COMPAIR

DELIVERABLE

D3.1 Sensor Strategy, Requirements Report

Project Acronym:	COMPAIR	
Project title:	Community Observation Measurement & Participation in AIR Science	
Grant Agreement No.	101036563	
Website:	www.wecompair.eu	
Version:	1.0	
Date:	12 May 2022	
Responsible Partner:	SODA	
Contributing Partners:	IMEC, TELR	
Reviewers:	Burcu Zijlstra (IMEC) Kris Vanherle (Telraam) External: Gitte Kragh Martine Van Poppel Karen Van Campenhout Andrew Stott	
Dissemination Level:	Public	X
	Confidential, only for members of the consortium (including the Commission Services)	

This project has received financial support from the European Union's Horizon 2020 Programme under grant agreement no. 101036563

Revision History

Version	Date	Author	Organisation	Description
0.1	05/04/22	Ajay Jamodkar	SODAQ	Initial structure
0.2	08/04/22	Burcu Zijlstra	IMEC	Inputs added
0.3	08/04/22	Kris Vanherle	Telraam	Inputs added
0.4	14/04/22	Kris Vanherle Daria Yakushkina Burcu Zijlstra	Telraam SODAQ IMEC	Group review
0.5	30/04/22	Daria Yakushkina	SODAQ	Final version
1.0	12/05/2022	Ajay Jamodkar, Jaap de Winter	SODAQ	Included comments and feedback

Table of Contents

List of Tables

List of Figures

Executive Summary

The D3.1 Sensor strategy and requirements report is a part of the COMPAIR deliverables in line with Annex 1 to the Grant Agreement. The current document presents the selection of the type of sensors with a focus on low-cost sensor units for the COMPAIR project, their specifications and integration possibilities. The report also pays special attention to the usability of these sensors for Citizen Science projects and how low-cost sensor can be used in a smart city environment as an intelligent data source.

The first few sections of the document provide a summary of the requirements set by the pilots in Athens, Plovdiv, Berlin and Flanders, and derive functional as well as non-functional technical requirements from them. Next, based on these requirements and a literature study, low-cost sensors that would be a suitable fit for the pilot projects are suggested.

Finally, the last two sections elaborate on the data validation and integration that will be undertaken in the future. It describes the compatibility of the data with other existing air quality sensor data, what kind of open standards will be used and how the metadata will be described. The re-usability of the sensor data includes a description of how data from the sensors will feed into the COMPAIR products (API use).

In terms of the current COMPAIR project, air quality sensors and traffic monitoring sensors are the main focus based on the selection results. This selection was made based on the performed analysis and initial requirements. Annex 1 and 2 of the document contains additional information on the conceptual devices and additional considerations about:

- Cost aspects
- Data type & connectivity

The sensor strategy section links to the pilot use cases, outlining what needs to be measured and how to use those sensors, generating open data for citizen science purposes and for local policy making.

Introduction

This document is about developing low-cost and user-friendly Internet of Things (IoT) devices to serve the needs of the Citizen Science (CS) initiatives in the project. Two main categories of sensor units are considered in order to measure, respectively, air quality and road traffic count. For air quality measurements, the report will first focus on selecting the appropriate low-cost off-the-shelf sensors for particulate matter (PM) and NO_2. The selection criteria will include sensitivity and expected accuracy, and cost and form-factor trade-offs to serve the specific application. These sensors will then be configured and integrated into DIY devices for the different CS pilots. Novel (more) reliable, low-cost NO_2 devices will be developed to complement the existing CS PM sensor network as presented in sensor.community. Moreover, low-power mobile personal devices will be developed for dynamic exposure. Regarding traffic count, the Telraam DIY sensors, which have proven to be successful in several citizen science initiatives, will be further improved to enhance user-friendliness.

Seven million people die every year from the effects of air pollution. The World Health Organisation (WHO) called it one of the most serious environmental threats to human health and has been a strong advocate of tighter air regulations. That is why it is essential to provide information about air quality in our surroundings as part of citizen services. Keeping this requirement in mind, the report will analyse various available solutions for measuring the air quality and how to deploy a user-friendly system that can equip citizens with the necessary tools to measure air quality themselves.

As part of the COMPAIR project, this document will focus on reasons behind the selection of the particular sensors and integration possibilities with other sensors to be used as part of the project. Further focus would be on suggesting improvements to the existing products to serve the needs of the citizens.

User requirements & objectives

As part of the COMPAIR project, user requirements were collected about air quality and traffic monitoring. The requirements were provided by representatives of the participating pilots in the COMPAIR project, who gathered these internally through surveys with citizens, feedback from team members as well as experience from past projects. The requirements were then processed by the project team and were summarised into user and technical requirements. The table below presents the user requirements for the air quality monitoring sensors as set by citizens and researchers.

Table 1: *User stories from citizens and researchers point of view*

#	Tool	Epic	User Persona	Action to be taken
1	Sensor requirements	sensor housing	As a citizen	I can carry the device while exercising without it bothering me (maximum similar to carrying a smartphone in terms of size and weight)
2	Sensor requirements	sensor housing	As a citizen	I can expose the device to all normal weather conditions (e.g. rain, wind, hail, cold & warm temperatures)
3	Sensor requirements	sensor housing	As a citizen	I can attach the device to various objects (e.g. bicycle, clothing) and easily attach and detach it
4	Sensor requirements	sensor housing	As a citizen	I can securely attach the device to e.g. my bike
5	Sensor requirements	sensor housing	As a citizen	I can see if the device is working via a simple status light
6	Sensor requirements	battery	As a citizen	I can easily charge my device daily (e.g. via USB, socket)
7	Sensor requirements	battery	As a citizen	I can count on the device to be fully charged within half an hour
8	Sensor requirements	battery	As a citizen	I can count on the device to last at least 24 hours without charging
9	App	Adjust settings	As a researcher	I want to adjust how often/frequently the sensors should actively measure
10	Sensor requirements		As a researcher	I can correlate the measurements to the GPS coordinates where the user has been
11	Sensor requirements	accuracy	As a researcher	I can rely on the accuracy of the sensor to meet the indicative label of VMM

.

The technical requirements are clearly divided into two parts. The first part focuses on the measurements of parameters related to air quality whereas the second part focuses on traffic monitoring.

Table 2: *Technical requirements for the sensors*

Pilots							
Description			Unit	Flanders	Berlin	Plovdiv Sofia	Athens
Air parameters & pollutants	PM10	Particulate matter <10um (micrometers)	µg/m3 (micrograms per meter cube)				
	PM2.5	Particulate matter <2.5um	µg/m3				
	NO_2	NO_2 gas (respiratory pollutant)	µg/m3				
	BC	Black carbon	µg/m3				
	O3	Ozone	µg/m3				
	ultrafine PM	Particulate matter <0.1um	µg/m3				
	Benzene		µg/m3				
	VOC	Volatile organic compounds	µg/m3				
	PAH	Polycyclic aromatic hydrocarbons	µg/m3				
	SO2	Sulphur dioxide	µg/m3				
	T	Temperature	degC				
	H	Relative humidity	%				
	Wind speed and direction		deg, m/s				
Vehicles	Number of vehicles		#				
	Type of vehicles		truck, car, bike				
	Speed		m/s				

high priority (3)
medium priority (2)
low priority (1)

Regarding air quality, the table shows that it is important for users to have a sensor that can be used in various weather conditions and as a static as well as a mobile device. Next it is important to citizens that the solution can easily become part of their daily routine without additional effort.

The next section will focus on available sensors in the market that can be used and provides a comparative study to suggest the ones that should be used for the development of an end product to match the user requirements.

Available sensors

This chapter provides an analysis of sensors for air quality monitoring and traffic monitoring. Each section describes available sensors based on the previously described requirements.

Air Quality Monitoring

In recent years, citizens are getting more and more aware about the adverse effects of poor air quality and are willing to take actions that can help to improve it. The first step in this direction is knowing about air quality and atmospheric pollution around them. Advancements in sensor technologies and development of the Internet of Things (IoT) has made it possible to significantly reduce the cost of portable sensors.

