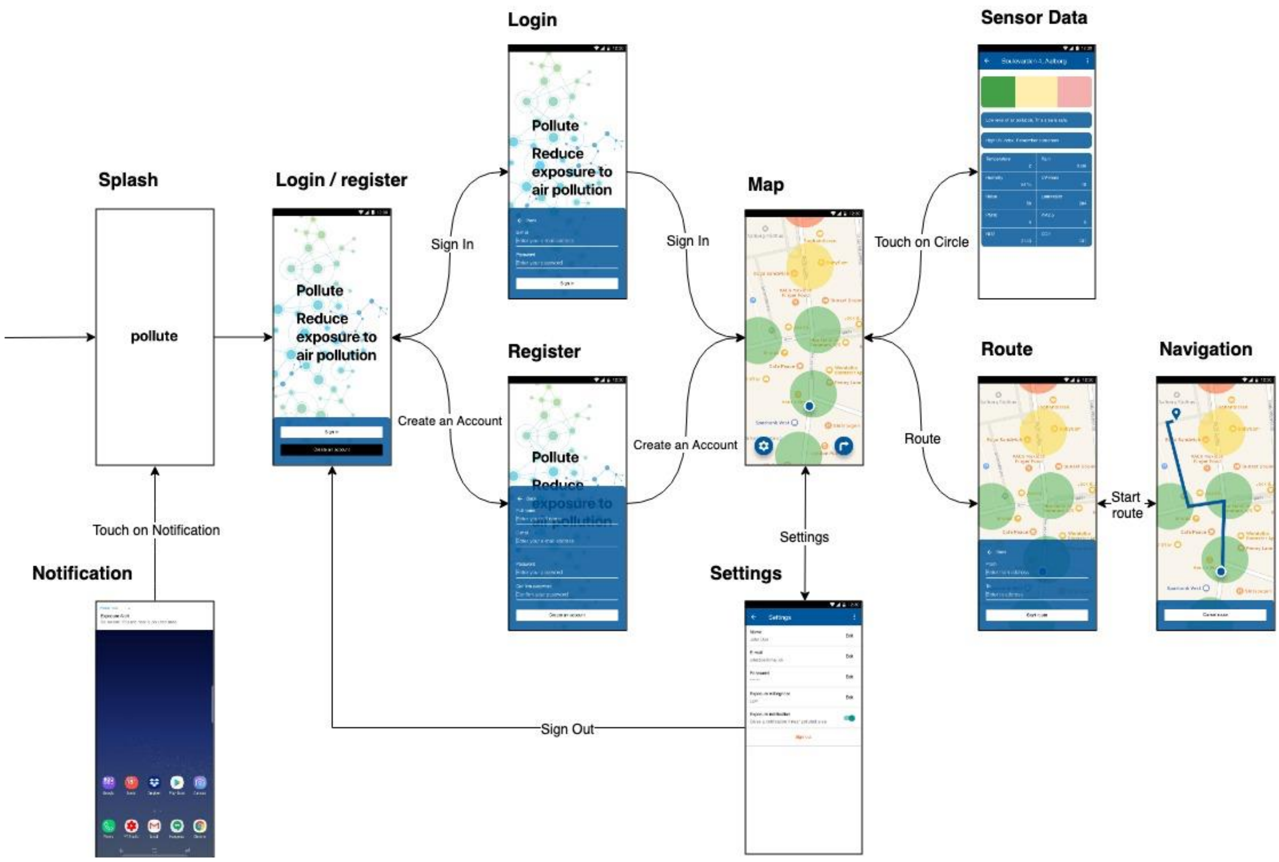

Figure 23: *The application's navigational flow*

7 Phase 3: Prototype Experiment

The following chapter is devoted to the description of the prototype that has been developed in order to conduct the prototype experiment. Furthermore, it describes the results of the prototype experiment, including both the analysis of the video recordings taken with GoPro camera, as well as the analysis of the answers to the questionnaire given to the test subjects after the experiment. Moreover, the chapter includes a summary of the experiment results.

7.1 Prototype

For the purpose of the experiment, there was developed a prototype. The prototype was developed as an Android application in Java. Furthermore, the prototype made use of an online MariaDB database and therefore, there were created scripts in PHP, so that the app could communicate with the database. The prototype included following functions:

- register an account
- login/logout
- view map with the device's current location

- search for route (with only a couple of routes being available due to the fact of them being hardcoded)
- display a chosen route

Yet, this chapter will only describe some of the above-mentioned functions, as not all of the functions were used during the experiment. Only the most essential function(s) were tested to prove the concept of the application.

Map Overview

The following activity presents the map with the sensors, as well as the device's current location. The current location is presented as a blue dot. This is unfortunately not visible one the screenshot below, as the screenshot was taken when the device was outside of Aalborg and therefore it is not visible on the map. It was visible during the prototype experiment though. Furthermore, this screen includes a menu button, which when clicked, will present menu items, and therefore, enable the user to choose "Search route" and move to the activity where they can set up a route.