When it comes to measuring air quality, there are several parameters that need to be considered to determine overall quality of the air. For example, for an employer, it is advisable to measure carbon dioxide in addition to temperature and humidity, since high CO_2 concentrations are associated with a higher risk of viral infections and lower workforce productivity. Whereas, inside a house, it is recommended to measure temperature (T), humidity (RH) and carbon dioxide (CO_2), volatile organic compounds (VOCs) such as mold emissions, fine dust (penetrating from outside to inside) and formaldehyde (HCHO) (Sensirion AG, 2020).

This section will focus on the technical requirements set for air quality monitoring. Going through the specifications mentioned in table 2, it can be seen that almost all the pilots would like to measure PM10, PM2.5 and black carbon. Apart from that, most pilots would also like to measure NO2, O3, temperature and humidity present in the air. In order to limit the scope of the research, only sensors related to the parameters that have been marked highest/medium priority by 3 or more pilots have been included in the study.

As part of the COMPAIR requirements, these parameters were analysed based on input from the pilots and experts and were sorted in order of priority. The following subsections will go over these parameters and the sensors that are available on the market to measure them in order to make low cost portable air quality monitoring sensors. Further, sensors for each parameter would be evaluated not just for their functionality but also for other factors such as availability in the market, costs etc.

PM Sensor

Particulate matter (PM) can be defined as the air-suspended mixture of both solid and liquid particles. Generally, they are classified as coarse, fine and ultrafine particles. Particles having a diameter of between 10 μm and 2.5 μm are classified as coarse particles. Coarse particles settle relatively quickly whereas fine (1 to 2.5 μm in diameter) and ultrafine (<1 μm in diameter) particles stay suspended in air for longer. To get a gauge of the sizes of particulate matter, one can consider the size of a human hair which has an approx. diameter of 50-70 μm and PM10 is referring to particles smaller than 10 μm. These particles include dust, pollen and mold spores. PM2.5 refers to particles smaller than 2.5 μm and comprises mostly combustion particles, organic compounds and metals.

The main source of PM is both human and natural resources. Though it is important to study natural sources like forest fires, pollen, mold etc., it is essential to understand the human generated sources and its impact on the environment as well as human health.

When it comes to measuring PM air pollution in urban environments, it is important to focus on PM2.5 as they have been found to be most detrimental to human health. In recent studies, particles of diameter less than 2.5 μm have been observed in the brain and leading to neurodegenerative diseases (Maher et al, 2016).

As part of COMPAIR it is an essential requirement to measure particulate matter as part of the air quality monitoring. Fortunately, low cost sensor technology has given rise to several off the shelf PM sensors that can be used to create affordable but effective PM monitoring devices. However these sensors need to be assessed before using them for the development of an air quality monitoring device as they often show degradation depending on the environmental conditions.

PM Sensor Selection:

There are several studies available that have evaluated different sensors in the market and summarised their findings. Based on the requirements set by the COMPAIR pilots for the air quality monitoring device (portable yet accurate device), it can be seen that a good PM sensor has to qualify on 4 key criteria that are as follows:

1. The sensor should have low power consumption during the data acquisition phase so that it can be used in an IoT environment.
2. The sensor should be able to operate reliably under different ambient conditions.
3. The sensor should have low integration complexity with data acquisition hardware and should not require special conditioning components.
4. Finally, a good sensor would be able to report information other than PM values such as measurement errors, resolution etc.

Based on the criterias set above, two sensors that are found to meet all the specs are the SPS30 by Sensirion and PM2012 by Cubic sensors ltd. The basis of this selection was the research published by the Italian National Agency for New Technologies that has compared around 50 low cost PM sensors and evaluated them on several criterias such as accuracy as well as usability of sensors for development of IoT devices (Alfano B. et al, 2020). In order to be sure about our sensor choice for PM, another study by RIVM (Dutch National Institute for Public Health and the Environment) was referred to which has been studying low cost air quality sensors (RIVM, 2022). Over the years they have tested several sensors such as Shinyei PPD42, SPS 30 and Nova Fitness SDS011. RIVM recommends SPS30 to be used in the future as it is very good at measuring PM2.5 values (RIVM, 2021). Based on these studies SPS30 seems to be one of the best sensors to build a portable device that can be used for measuring air quality. Another advantage of SPS30 is that it has been found to be quite reliable when it comes to measuring PM values even when the environment is continuously changing (device containing the sensor is moving) due to its short sampling period of 1s.

Temperature and Humidity Sensor

An air quality measurement device is incomplete without integrating it with ambient temperature and humidity sensors. These values are not only required for user experience but are also valuable data points for researchers who want to run advanced algorithms to gain valuable insights and patterns. There are several types of temperature and humidity sensors available in the market which are suitable for the current use case. For selection of the best suitable sensor we focused on only low cost sensors that can be reliably integrated with IoT devices without adding much hardware complexity and their ability to be used in power savings mode when they are not measuring data.

Based on these criteria and our experience with using temperature sensors in past projects, we shortlisted BME280 and SHT31 as the most suitable sensors. As performance and ease of usage of both the sensors are at par, the final choice between BME280 and SHT31 will depend on their global availability as currently there is a global shortage of temperature sensors after the COVID pandemic. A quick scan of the market showed that BME280 is currently having very long lead times for procurement which makes SHT a better choice. Both the sensors can have very short sampling intervals making them suitable for measuring temperature and humidity even while moving.

Black Carbon Sensor

Black carbon (BC), a measure of soot, is part of a fine particulate matter air pollution which is formed by incomplete combustion of fuel, such as emissions from diesel engines, cook stoves and wood burning heaters, and contributes to climate change. A new collaboration is considered to add black carbon to the measured pollutants in COMPAIR. The Black carbon meter is developed by an air quality consultant at NGO Environmental Action Germany and his team. The device has a 3D printable casing and is based on sampling airborne particles on a filter and monitoring the attenuation of light at the collection area, which is translated into a black carbon concentration. A first evaluation of the sensor data which was provided by the potential collaborators showed that the low cost sensor-reference comparison dataset was too limited to draw conclusions on whether the sensors are usable during COMPAIR, and that BC emissions from diesel vehicles and wood burning may be not possible to distinguish. Additionally, unlike the other sensors included in the project, this type of sensor may need frequent maintenance (e.g. changing of filters, checking attenuation) and integration of sensor data into COMPAIR platforms may be challenging. These points are being evaluated and checked with the pilots to clarify whether such a sensor may be a viable option for COMPAIR.

NO_2 Sensor

Nitrogen dioxide (NO_2) is one of the six widespread air pollutants that are included in the international air quality standards. It is formed during combustion processes, such as fuel combustion from vehicles or industrial combustion from power plants and boilers (Chauhan et al, 1998). Indoors, NO_2 can also be emitted by kerosene or gas space heaters and gas stoves in substantial amounts (Hesterberg et al, 2009). Exposure to high levels of NO_2 can lead to a number of adverse effects including inflammation of the airways, reduced lung function and asthma, and is also linked to cardiovascular harm with significantly increased harm in susceptible populations (Kawamoto et al, 1993). Urban areas with high vehicle density are of particular concern for elevated NO_2 levels. Such local pollutants may not be captured at the source by the sparsely distributed reference grade measurement stations deployed by the government and health institutes.

Low-cost sensor technologies are becoming widespread for measuring NO_2 pollution in a fine-grained manner. However, the sensors suffer from susceptibility to environmental conditions (temperature, humidity) and cross-reactivity to other pollutants, leading to sensor drift and decreased sensitivity over time. This decreases the reliability of measured values and thus makes off-the-shelf low-cost sensors less suitable for a citizen science deployment.

NO_2 Sensor Selection

Several studies are available in literature that aim to evaluate various low-cost NO_2 sensors. However, comparison of sensor performance using a multitude of studies or reports is often challenging since sensor performance can greatly be influenced by the electronic architecture of the sensor unit, design of sensor enclosure or the deployment conditions (exposed concentration, presence of interfering pollutants, length of study). For the selection of NO_2 sensor to be integrated in CompAir, we focus on the LIFE VAQUUMS project lead by the Flemish Environmental Agency (VMM) which is a comprehensive study that covers selection of sensor components, their lab and field evaluation with a long field testing period exceeding a year.

During the project, 5 low-cost NO_2 sensors were selected and tested out of 10 candidates based on price, availability and expert advice. The sensors were tested both under laboratory and field conditions, by placing the low-cost sensors next to a reference-grade chemiluminescence analyser (42i ThermoFisher Scientific) operated according to standard EN14211. During the 400-day field test, sensors were tested according to data correlation with reference grade sensor, data availability, between-sensor uncertainty and expanded uncertainty, prior to and after calibration. When all of the quantified performance indicators are considered, the Alphasense NO_2-sensor B43F demonstrated acceptable performance. The following table shows the range of performance parameters derived by VMM.

***Table 3:** The range of performance parameters of the Alphasense NO_2-sensor (VMM)*

		Alphasense B43F	
	Unit	**Raw**	**Calibrated**
Coefficient of determination (R^2)		0.23 to 0.58	0.36 to 0.64
Mean bias	μg/m3	-14 to 5	5 to 10
Between sensor uncertainty	μg/m3 (%)	19 µg/m3 (91%)	15 µg/m3 (41%)
Expanded uncertainty at hourly limit value of 200 μg/m3	%		11 to 92%
Expanded uncertainty at daily limit value of 40 μg/m3	%		33 to 76%

The EU ambient air quality directive 2008/50/EG, which does not have a framework for evaluation of low-cost measurement methods, states a maximum relative expanded uncertainty for indicative NO_2 measurements at 25%. Few of the sensors, when evaluated at the hourly limit value, meet this measurement uncertainty target. The CEN/TC264/WG42 standardisation working group prepared a Technical Specification (TS 17660) that describes the test protocol, Data Quality Objectives (DQO) and performance requirements. The classification includes three classes, of which the lowest class (not related to regulatory measurements) can be used for CS projects and requires an expanded uncertainty of less than 200% at limit value (Certification of Sensors System for Air Quality Monitoring | Ineris Services, n.d.).

Alphasense sensor NO_2-B43F was also evaluated by the National Institute for Public Health and the Environment of the Netherlands (RIVM) in a 2017 study, which showed similar performance and stated that despite the existing limitations, the sensors can provide meaningful information (Wesselink, n.d.). Therefore we select this sensor to integrate into a newly to be developed air quality device. Combined with the optimum sensor unit electronics, design and calibration, the sensor can provide valuable insights regarding traffic and gas heating related pollutants in the citizen science deployments.

Ozone Sensor

Ground-level ozone (O_3) is a harmful air pollutant and is the main ingredient of smog. It is created by chemical reactions between nitrogen oxides (NO_x) and volatile organic compounds (VOCs), accelerated by the presence of solar radiation and high temperatures. Exposure to elevated concentrations of ozone is associated with a wide range of respiratory diseases such as pneumonia, asthma and allergic rhinitis (Ebi, K. L., & McGregor, G. (2008)). Five types of ozone sensors from various suppliers were also evaluated and field tested in the LIFE VAQUUMs project mentioned in the previous section. Considering all the evaluated parameters (Reference correlation, between-sensor uncertainty, data availability and expanded uncertainty), the Alphasense OX-B431 shows promising results in the field tests. It is noted that the Alphasense sensor measures the sum of NO_2 and O_3 gases, therefore in order to derive the ozone concentration NO_2 measurements also have to be included in the monitoring plan.

Since ozone can react with compounds emitted from vehicles (NOx) and get removed from the air, ozone pollution is more prominent in rural areas than in cities. Therefore a critical evaluation needs to be performed to determine whether adding ozone measurements to the urban microenvironment monitoring in the COMPAIR project will provide significant insights on air pollution.

Traffic Monitoring

The currently available traffic counting sensors used in a citizen science setting, are limited to manual counting using apps and the current Raspberry Pi based Telraam sensor which was launched in 2019. The following table represents additional user stories for traffic sensors that were formulated by the COMPAIR pilots:

***Table 4:** Additional user stories for traffic sensors*

#	Tool	Epic	User Persona	Action to be taken
12	Policy Monitoring Dashboard	Display Traffic	As a citizen	I can inspect the current traffic in different modi
13	Policy Monitoring Dashboard	Display Traffic	As a citizen	I can inspect the historical traffic in different modi
14	Policy Monitoring Dashboard	Display Traffic	As a citizen	I can compare the traffic between 2 time windows
15	Policy Monitoring Dashboard	Manage dashboard projects	As a citizen	I can select traffic sensors

Traffic sensor

The basis of the traffic counting sensor in COMPAIR is the Telraam sensor. Telraam was initially developed by Transport and Mobility Leuven (TML) and due to its success, was spun-off from TML into a separate company, Rear Window, partner in COMPAIR. The Telraam sensor has been improved in scope of the WeCount project. A more elaborate description of the final Telraam sensor as completed in WeCount is summarised in this WeCount project deliverable (Final WeCount Platform and Sensor Kits - DEM, 2021).

However, the conclusion of the WeCount project was that the current Telraam sensor was not fully suitable for an inclusive and immersive citizen science project. Major modifications are needed that would lead to a completely new design. The sensor design strategy for the traffic counting is thus building on the ongoing development of a new Telraam v2.0 sensor design, which has been further elaborated in the sensor strategy section of this document.

Sensor Strategy

Air Quality Sensor Design for COMPAIR

In the previous sections, user requirements were analysed and various sensors were suggested that can be used for the development of a low-cost air quality monitor to meet the citizen science requirements. It is clear from the sensor selection section that except for Black carbon and ozone measurements, all other parameters can be integrated in the form of an IoT device that suits the needs of citizens for measuring Air Quality in their surroundings.

After observing the suggested choices of sensors and scanning available IoT development boards in the market, the current version of the SODAQ Air was found to be well suited as a base development board for the designing the Air Quality monitoring sensor. It uses SPS30 as a PM sensor and SHT31 for temperature and humidity measurements. Annex I provides more details about its current specifications and functionality. One of the key advantages of using SODAQ AIR for COMPAIR pilots is that it already meets several of the requirements as set by the pilots such as the ability to measure air quality while being stationary as well as when being in motion. Currently, it is also used by the University of Utrecht for a European research project and in several other pilots with municipalities for measuring air quality by citizens in the Netherlands.

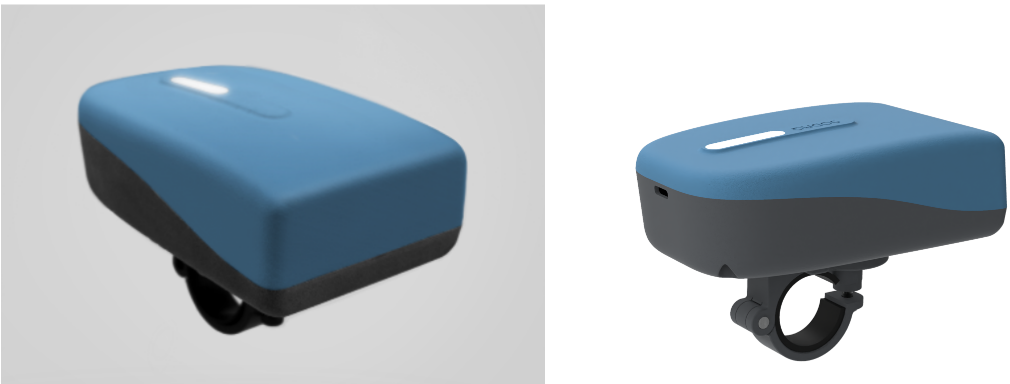

Figure 1: SODAQ AIR device

The current version of SODAQ Air (as shown in Figure above) has been designed keeping in mind that the device will be used by users from all age groups to collect air quality data about their surroundings. The device resembles a slightly larger bicycle bell and measures location of the device, the concentration of particulate matter (PM1.0, 2.5,10), temperature and humidity.

The sensor transmits this data to the cloud via LTM/NB-IoT networks and thus the user can use it in most of the European nations where there is IoT network coverage. There are LED lights on the device that instantly display the local conditions, battery status and notify the user of the air quality. The data collected from the devices is sent to a cloud environment where both the individual and collective results are displayed on a global map. Instead of a rechargeable battery, the device has a supercapacitor which can be recharged faster than a

Lithium Ion battery. Supercapacitors also increase the lifespan and durability of the device as they can have far more charging and discharging cycles as compared to regular batteries.