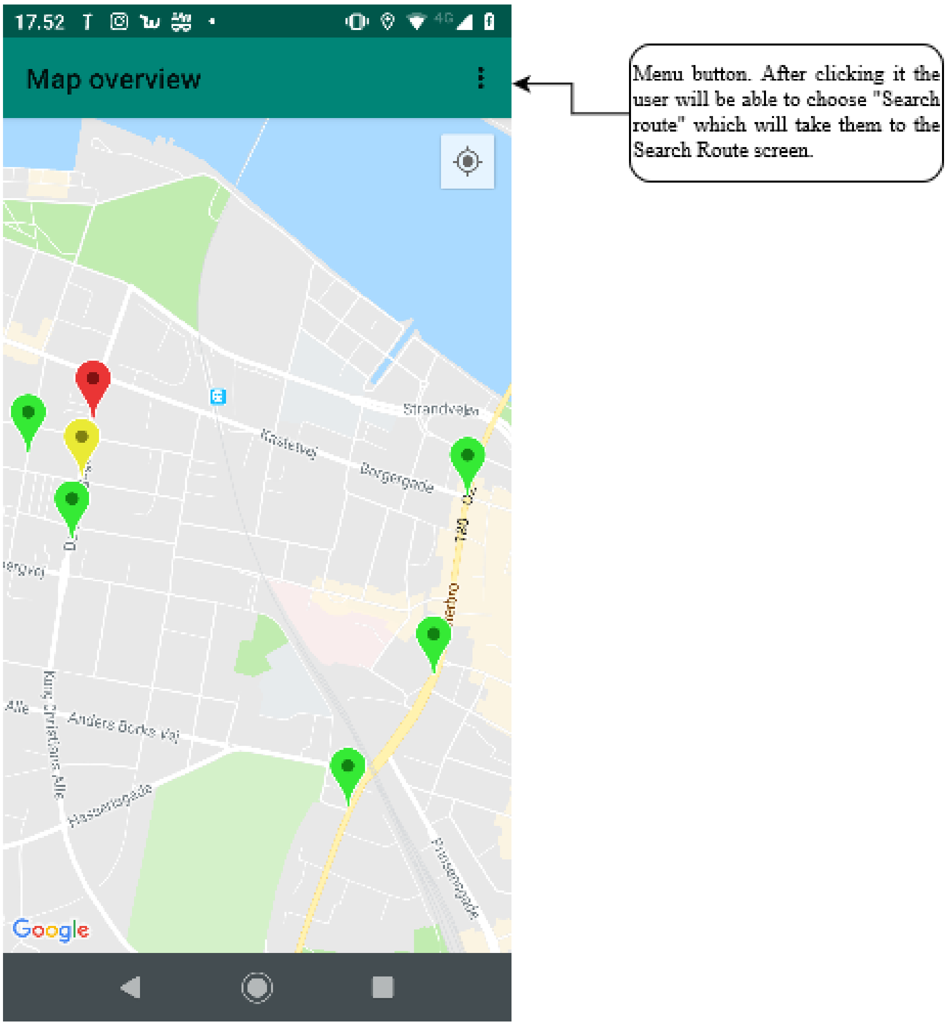

Figure 24: *Map overview screen in the prototype*

Search route

This activity displays two edit text fields – one for entering the start address and one for entering the end address. The user confirms the addresses choice by clicking the button "Search". Furthermore, there is also a button "Cancel" if the user wants to cancel the search and go back to the Map Overview screen.