Looking at the requirements set by COMPAIR in Table 1 and features of SODAQ AIR as presented in the previous section, it can be seen that most of the requirements (in terms of usability topics 1-6 from table 1) are already present in the current design of AIR.

Next, on analysing the essential parameters that are expected to be measured, one can see that the current version of AIR cannot measure NO_2, black carbon and O_3. As the next step, feasibility of integrating the NO_2 sensor in addition to the PM and T&H sensors will be evaluated. We propose to add NO_2 sensing functionality to the sensor unit and optimise it for a citizen science deployment. The new sensor design will use the highest performing low-cost NO_2 sensor as selected in the previous section and will be designed to minimise the interference of environmental conditions. As there is already a temperature-humidity sensor present, it will allow calibration of the sensor based on local microenvironments. This will ensure baseline reliability of the sensor.

On the other hand, in our preliminary investigation we see major challenges with integrating currently available O_3 and black carbon sensors. They cannot be easily integrated to AIR without significantly compromising on the size and power consumption of the device. Hence for the time being it is suggested that if it is essential to measure these two parameters, separate sensors like BCmeter and AirSensEUR or ACT400 by Vaisala can be installed at various locations in the cities. The data from these sensors then can be combined with the data from other mobile devices in the cloud.

There are some more features like ability to charge fully in half an hour, working for 24 hours on a single charge and ability to change settings like data frequency from the app which are not yet present. These requirements need to be evaluated technically to understand if all of them can be met together along with other functionalities. The main challenge foreseen here is successfully developing a low cost and low power device which still meets all other functional requirements such as user friendliness, portability and weather proofness.

The image below shows a concept design for the development of the device for the COMPAIR pilots that includes a NO_2 sensor in it. It is a preliminary design which needs to be critically evaluated to understand if it can meet various requirements set by the pilots as well as technical constraints. In the next phase of the project, apart from analysing and refining the requirements, detailed concepts will be developed for validation of the set requirements. In order to test these concepts tools like 3d printed casings will be used.

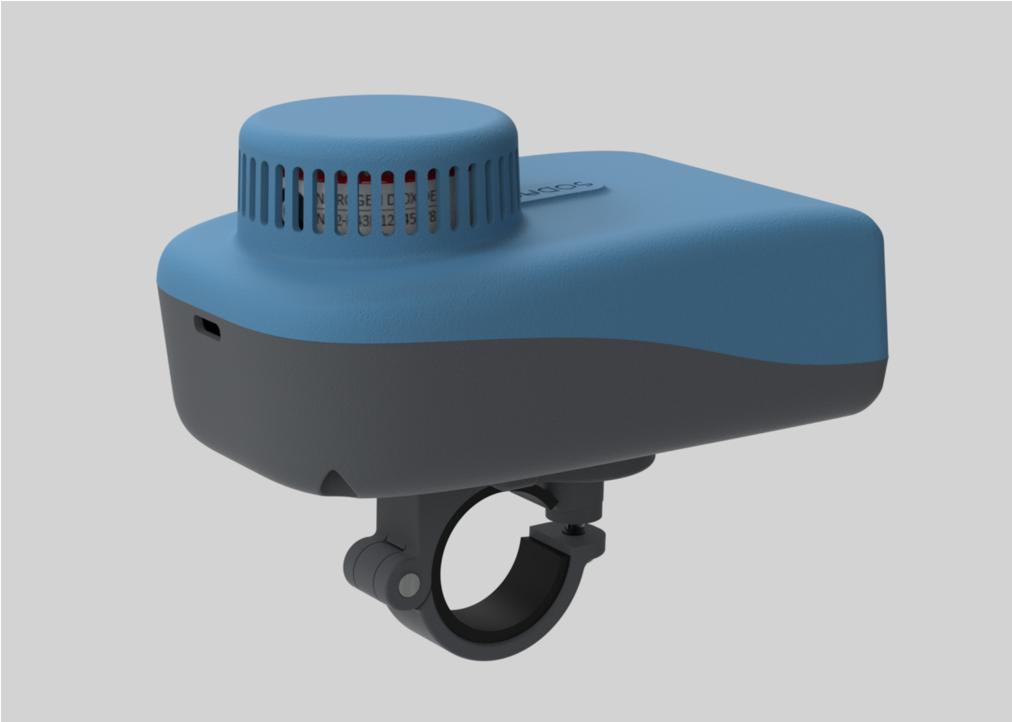

Figure 2: SODAQ concept of combined design

In terms of other features, while redesigning the hardware, the impact of adding a NO_2 sensor on battery performance will be evaluated. Further, it will be assessed whether it is possible to include fast charging options and battery lifetime without affecting the cost and form-factor of the final product.

Timeline: Air Quality Sensor

This section provides a rough timeline for the development phase of the Air quality sensor using the SODAQ AIR as the basis for further development. A more detailed planning and discussion of the sensor development challenges will be presented in the next deliverable D3.2.

- Refinement of requirements and detailed planning: Q2 2022
- Conceptualization Industrial Design and Hardware: Q3 2022
- Industrial design and hardware redesign: Q4 2022
- First 3d printed prototypes ready for (internal) testing: Q1 2023
- Continuous improvement, integrate user feedback and testing results over a period of 6-9 months: Q1 2023 - Q3 2023
- Redesign for production: Q3 2023
- Ready for production (to be made available for deployment in large volumes): Q4 2023

Traffic Monitoring Solution for COMPAIR

The basis of the traffic counting sensor in COMPAIR is the Telraam sensor which was developed by TML and is currently further developed by Rear Window, partner in COMPAIR. The current Telraam sensor uses a Raspberry Pi 3A+ as a hardware platform and Python OpenCV object detection algorithms to detect traffic. This combination has proven to be highly efficient at delivering a low-cost alternative for traffic counting technology, with a reasonable accuracy. It sends data over wifi and sends data every 1 hour. Further, the data is then processed in the cloud and can be shared using API's.

Figure 3: Original Telraam sensor as used in WeCount

The Telraam sensor and hosting platform were thoroughly tested and improved in the H2020 WeCount project, with the aim to test and improve the sensor in an immersive citizens science setting. Although multiple improvements were made to increase ease of use, a key conclusion at the end of the project was that the Telraam sensor as is, was not sufficiently robust and user friendly to be used in an inclusive citizen science setting and that a new sensor design was needed. The feedback from WeCount project as well as detailed analysis of it which is the stepping stone for the next version of the Telraam sensor is discussed in detail in Annex 2.

With these findings from the initial Telraam development and the WeCount project in mind, we established the sensor strategy for the traffic counting sensor in COMPAIR. First and foremost, COMPAIR is a citizen science project. This means any sensor technology to be used by citizens needs to be designed for handling and installation by citizens. Design choices from the user perspective are heavily influenced by the experience of Telraam in the WeCount project.

In order for sensors to be successfully used in a citizen science project, the sensor must be easy to use and install. This is absolutely essential to build an inclusive community of citizen scientists that go beyond the "usual suspects" of highly educated, tech-savvy citizens. It is COMPAIR's objective to indeed employ such an inclusive approach.

This starting point has strong implications for the sensor design from a useability perspective. We have identified the following key requirements for a next generation Telraam sensor:

1. To ease the installation, an easier physical mounting procedure, preferably an integrated camera/computing system without a camera cable, to physically install the sensor device. Currently, the mounting to the window is left to the participants, using different options. We need to replace this with a more simple and clean-cut procedure.

Figure 4: Traffic sensor mounting

2. To avoid manual handling by the user for the installation, in particular the selection of the "field of view" of the camera-system. In the current Telraam system, users have to set the camera-angle themselves by manually moving the hinge of the camera mount to the proper position, oriented towards the street. The field of view can be checked from the live feed while setting up the device and connected to it in hotspot-mode. This procedure requires linking to the live feed of the camera system (non trivial for non-tech users) and leaves room for errors. Most importantly, it adds another single point of failure (i.e. wrong field of view setting) rendering data collected useless.