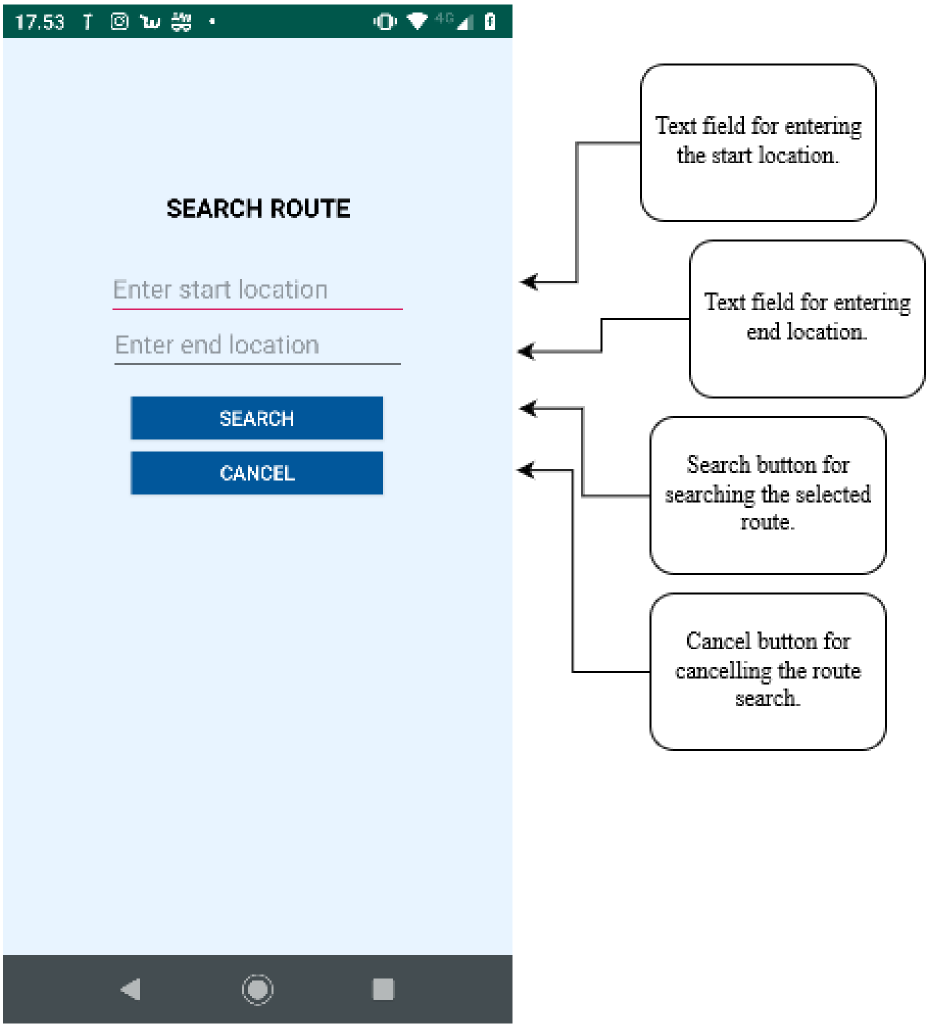

Figure 25: *Search Route screen in the prototype*

Map Overview with selected route

This screen is basically the same screen as the Map Overview screen with the difference that it displays the route chosen in the Search Route screen.

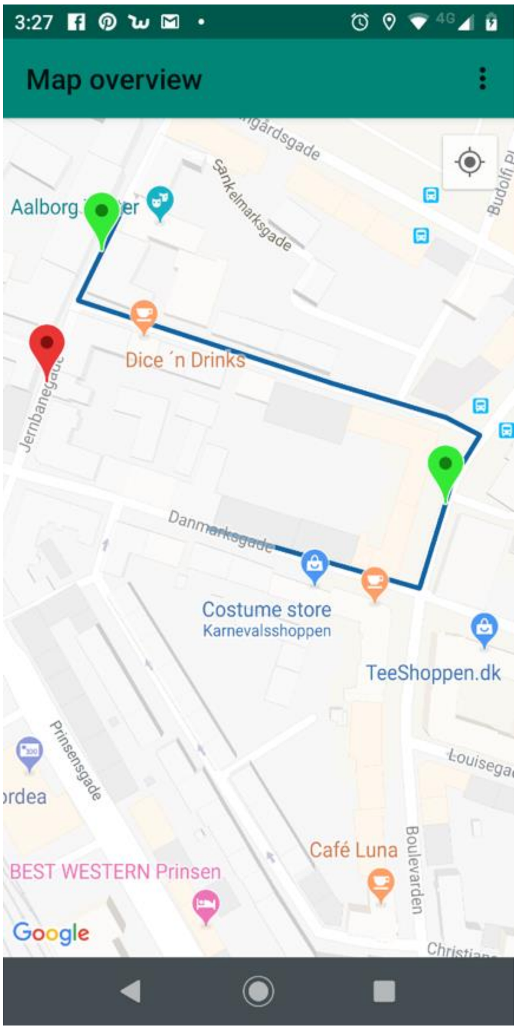

Figure 26: *Map Overview screen with a selected route*

7.2 Analysis

The following section describes the results of the prototype experiment. The experiment included 9 test subjects. The experiment was conducted with the use of a bike and an Android smartphone. Furthermore, it was recorded with a GoPro camera mounted to the participants' heads. The test participants were asked to search a route (from Jernbanegade 11, 9000 Aalborg to Danmarksgade 9, 9000 Aalborg, through the streets Sankelmarksgade and Boulevarden) and to bike from start to end point. After the test the participants were given a short questionnaire consisting of 6 open questions.

Test subject #1 has the application open and navigates to the route view. The user proceeds to enter the address of the starting point and end point of the route and clicks on search. The app then forwards the user to the navigation view, which displays the most appropriate route based on air pollution level. The user then continues to magnify the map in order to get a better look of the route and after studying the route for around 8-10 seconds, the user turns of the screen of the smartphone, puts the smartphone in to their pocket and mounts the bike to start commuting. The user continues down Jernbanegade and turns left on to Sankelmarksgade. While biking down

Sankelmarksgade, it seems that the user has some trouble with the GoPro, that is mounted on the user's head by headband, as the camera shakes a lot and changes position. Nonetheless, the user continues down Sankelmarksgade, turns right onto Boulevarden, continues down the street and turns right onto Danmarksgade. The user bikes down Danmarksgade until the user reaches their destination, after the which the user pulls the bike to the side, adjusts the headband with the GoPro, pulls out the smartphone and opens the application. As the user opens the application, the user is presented with the route view, displaying the user's route and their location. The user's location hasn't changed since the user started commuting and the user tries to update the location by clicking on the location button. The location button is meant to get the user's location and adjust the map, so that the user's current location is in focus. After a couple of clicks, the user's location is updated, and it is clear that the user has reached their destination. The user ends the test session by turning the GoPro off.

Test subject #1's test session is then evaluated by the evaluation survey containing the 6 questions. The evaluation showed the user did not experience any issues while finding the route, or while following the route, as the user mentions that they knew the route. The user's knowledge of the city could have influenced the amount of interaction the user had with the application, as the user only interacted with the application in the beginning and in the end. The user explained that the interactions were made to respectively find the route and to see if the user reached their destination. The user found the application easy to understand but suggests that the application would be easier to use, if the app already had the user's current address, which would only require the user to input the address of the end point. The recording of the user's commute displayed some issues which the GoPro, which the user confirmed by telling that the GoPro was not mounted properly, which resulted it being loose and almost falling a couple of times.

Test subject #2 starts by mounting the bike and then opening the application. After opening the application, the user navigates to the route view, after which the user continues by entering the addresses of the route's starting point and end point in their respective input fields. Inputting the addresses seems a bit time consuming, as the user spends a lot of time on this activity. After entering the addresses, the user clicks on the search button and is forwarded to the navigation view, which displays the map containing the most appropriate route for the user's commute. The user's studies the map for a couple of seconds, after which the user turns of the screen of the smartphone, puts it into their pocket, and starts biking. The user bikes down Jernbanegade, turns left on Sankelmarksgade, continues down the street, turns right and continues down Boulevarden. Finally, the user turns right onto Danmarksgade and bikes until the user reaches their destination. The user ends the test session by turning off the GoPro.

The evaluation of the test subjects #2's test session showed that the user did not experience any issues while finding the route or while following the route during the commute. The user only interacted with the application on one occasion, which was for finding the route. The user also found the application easy to understand and use, for which the user mentioned that the application was very simple. When asked if the user experienced any issues during the test, the user mentioned that they are not used to Android operating system, which was the operating system of the smartphone used during the test. This could have influenced the user's test and could be the reason, it took the user a bit longer to input the addresses of the starting and end point. The user did not suggest any improvements concerning the application.

Test subject #3 has already mounted the bike and starts from the route view, on which the inputs the addresses of the starting point and end point. The user shows signs of having a bit trouble with the smartphone's keyboard but manages to input the addresses and clicks search. After clicking on search, the application generates the user's route and forwards the user to the navigation view, on which the user is presented with a map displaying their route. The user magnifies map in order to assess the route, and rotates the map, in order to get a better idea of which way to go. After studying the map for a while, around 10 seconds, the user puts the smartphone in their pocket and starts biking down Jernbanegade and turns left onto Sankelmarksgade. While biking down Sankelmarksgade, the user takes the smartphone from their pocket and studies the map. It is noteworthy that the user has not turned off the screen of the application, and continues to not do so, after studying the map and putting the smartphone back into their pocket. The user continues down Sankelmarksgade, turns right onto Boulevarden, continues down the street and turns right onto Danmarksgade. The user continues down Danmarksgade and stops when they have reached their destination. Right before reaching the destination, the user pulls out the smartphone with the screen still on and studies the map with the route. The test session ends by the test moderator turning of the GoPro.

Test subject #3's evaluation survey showed that the user did not experience any issues while finding the route, while following the route or just during the test in general. The user listed that they interacted with the application in the beginning to find the route and during the commute, to see if they were going the right and which way to go. The user did not mention they interacted with the application at the end, when reaching the destination but it is clear from the recordings of the test, that the user also interacted with the application at this occasion. The user found the application easy to understand and use and did not have any suggestions for improving the application.

Test subject #4's session starts by the user already having entered the addresses of the starting point and end point and having studied the map. The recording started a bit too late, which is why the session starts by displaying that the user begins to bike down Sankelmarksgade. At the end of Sankelmarksgade, the user turns right onto Boulevarden. The user has had the smartphone in his hand during the entire trip and while biking down Boulevarden, the user studies the map, and turns right onto Danmarksgade. The user bikes down Danmarksgade until they have reached their destination. The test session ends by the GoPro disconnecting the recording.