3. Use of wifi is to be avoided for multiple reasons. First of all, configuring the sensor to connect to the local wifi-network is an extra installation step requiring an extra effort from the citizen scientist. It is not trivial for non-technical users to perform this configuration, creating an additional burden in the deployment that risks an unsuccessful installation. Moreover, in case there is a change to the local wifi network of the owner, a reconfiguration is required on behalf of the user. To conclude, wifi is not always reliable as a communication protocol which may require user interactions post installation (e.g. reboot the device), again requiring high commitment from the user, risking drop-outs which is fatal for a sensor designed for long-term measurement campaigns.

4. For the current Telraam sensor, connecting the data collected with the right street segment in the database, requires a manual input from the user. This again gives an opportunity for human error and entails an installation effort on behalf of the user. A new sensor should consider including a GPS & compass module which allows

automatic road segment selection in the back-end, requiring no intervention from the user for the setup.

Figure 5: Telraam dashboard

5. Finally, as the sensor is installed in a clearly visible location (i.e. a window), an elegant and professional appearance is an important factor as well. The current sensor looks very much “DIY”, which is indeed appealing for the DIY community of tech-savvy users. However, a DIY appearance does not appeal to the majority of users COMPAIR aims to attract. In fact, it has been a reason for users to stop hosting a Telraam sensor, as is evident from feedback received from current drop-outs. Moreover, the current sensor is (literally) a black box with no possibility of engaging with the user. A new sensor should at least be visually more appealing, ideally with options for the user to engage with it. An interface such as a dynamic display is an option to consider for a new Telraam sensor.

The above design considerations can be broadly summarised as a need for a true “install and forget” device. Sensor installation can require some effort on behalf of the user, but it should not require any technical knowledge a priori. Stability after installation is paramount for retention. A nice and professional device will further increase the uptake, engagement and sense of being part of a community of professional citizen scientists.

Timeline: Telraam v2

Many of these design considerations above have already been made in the wake of the WeCount project and have already been initiated by Rear Window in a new sensor development trajectory. The consultation of pilot users in COMPAIR reaffirmed the sensor design considerations and further tweaked design choices.

Because the development trajectory was already started before the COMPAIR project started, we have a head start in the development of this new sensor for use in COMPAIR. Timeline below summarises the key milestones and timings for a Telraam v2 design strategy.

- First prototype ready for (internal) testing in a first pilot: 2022 Q4
- Continuous improvement, debug sensor v2.0 over a period of 6-9 months: 2022 Q4-2023 Q3

- Completion of an improved version v2.1, based on user feedback from the first pilot deployment, available for deployment in large volume (replication cases): 2023 Q3

Data validation & calibration

As a part of COMPAIR, IMEC will use and further develop air quality sensor calibration algorithms based on combining low-cost sensor data, environmental data and reference grade sensor data located at a distance to the low cost sensors. This approach, developed and validated in several testbeds in Belgium and The Netherlands (Hofman et al, 2022) is deployed as a cloud-based calibration service that improves the accuracy of sensor data in real-time and makes the calibrated data available to COMPAIR visualisation platforms. Existing knowhow of IMEC on sensor calibration is based on particulate matter and NO_2 sensors with similar measurement principles but different manufacturers, in countries that have a relatively dense network of high-end reference sensors. Thus, we expect that the calibration strategy may have to be modified depending on the pilot location, which will have varying weather conditions (e.g. hotter summer months) and a more sparse network of reference sensors. Calibration algorithms for a particular use case can only be validated using field sensors deployed at the region of interest. Therefore an initial evaluation of the calibration algorithm will be done using data from Flanders, in a VMM benchmark study planned between June and September 2022. For the other pilot regions, the calibration algorithm will be validated when the first sensors are deployed, using a subset of the sensors deployed at high-end reference stations.

Data integration

Sensor data and metadata between the SODAQ and imec platforms is provided in JSON format. The data currently includes hardware-related information, version, timestamp, battery voltage, microclimate measurements, PM measurements, satellite and location-related information, and motion status, as observed below.


```
{    "imei": 352656108696991,
     "versionMajor": 0,
     "versionMinor": 1,
     "versionRevision": 0,
     "timestamp": 1648117545852,
     "voltage": 3346,
     "temperature": 24.554054260253906,
     "humidity": 25.68702507019043,
     "pm_1p0": 22.40703010559082,
     "pm_2p5": 23.848142623901367,
     "pm_10p0": 23.997222900390625,
     "sats": 17,
     "h_acc": 1361,
     "v_acc": 1753,
     "lat": 52.0757963,
     "lon": 5.1858017,
     "rsrp": 46,
     "motion_status": "",
     "gps_utc_epoch_time": "",
     "imsi": "",
     "iccid": "",
     "version": "v0.1.0",
     "name": "352656108696991",
     "device_timestamp": 1648117543    }
```


In terms of data standardisation, implementing the Open GeoSpatial Consortium (OGS) SensorThings API standard is considered. SensorThings API is a non-proprietary, platform-independent international standard to interconnect IoT devices, data and applications over the web. It is built on widely adapted open standards, such as web protocols and OGC sensor web enablement (SWE) standards, which includes the ISO/OGC Observation and Measurements data model. OGC SensorThings API provides a sensing functionality to manage and retrieve observations and metadata from the IoT system, and it provides a standard way of parametrizing task-able IoT devices. It follows REST principles, uses efficient JSON encoding for resource-constrained IoT devices, MQTT protocol, flexible OASIS OData protocol and URL conventions. The applicability of such a standard will be evaluated along with the finalised platform and application requirements.

Data from the Telraam sensors would be used to provide interesting insights about Traffic on the streets. This data can be even further processed to correlate with Air quality data to find useful patterns. The traffic counting Telraam v2 sensor will focus on getting data that can be used to distinguish multiple modes of traffic: such as car, bike, pedestrian and heavy vehicles. The goal with the new design of the sensor is to do it with increased accuracy and further distinction between modes, specifically with light/heavy freight, buses and motorcycles as separate categories. There are also possibilities to add more options like Traffic speed but this is currently not a user requirement specified by the COMPAIR pilots.

One limitation of the current Telraam sensor is that it can only count traffic during daytime and developments are planned such that the new Telraam sensor should be able to at least collect basic counting data in dark conditions, for example only collecting traffic counts for cars or an aggregate category, while accepting a lower accuracy.

For connectivity, Telraam will focus on moving away from wifi (see Annex 2) and choose a stable communication protocol that does not require a setup/configuration by a user. Further, the time resolution of data would be increased to every 15 mins (from 1 hour), allowing for more fine-grained assessment of mobility "events".

All the data coming from sensors will be pushed to a cloud environment, for easy visualisation and redistribution to third parties, within or outside the project team, via API's. The Telraam data-infrastructure is designed for the current Telraam sensor and is also fit for purpose to ingest and process data from the new sensor design. The current API is used by third parties and is well documented.

A point of attention is to ensure the current data architecture is fit to scale and allows for new API end-points to be developed as project dashboards require. API design is mostly outside of the scope of the sensor strategy in this deliverable, but it does have some implications for sensor design decisions. For example, the need for a temporal granularity of 15' does not only require an adaption of the API, but -obviously- also a sensor which is able to produce data with a granularity of 15 minutes.

We summarise the key elements in the Telraam v2 sensor design strategy, using the MosCoW method:

Table 5: *The summary of Telraam sensor key elements*

MoSCoW	Description
Must have	● Easy physical mounting procedure ● Data connectivity using LoRa (or LoRa-like) protocols ● Accuracy of car countings > 90%
Should have	● Wide angle lens requiring no manual intervention from user ● Unit "fly-away" cost <150€ ● Accuracy of car countings > 95% - other modes > 85% ● Power consumption <5 Watt ● (basic) counts when dark - at least for cars
Could have	● Automatic location & orientation fix ● Low energy consumption & power independent (e.g. solar/battery powered)

	- Split between more categories (at least light/heavy freight, bus, motorcycle) - Interactive screen (touchscreen/LCD/e-ink) - Speed calculation
Won't have	- High-end hardware (e.g. Jetson Nano or Google Coral) - Other indicators apart from traffic counts & speeds

The modified Air quality sensor is not as far ahead in the development process as compared to Telraam and there are still open topics related to the requirements set by COMPAIR pilots that conflict with the technical possibilities. SODAQ is working on refining those requirements and is discussing these topics with the pilots as a next phase of this project (Q2/Q3 2022). Based on the outcome of these discussions a similar table will be generated.