Test subject #4's evaluation showed that the user did not experience any issues while finding the route or while following the route during the test session. Although the did mentioned that they experienced the tire of the bike being flat, which was an issue during the test. In terms of interactions, the user mentioned that they interacted with the application in the beginning to find the route, and during the commute to follow the route. This number is in accordance with the observations from the recordings. The user found the application easy to understand and use but suggested that it would be an improvement, if the smartphone could be mounted onto the bike's handlebar. This suggests that the user needs constant access to the map displaying the route during the commute.

Test subject #5 starts the session by having entered the addresses of the starting point and the end point. The user then clicks on search, after which the application forwards the user to the route view displaying a map with the user's route. The user quickly studies the map and starts commuting by mounting the bike with the smartphone in their hand. The user turns left onto Sankelmarksgade, continuing down the street still with the smartphone in their hand. The tries to study the map during the trip but it seems that map has been navigated away, while the user has the smartphone in their hand. The user's makes a couple of tries in order to find the route but gives up and just commutes down Danmarksgade. The user stops when they have reached the destination and ends the test session by disconnecting the GoPro.

Test subject #5's evaluation showed that the user did not experience any issues while finding the route, while following the route or just during the test in general. The user mentioned that they interacted with the application in the beginning to find the route and during to the commute to see when to turn. The user found the application easy to understand and use but suggested that it could be improved by adding some functionality that could provide voice navigation.

Test subject #6 starts the session by having entered the addresses of the starting point and the end point. The user then clicks on search, after which the application forwards the user to the route view displaying a map with the user's route. The user then magnifies the map in order to see the route more clearly and then studies the map for a while, around 10 seconds. The user then takes of down Jernbanegade, turns left to Sankelmarksgade. The user stops on Sankelmarksgade, pulls out the smartphone, and studies the route. Then user then takes of again down Sankelmarksgade, turns right onto Boulevarden, continues down Boulevarden and turns right onto Danmarksgade. The user continues down Danmarksgade until the user reaches their destination, after which the user once again pulls out the smartphone and checks the map. The test session ends with the disconnecting the GoPro.

Test subject #6 did not have any issues finding the route and following the route. In terms of interactions the user mentioned that they had an interacted with the application in the beginning to find the route, sometime midway to see which way to go further ahead, and finally when arriving at the destination to check the map. The user found the application easy to understand and use, to which the user mentions that the application reminds them about the navigation apps for cars. The user informed that they experienced an issue with the bike having a flat tire.

Test subject #7 also starts the session by having entered the addresses of the starting point and the end point. The user then clicks on search, after which the application forwards the user to the route view displaying a map with the user's route. The user asks the moderator for assistance on how to get started. The moderator helps the user magnify the map in order to see the route more clearly. The user then checks out the map shortly and takes of down Jernbanegade, turns left onto Sankelmarksgade, continues down on Sankelmarksgade and turns right onto Boulevarden. The user continues to commute down Boulevarden, turns right onto Danmarksgade and keeps going until they arrive at their destination. The test session ends with the test moderator turning off the GoPro.

Test subject #7's evaluation shows that the user did not experience any issues finding the route and following the route or during the test in general. The informed that they knew the route and only interacted with application once in the beginning to find the route. The user found the application easy to understand and use but suggests that the application could be improved, if it provided some information about the negative effects of being exposed to air pollution.

Test subjects #8 test session with the user clicking on the search button in order to find a route. The application then forwards the user to the navigation view, after which the user studies the map for a couple of seconds. The user then takes off by turning right down Sankelmarksgade. While biking down Sankelmarksgade the user interacts with the application to see the map and puts the smartphone in their pocket afterwards. The user turns right onto Boulevarden, continues down Boulevarden and turns right onto Danmarksgade. While turning the user pulls out the smartphone and studies the map on the application. The user keeps watching the map while biking down Danmarksgade and stops when they have arrived at their destination. The user stops the test session by turning off the GoPro.

Test subject #8's evaluation shows the user did not have any issues finding the route by using the application and could you use the application to see if they were going the right way. The had some interactions with the application, once in the beginning to find the route, and a couple of times during the commute to check the route. The user found the application easy to understand and use but suggests that the navigation view of the application could be more zoomed in or in focus.

Test subjects #9 test session with the user clicking on the search button in order to find a route. The application then forwards the user to the navigation view, after which the user magnifies the map and studies it for a while, around 9-10 seconds. The user then takes off down Jernbanegade, turns left and continues down Sankelmarksgade and turns right and bikes down Boulevarden. The user finally turns right and continues down Danmarksgade until the user reaches their destination. When approaching the destination, the user pulls out the smartphone and checks the map. The test session ends with the turning off the GoPro.

Test subject #9's evaluation showed that the user did not experience any issues finding the route, following the route and during the test in general. The user mentions that they only interacted with the application in the beginning to find the route but the recording shows that the user also interacted with the application, at the end when approaching the destination. The user found the application easy to understand and use but the suggests the design of the application could be improved.