Conclusion

One of the key goals of the COMPAIR project is to develop IoT devices for citizens which can be used to measure air quality and to monitor traffic in an urban environment. In this deliverable, based on the requirements set by the pilots, a sensor and data integration strategy has been proposed. There are two main IoT devices that need to be developed for COMPAIR pilots to be used by the citizens. First one is a portable air quality monitoring device and the second one is a traffic monitoring device that can be easily installed at home on windows.

In the case of the Air Quality monitoring device, after analysing the requirements set by the pilots for various parameters to be measured, it was seen that Particulate Matter (PM), NO_2, temperature and humidity are the most important ones. After going through the literature and keeping in mind the functional requirements, for each of the parameters sensors were selected. For PM values SPS30 by Sensirion, Alphasense sensor NO_2-B43F for NO_2 and SHT31 for temperature and humidity were found to be the best sensors. Apart from that, two other parameters (black carbon and O3) were analysed but for the time being available sensors in the market cannot be integrated in a portable sensor device without really affecting the user friendliness of the device. That's why these two values will not be measured by the portable devices and, if required, separate existing stationary sensors can be installed in various locations. Further, the choice of sensors and requirements set by the pilots led to the conclusion that the current version of the SODAQ AIR is one of the best devices available on the market to carry out the development of the Air quality monitoring device. The SODAQ AIR which has an open source hardware design will be used as the base development board for the next stages of the development.

Next in terms of development of the traffic monitoring solution, it was found that currently available traffic counting sensors used in a citizen science setting, are mostly limited to manual counting using mobile Apps and some DIY solutions. The only solution that was found to be reliable yet scalable was the Telraam sensor which is also being used in the WeCount project. After analysing the user requirements, it was also seen that the current Telraam sensor is not fully suitable for an inclusive and immersive citizen science project and therefore major improvements will be carried out under the COMPAIR project to make it suitable for the citizen science use case.

When it comes to data handling from these devices, its validation and integration, IMEC will be playing a key role. As part of the COMPAIR, IMEC will use and further develop air quality sensor calibration algorithms based on combining low-cost sensor data, environmental data and reference grade sensor data located at a distance to the low cost sensors. Next, the data from the Air quality sensors and Traffic monitoring will be processed in the cloud and information would be made available to COMPAIR visualisation platforms. In terms of data standardisation, a suggestion is made to implement the Open GeoSpatial Consortium (OGS) SensorThings API which is a non-proprietary, platform-independent international standard to interconnect IoT devices, data and applications over the web.

Finally, it can be seen that this is the first step in the development of a combined air quality and traffic monitoring solution to be used by citizens. In the next phase of the project, first of all requirements will be critically evaluated and will be frozen so as to start the development of the final concept for the Air Quality monitor sensor. For Teleraam this process has already begun.

References

Books/Articles

Maher B., Imad A. M., Karloukovski V., (2016) Magnetite pollution nanoparticles in the human brain https://doi.org/10.1073/pnas.1605941113

Alfano B., Barretta L., (2020) A Review of Low-Cost Particulate Matter Sensors from the Developers' Perspectives https://doi.org/10.3390/s20236819

Sensoren voor luchtkwaliteit RIVM, (Feb, 202) Sensoren voor luchtkwaliteit

Chauhan, A. J., Krishna, M. T., Frew, A. J., & Holgate, S. T. (1998). Exposure to nitrogen dioxide (NO_2) and respiratory disease risk. Reviews on Environmental Health, 13(1–2), 73–90.

Hesterberg, T. W., Bunn, W. B., McClellan, R. O., Hamade, A. K., Long, C. M., & Valberg, P. A. (2009). Critical review of the human data on short-term nitrogen dioxide (NO_2) exposures: Evidence for NO_2 no-effect levels. Critical Reviews in Toxicology, 39(9), 743–781. https://doi.org/10.3109/10408440903294945

Kawamoto, T., Matsuno, K., Arashidani, K., Yoshikawa, M., Kayama, F., & Kodama, Y. (1993). Personal exposure to nitrogen dioxide from indoor heaters and cooking stoves. Archives of Environmental Contamination and Toxicology, 25(4), 534–538. https://doi.org/10.1007/BF00214345

Hofman, J., Nikolaou, M., Shantharam, S. P., Stroobants, C., Weijs, S., & La Manna, V. P. (2022). Distant calibration of low-cost PM and NO2 sensors; evidence from multiple sensor testbeds. Atmospheric Pollution Research, 13(1), 101246. https://doi.org/10.1016/j.apr.2021.101246

Ebi, K. L., & McGregor, G. (2008). Climate change, tropospheric ozone and particulate matter, and health impacts. Environmental Health Perspectives, 116(11), 1449–1455. https://doi.org/10.1289/ehp.11463

Final WeCount Platform and Sensor Kits - DEM. (2021, May). WeCount: Citizens Observing UrbaN Transport. https://we-count.net/_uploads/D3.2-Final-WeCount-Platform-and-Sensor-Kits-DEM.pdf

Websites

Sensirion AG (2022) Indoor Air Quality Brochure https://sensirion.com/media/documents/87EDEFB9/62601F86/Sensirion_Indoor-Air-Quality_Brochure.pdf

PM2.5 Sensor for HVAC and air quality applications SPS30 (2022) https://sensirion.com/products/catalog/SPS30/

Laser Particle Sensor-PM2012 (2022) https://pdf.directindustry.com/pdf/cubic-sensor-instrument-co-ltd/laser-particle-sensor-pm2012/54752-905606-_3.html

National Institute for Public Health and the Environment Ministry of Health, Welfare and Sport (2022) Measuring together https://www.samenmetenaanluchtkwaliteit.nl/

Black carbon meter (BCmeter) product page https://bcmeter.org/

AirSensEUR (JRC) https://www.samenmetenaanluchtkwaliteit.nl/apparaten-en-kits

Bologna, C. (2019, October 31). Why some people with anxiety love watching horror movies: https://www.huffpost.com/entry/anxiety-love-watching-horror-movies_l_5d277587e4b02a5ad57b59e

Wesselink, J. (n.d.). Meten van NO_2 Met Goedkope Sensoren: https://www.samenmetenaanluchtkwaliteit.nl/document/rivm-notitie-meten-van-no2-met-goedkope-sensoren

SODAQ AIR map dashboard https://airmap.sodaq.com/

Certification of sensors system for air quality monitoring | Ineris services. (n.d.). Prestations.Ineris.Fr. https://prestations.ineris.fr/en/certification/certification-sensors-system-air-quality-monitoring

Live traffic counting by citizens http://we-count.net/

BME280 Humidity sensor product page https://www.bosch-sensortec.com/products/environmental-sensors/humidity-sensors-bme280/

Digital humidity and temperature sensor SHT31-DIS-B product page https://sensirion.com/products/catalog/SHT31-DIS-B/

Kendryte K210 product page https://canaan.io/product/kendryteai

Annex 1: SODAQ Air

Figure 6: SODAQ AIR for air quality monitoring

SODAQ started developing the second version of SODAQ AIR motivated by its vision for a global air quality network and combining it with our learnings of the Sniffer bike project,. The device is a smaller, smarter version of the sensor that has a new mounting system, making this AIR the most user-friendly model to date. It has been designed keeping in mind that the device will be used by users from all age groups to collect air quality data about their surroundings.

Device Behaviour

The device resembles a slightly larger bicycle bell and measures the location of the device, concentration of fine particulate matter (PM2.5,1.0,10), temperature and humidity. The data is then transmitted to the cloud via LTM/NB-IoT networks. The frequency of sending data depends on whether the device is moving or stationary. The device can act as a static environmental sensor to measure air pollution from a fixed location over an extended period of time, making it the ideal solution to be used at home or in the garden. LED lights on the device instantly display the local conditions and notify the user of the air quality.

Static vs Mobile

The device supports two modes of data collection and transmission. When the device is stationary, it collects data about the air quality every 5 minutes. It first enables the sensors and lets them warm up for sufficient time before collecting data. The collected data is sent over UDP to the cloud. Currently, no backup of the readings are kept on the device. When not measuring the device goes to deep sleep mode to save power.