7.3 Summary

This section includes a summary of the results from the analysis of the data from the prototype experiment, in the previous section. The summary does not necessarily include all results from the analysis but only the most significant results, selected by the researchers.

Naturally, all users interacted with the application before beginning their commute, in order to find the route and to check the map and the route. However, it was noteworthy that most of the users, 6 out of 9, actually interacted with the application while biking, in order to check the route and figure out which way to go further ahead.

Looking at the evaluations of the test subjects from the post-test debriefing, for which the first questions was: *Did you experience any issues setting/finding the route?* None of the participants reported any issues regarding the issues finding a route with the prototype. This can mean that this part of the prototype is intuitive.

The second question was: *Did you experience any issues while commuting or following the route?* All of the participants answered no to this question. Furthermore, one participant stated that the route was easy, two of them stated that they knew the route prior to the test. Moreover, two participants gave additional information stating that the prototype showed them the route and their current location and therefore, they could see if they're going the right way.

The third question was: *When and why did you interact with the app? List all your interactions.* All of the participants answered that they interacted with the prototype in the beginning of the experiment in order set up the route. 5 participants interacted with the prototype during going through the route in order to see when and where to turn or to see if they are going the right way. 4 participants interacted with the prototype at the end of the route in order to see if they are already there. The answers to the question show that more than half of the participants needed to check the route while biking. The rate of users having the need to check the route while they are biking could probably be bigger if the route was longer or more complex. Furthermore, some of the participants stated that they knew the route prior to the test, and therefore, they probably did not need to check if they are going the right way.

The fourth question was: *Was the app easy to understand and use?* All of the participants answered that the app was easy to use. Furthermore, two participants additionally stated that the prototype was very simple. One of the participants said that the app reminded a lot the navigation for cars. The fact that all of the participants said that the app was easy to understand, and use is probably caused by the fact that the participants are used to using navigation apps in their everyday life.

The fifth question was: *Did you experience any issues during the test?* Five participants answered that they did not experience any issues during the test. The rest of the participants reported some issues, but none of the issues was related directly to the prototype itself. The issues reported by the participants included:

- the bike having a flat tire
- GoPro not being mounted properly
- the participant not being used to Android operating system.

The sixth question was: *Do you have any suggestions in terms of improving the application?* Only three participants answered no to this question. The rest of the participants provided useful information on what could be improved. The answers on what could be improved include:

- having the option of choosing the current address without having t type it in while searching for a route
- having voice navigation
- the app could provide information about negative effects of being exposed to air pollution
- navigation being more zoomed in and focused
- having the phone mounted to a bike
- the design could be improved.

To sum up, the prototype experiment can be considered successful. The test participants did not report any major issues with the prototype and stated that the app is easy to use. This can suggest that the solution is intuitive to use. Furthermore, the participants provided useful insight into what could be improved or added to the app.

8 Discussion

This chapter includes a discussion of the results from the project, primarily the results from the prototype experiment. The results will be compared to related research and applications, as presented earlier in the project, and be held up against the research question. Furthermore, the discussion will also include illuminations on the project process and suggestions for further research. Lastly, the limitations of the project will be discussed, in order to clarify the validity of the findings.

According to the project's research questions, we have managed to develop a smartphone application that can be used to reduce bicyclists exposure to air pollution. Inspired from related research claiming that the choice of route effects bicyclists exposure to air pollution, combined with real-time or almost real-time data from sensors monitoring the air pollution level, the application is built on the concept of a smart city infrastructure, which at least requires that sensors are mounted or placed all around and throughout the city. This is necessary for the application to be able to receive real-time data about the air pollution level in the different parts of the city, to properly navigate the bicyclists through the least polluted routes. The application is therefore dependent on such an environment.

Compared to the related solutions presented earlier in this project, this solution differs on how it works. Regardless of it being a smartphone application or web application, most of the existing solution works by acquiring a personal mobile sensor that monitors the pollution level around the person carrying it. These sensors are generally connected to an application that utilizes the data from these mobile sensors, and then informs the user about the air pollution level around them or eventually warns them, if they are in a polluted area. The most significant and essential difference between the existing solutions and the solution presented in this project, is that the existing solutions gets their data from the personal sensors. This, first of all, requires that the users buy the sensors and carry them around with them. Secondly, they aren't able to provide users with an insight into the air pollution level of an area located outside the individual user's sensor's range, whereas the sensors used by the application presented in this project, are mounted on light poles throughout the city, which gives the opportunity to sense the air pollution level anywhere in the city, and ultimately be able to identify lesser polluted streets and routes. Finally, the target group of the application presented in this project is bicyclists and the main functionality of the application is that it allows users to enter addresses of their starting and end point, and have the application generate the shortest possible route, meanwhile ensuring that the user will not be exposed to a higher level of air pollution than the user is willing to. However, each solution has its advantages and disadvantages. The existing solutions, that utilize data from personal mobile sensors, are more flexible in the manner, that they do not require an environmental infrastructure of a smart city with sensors mounted everywhere, as the solution presented in this project does. They are independent and they can sense themselves, anywhere and all around the world. They require a personal incentive or aspiration rather than external motivators, such as municipalities or governments. People wanting to solve the problem of being exposed to air pollution can do this immediately by themselves. One solution is therefore not better than the other. They focus on solving the same problem, but they have different requirements, and they provide different experiences to their users.

Furthermore, the application requires the sensors to be mounted close enough to each other, for it to be able to segregate between the air pollution levels at a street level. The project focuses on solving the problem related to the research question and focuses primarily on development of the application, rather than the sensors or the air pollution data, which is supported by the usage of virtual or fictional sensors for the prototype testing in this project. Future related research could therefore consist of finding out the range of the data collected by the sensors, and how close the sensors need to be for the application to be able to effectively segregate between streets, in terms of air pollution level and navigating through the least polluted streets and routes. This project includes a first version of the application build to solve the problem stated in the research question. Looking ahead, the application can be further developed and improved by iterating through prototype testing and development. The results from our one and only prototype test, also shows that the users would like to have additional functionality or accessories that could be advantageous for the activities they carry out. Based on a suggestion from one of the test subjects, one example and usage of an additional functionality could be voice navigation to navigate while biking the route. This could potentially remove the users need to use the application while biking in order to navigate, as observed during the prototype tests of multiple users and highlighted in the analysis. Another simpler and more obvious example of an improvement, also based on suggestion from a test subject, could be to develop the application, so that it also informs the users about the negative effects of air pollution, as people might not be fully aware of these.

Finally, discussing the limitations of the findings discovered from the research carried out in this project, they are only valid for bicyclists in Denmark and for the city of Aalborg. There is potential for the application to be expandable and applicable to other cities and countries, and the use of the application is not limited to bicyclists, as it might also be usable, for example, for pedestrians but the research and results from this project does not cover the groundwork for this. The results are therefore limited to the aforementioned context. Furthermore, the results from our survey shows that our potential users, the target group, generally has a wide age range and a variety of different occupations, as they are in the ages of 15 to 66 and consist of people that are students, employed, unemployed and pensioners. Our results also show that our potential users most frequently and primarily consist of young people and students – just like the researchers. This could have been heavily influenced by our choice of channel, when distributing the survey. The survey was distributed by the researchers through one social media channel, Facebook, and to people in their social circle. Naturally, this could create and echochamber effect, due to which most of the potential users could have the same characteristics as the researchers. Even though sharing the survey on Facebook acquired us a lot of responses, which was a success, we could have tried to distribute the survey through multiple other channels, in order to get more varied responses by reaching out to different demographics. The potential users of the application, as described in this project, might therefore not be the ideal target group for a solution such as the one presented in this project. They should although be considered as the humans, which the application is designed for and developed to.

9 Conclusion

In order to answer the research question, we divided our work into three phases: the survey, the application and the prototype experiment. We started with an online survey that would allow us to better understand the potential users of the app and their motivations. The results of the survey gave us insight into who the potential application users would be what their motivations would be and if they would be interested in using the solution. The potential user group consists equally of men and women between 15 and 66 years old. The user group consists mainly of students, but employed, unemployed and pensioners would also be using the application. Most of the potential application users bike frequently – every day or a couple of times a week. The survey also provided us with the information that the potential users were concerned with the topic of air pollution. Furthermore, most of the respondents were interested in using a solution that would help them reduce their exposure to air pollution while biking.

The information gathered through analysis of the responses from the questionnaire combined with our findings from the previous project, contributed to great extent in the design of a prototype of the solution. As a result of the activities conducted in the early stages of the project, there was developed an Android application prototype that addresses the issue of bicycle commuters being exposed to air pollution. The prototype shows the bicycle commuter, the least polluted route omitting the points where the levels of air pollution are elevated. Therefore, if the commuter follows the route suggested by the application, they avoid polluted areas and consequently, reduce their exposure to air pollution.

With the prototype developed, there took place a prototype experiment. The prototype experiment was considered successful, as the participants did not report any serious issues while executing the experiment tasks with the use of the prototype. Furthermore, the experiment provided a useful information on how the prototype could be improved and developed further.

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Appendix 1 – Survey

Introduction

The following survey is a part of research for our Master Thesis at Aalborg University. The purpose of the survey is to understand the motivation behind biking, as well as to measure if people biking are interested in air quality and consequently if they would be interested in using an application that would provide them with current air pollution levels. The survey consists of 13 questions and it takes approximately 5 minutes to complete. Thank you for your participation.