In the mobile mode, when triggered by motion, the device first connects to the network, enabling the sensors (for warm-up). Then it starts collecting data and sending data over UDP every 10 seconds. If the device remains static, basically no motion is detected for a period of 3 minutes (configurable in the firmware) then the device will disable all the sensors and disconnect from the network.

Firmware Over the Air

The device has the capability to receive firmware updates and thus it is possible to release new updates to the device in the future.
There are are two ways the device can receive an update:

1. When the device powers on or resets because of user intervention, it is going to perform a FOTA(Firmware Over the Air) operation. If there is no new update then the device will perform its normal operation.
2. Another input to the device is when it gets connected to the power. At that point the device will try to perform a FOTA update. If a FOTA is available then the device will enter the FOTA state.

Data Visualisation

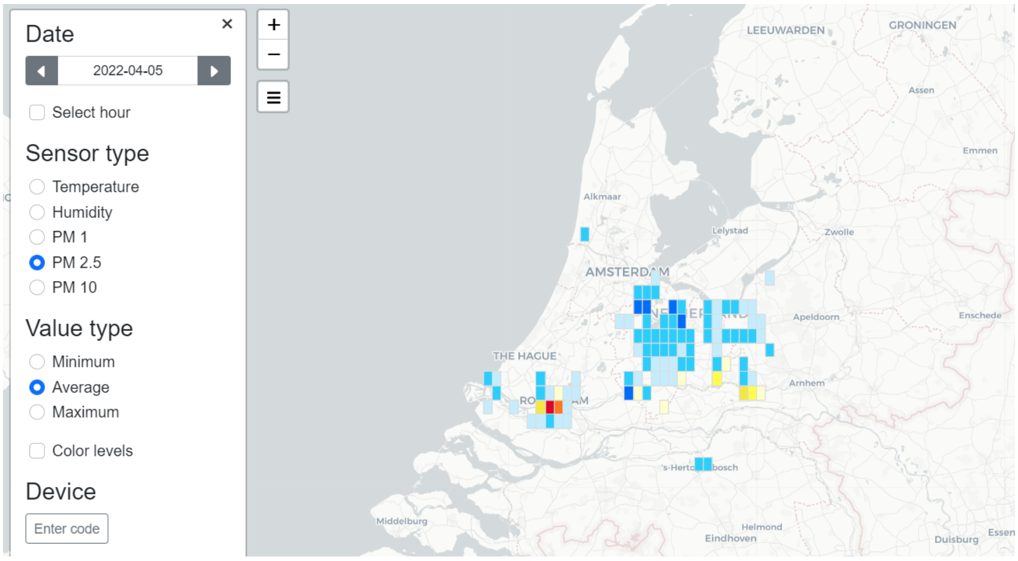

Figure 7: SODAQ AIR map dashboard

The data collected from the devices is sent to a cloud environment where both the individual and collective results are displayed on a global map. Using the global map, users can see air quality anywhere in the world, and by using a unique identifier code linked to their device, users can see the air quality of their own routes while maintaining complete anonymity. Because the sensor also measures temperature, it can be used to detect temperature patterns and from them discern heat islands; urban areas which accumulate heat potentially leading to heat stress.

Cost Considerations

The device has been designed keeping the longevity and sustainability of the devices. That's why the bill of material has been kept to the minimum and design features like screws have been used wherever possible. This also allows to promote repairability of the devices in the long term. Instead of a battery, the device has a supercapacitor which can be recharged, increasing the lifespan and durability of the device. Table below summarises the main hardware components used on the device.

Table 6: Hardware capabilities of Air

Major Features	Component
LTE-M/NB-IoT Modem	NRF 52840
GPS	Ublox
PM Sensor	SPS30
Accelerometer	LIS2DH12TR
Temperature and Humidity sensor	SHT 31
Power Source	LIC Super cap 10500 mAh

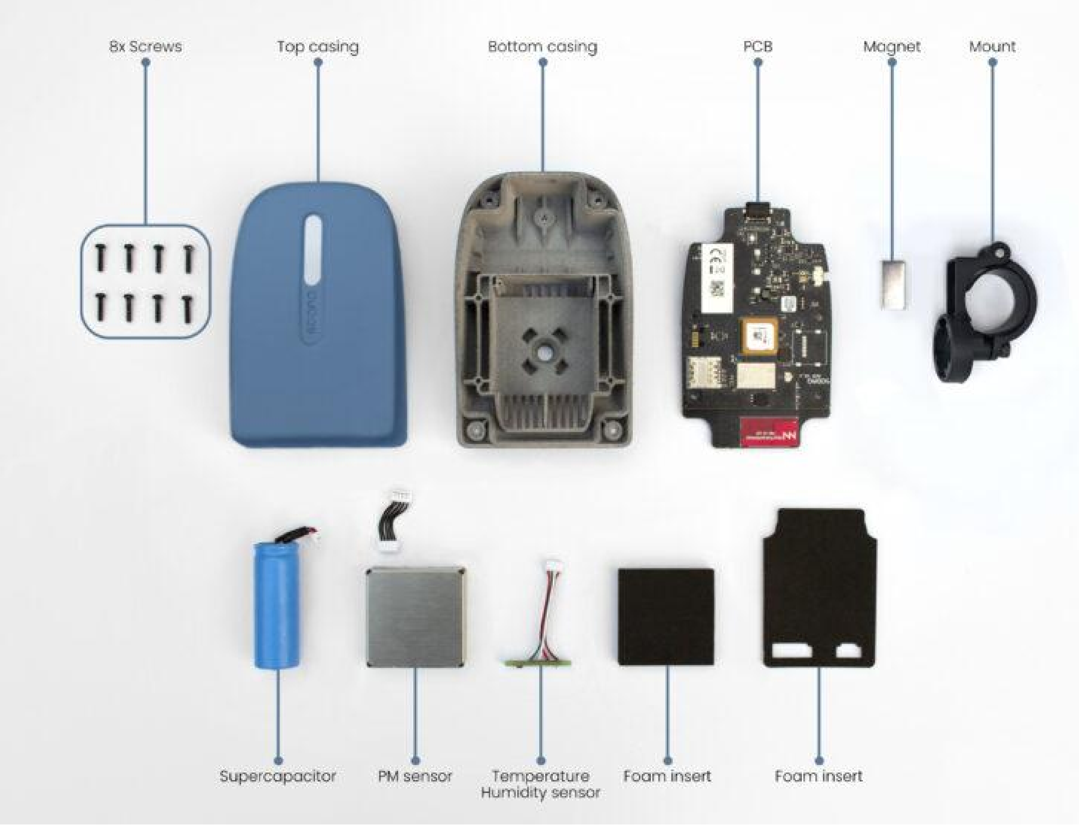

Figure 8: SODAQ AIR components

The price of the sensor has more than halved since the first prototypes. The AIR was created with a Creative Commons (CC) licence, to further the reach and spread of the global air network. By creating the AIR with the CC licence, access to the complete schematics of the device and data are free of charge to individuals, learning institutions, and nonprofits. This allows other parties to manufacture or modify the sensor themselves and use the data to create changes for the betterment of air quality.

Annex 2: Telraam device

As discussed before, though the functionality of the Telraam sensor and hosting platform are proven, it was also found out during the the end of the project H2020 WeCount project that the Telraam sensor as is, was not sufficiently robust and user friendly to be used in an inclusive citizen science setting and that a new sensor design was needed. This Annex details out the conclusions of the WeCount project and further delves into the design process undertaken to come up with the requirements for the next version of the sensor that will also be used in the COMPAIR project.

The key conclusions in terms of required improvements are:

- The hardware setup (i.e. casing) is not professional. The hardware casing is a standard Raspberry Pi casing and in particular the variable quality of the hinge of the camera mount leads to errors in the field of view and consequently faulty data. The window mounting system consists of poor quality tape/velcro, leading to frequent drops of the camera. While these drawbacks may even appeal to a niche "makers/nerd" community, such a setup is insufficient for general deployment and unacceptable for professional clients (i.e. local authorities).
- The software is unstable requiring frequent resets by participants. Only about half of the deployed devices are truly "install and forget", requiring interventions by the citizen-owner to reset and/or re-install the software. Despite incremental improvements during WeCount, technical problems persist. Our assessment is this can only be resolved by starting from scratch.
- The onboarding is complex and error-prone; a connection switching network to an ad hoc wifi hotspot needs to be made by the participant to set wifi credentials for connectivity of the device.
- Most importantly, the quality of the traffic counts is variable insofar these have been verified and the quality of the counting is prone to environmental conditions. The distinction between cars and large vehicles is a known issue with the current approach and subject to large uncertainty. The quality of bicycle counting is poor due to misclassification, especially with groups of cyclists. While we are transparent about the quality of the traffic data, we find in particular from professional users and local authorities that quality levels of the current devices are insufficient to fully replace existing traffic counting techniques, thus limiting the market penetration with the current device. More robust and stable quality levels are required to build trust.