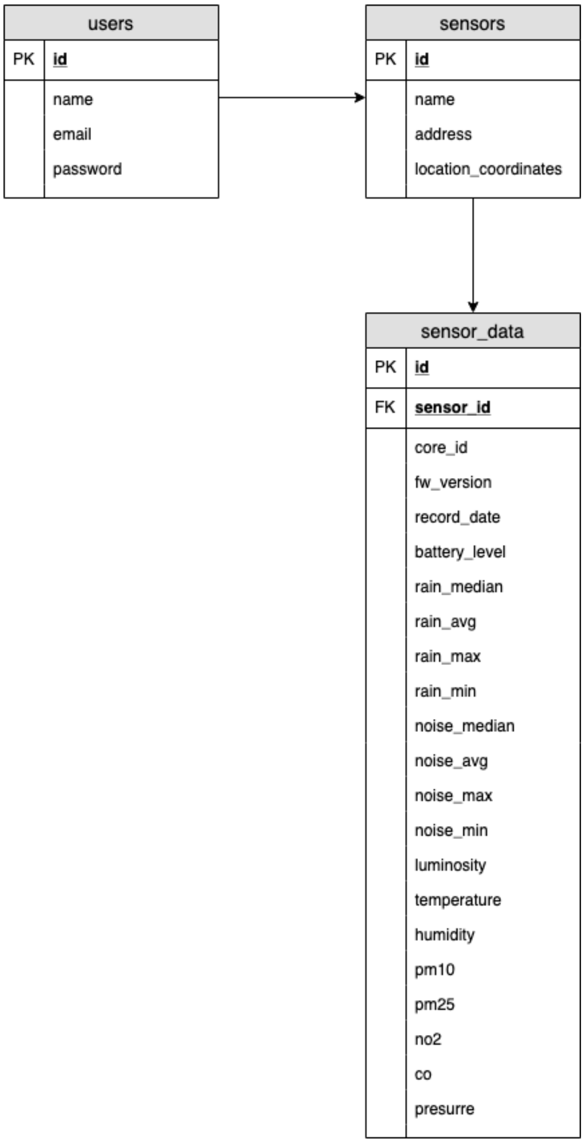
Structure

1. Age (Open question)
2. Gender
    a. Male
    b. Female
3. Occupation
    a. Employed
    b. Unemployed
    c. Student
    d. Pensioner
4. Which zip code do you live in?
5. How often do you bike?
    a. Everyday
    b. A couple of times a week
    c. Once a week
    d. A couple of times a month
    e. Less often than a couple of times a month
6. You most often use your bike as…
    a. a way to get to school/work etc.
    b. a way of exercising
    c. Other: _____________
7. What time do you bike most often? (Multiple answers possible)
    a. In the morning
    b. During working hours
    c. In the afternoon
    d. In the evening
8. On average, how much time do you spend biking a day (e.g. 20 minutes, 1 hour etc.)? (Open question)
9. How far do you usually bike?
    a. 0-5 km
    b. 5-10 km
    c. Above 10 km
10. The air quality is important to me.

a. Strongly agree
b. Agree
c. Neutral
d. Disagree
e. Strongly disagree

11. The noise pollution problem is important to me.
    a. Strongly agree
    b. Agree
    c. Neutral
    d. Disagree
    e. Strongly disagree
12. Would you use an application that would inform you about the current air pollution levels?
    a. Yes
    b. No
    c. Maybe
13. Would you consider changing your biking route if you knew that the rout you've chosen initially includes polluted areas?
    a. Yes
    b. No
    c. Maybe

Appendix 2 – ER diagram



Appendix 3 – MoSCoW

Prioritization of the application's functions for the development process has been done according to the MoSCoW rules, which suggest that they should be categorized into the following four categories: must have, should have, could have and want to have but won't have this time around (Benyon, 2014). All functions that are necessary and vital to solving the problem will be categorized as must have.

The must have functions will be used to evaluate if the development process was a success or not, as all functions in this category must be developed, see table 8.

#	Function
1	Display map
2	Display sensors
3	Get and display user's GPS location
4	Generate and display route
5	Display sensor data
6	Display exposure notification

Table 8: *Functions categorized as a must have*

Functions categorized as should have are important for the application's functionality, but the application will work properly without them to solve the problem, see table 9. These will be developed if there is enough time during development, otherwise, they will be left out of the project's scope.

#	Function
1	User registration
2	User login
3	Turn on/off exposure notification

Table 9: *Functions categorized as should have*

The could have functions are not a necessary part of the application for the application to work properly and solve the problem, see table 10. They are easily left out of the project's scope but will be included if there is enough time to develop the individual functionality.

#	Function
1	Edit user's name
2	Edit user's e-mail address
3	Edit user's password
4	Edit exposure willingness

Table 10: *Functions categorized as could have*

None of the application's functions were identified and categorized as want to have but won't have this time around.