The issues above lead to poor user retention as participants get frustrated and will abandon efforts to keep the device active. Secondly, it generates an (avoidable) load on the helpdesk team to resolve technical issues.

While some improvements have been made in the meantime (e.g. further improvement of the software to increase robustness and a new camera-module which is more stable), the decision was made to design an all-new sensor.

Secondly, the accompanying Telraam platform to host and visualise the data, was largely deemed adequate for the task, with generally positive feedback from participants and professional data consumers. Options for improvement on the platform that may impact sensor design choices include:

- Increase the data processing. Currently, data processing consists of relatively simple post-processing steps deriving fairly simple indicators for traffic. The current setup does not detect anomalies (i.e. true data signals that point to an abnormal change in the traffic situation such as spike in traffic due to a diversion) nor artefacts (i.e. faulty data such as reduced traffic volume due to blocking of the camera field of view). These automatic detection algorithms are required to build trust in the system and improve reliability of the data.
- The platform currently lacks any user engagement; the potential of providing contextual information by users to clarify anomalies in the data is not exploitable with the current platform (i.e. allowing users to provide information on a short term road diversion to explain a spike in traffic volumes). Other opportunities to increase user engagement are ranking of streets and developing a badge system to reward active contributors.
- The cloud infrastructure and API functionality can be further improved to be more robust (SLA's), stable and scalable to support a larger sensor-base and more granular datasets (e.g. shorter time intervals).

We distinguish between various components on the user requirements: anything related to the user experience (1), technology choices in terms of hardware and software (2), cost considerations (3), data types and connectivity (4) and sensor interaction with cloud and cloud to public (5). We elaborate on each of these components individually and conclude on key design choices for the sensor development.

Hardware/software

The current Telraam sensor is using a Raspberry Pi 3A+ as a hardware platform, using Python OpenCV object detection algorithms to detect traffic. This combination has proven highly successful to offer a low-cost alternative for traffic counting technology, with a reasonable accuracy.

From the perspective of a sensor to be used in a citizen science project, the hardware and software design choices are mostly irrelevant, apart from the robustness and reliability of the data being collected. We learned from the WeCount project, from user and mobility professionals who engaged with Telraam, that the data accuracy of the current Telraam version is sub par and should be improved. Data accuracy is the key driver for the selection of the hardware/software combination.

However, the accuracy improvement of the traffic counts with a Raspberry Pi based system have reached their limits. The current detection scripts require constant 60-70% CPU level of the Raspberry Pi and optimizations options in the software scripts have been exhausted. The Raspberry Pi platform is not performant enough to accommodate more complex detection algorithms. This leads to the conclusion that a new hardware/software combination is required for a new Telraam version, if at all possible. The logical candidate is using an “AI on edge” approach using an appropriate hardware platform that can accommodate more demanding AI-scripts. Also, the use of true edge computing (i.e. fully process sensor data on the edge device itself) allows for very small data packages to be sent to the cloud, which in turn gives more options in terms of communication protocols. Also, edge computing is privacy preserving by design which will appeal to the users concerned about privacy.

Multiple examples exist of traffic counting using AI techniques, specifically using Tensor flow. These algorithms require a more performant hardware platform than a Raspberry Pi. Examples include Jetson Nano and Google Coral. Obviously, these are (a lot) more expensive than a Raspberry Pi system, easily increasing the overall sensor unit cost by factor 3 to 5. We consider this too high a cost increase for use in citizen science projects (see next chapter for details).

The design challenge for the hardware/software choice, lies in finding the optimum between performance (mainly with respect to accuracy) and cost. A previous analysis has led us to the Kendryte K210 as the key-component to host an AI-based detection algorithm. A “pruned”, re-trained AI detection algorithm is likely sufficient to reach the accuracy we deem sufficient for analysis purposes (at least 90%, ideally 95% or higher), in most sites.

Further, on the hardware, echoing the requirements from the user perspective, the use of a wide-angle lens will cancel the need for a (manual) orientation of the camera, highly desirable to lower the burden of installation for the user. A survey revealed that use of a wide angle lens does not come with a quality or cost penalty, however it does require an additional step on the software side i.e. automatically detect the field of interest, more specifically the part of the view in which passing traffic is active which needs to be dynamic.

Power consumption is a point of attention as AI-scripts can require a lot of electricity power which is detrimental in 2 ways:

1. High power use requires (active) cooling and could limit the application of Telraam (e.g. southern-faced window during summer)
2. High power consumption has a cost, to be borne by the user.

At minimum, power consumption should be limited to a few Watts. Ideally, power consumption should be low enough to enable a battery powered, possibly in combination with a solar panel, device requiring no external power source.

To conclude, a new sensor ideally builds on open source software principles, allowing for deep citizen science with tech savvy and hyper-engaged participants interested to co-design the code. We consider this a nice-to-have as it will appeal to a very small subset of citizen scientists in COMPAIR.

Cost considerations

As pointed out in the previous section, there exists a sweet spot between useability/accuracy/performance versus sensor cost. In the case of citizen science, finding this sweet spot is not trivial. Our starting point for the COMPAIR traffic counting sensors, is self-installation by citizens. As such, sensor units need to be cheap enough to allow an acceptable risk associated with loss or damage as a consequence of (mis)handling by non-expert citizen scientists. At the same time, sensors should be sufficiently performant to generate valuable data.

To determine this sweet spot is not an exact science and the only indications from previous projects, i.e. WeCount can help to benchmark. WeCount aimed for a Telraam traffic sensor in the price range of 75€/unit for the initial Telraam sensor, but was unable to attain this price point, landing closer to 125€/unit. While this reduced the amount of sensors available, it didn't impact the project as a whole.

We think a unit cost of 150€ is low enough to "commoditize" the Telraam sensor as a near-expendable product, ideally reducing the unit cost further below 100€

Data type & connectivity

In line with the user requirements, the traffic counting Telraam v2 sensor, should be able to distinguish multiple modes of traffic: at least car, bike, pedestrian and heavy vehicles. As the current Telraam sensor is already able to do this, a newly designed sensor should be able to do so as well, preferably with increased accuracy and further distinction between modes, specifically with light/heavy freight, buses and motorcycles as separate categories. Traffic speed can be estimated as well and could be added, although this is not currently a user requirement from the COMPAIR pilots.

More importantly, the current Telraam sensor can only count traffic during daytime. This is considered a serious drawback, based on feedback from current users. A new Telraam sensor should be able to at least collect basic counting data in dark conditions, for example only collecting traffic counts for cars or an aggregate category, while accepting a lower accuracy.

For connectivity, it's essential to move away from wifi (see previous section on user side) and choose a stable communication protocol that does not require a setup/configuration by a user. Multiple options exist: GPRS/LTE/LoRa or multi-protocol type of communication. Also, preferably, the time resolution should be increased from 1h to 15', allowing for more fine-grained assessment of mobility "events".

Cloud

To conclude, the sensor data needs to be pushed to a cloud environment, for easy visualisation and redistribution to third parties, within or outside the project team, via API's.

The Telraam data-infrastructure designed for the current Telraam sensor, is fit for purpose to also ingest and process data from a new sensor design. The current API is used by third parties and is well documented.

A point of attention is to ensure the current data architecture is fit to scale and allows for new API end-points to be developed as project dashboards require. API design is mostly outside of the scope of the sensor strategy in this deliverable, but it does have some implications for sensor design decisions. For example, the need for a temporal granularity of 15' does not only require an adaption of the API, but -obviously- also a sensor which is able to produce data with a granularity of 15 minutes.