Report of Interdisciplinary Project

2019/20

Q-Air Gotchi

ICT4SS
Information and Communications Technologies for Smart Societies

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1. Q-Air Gotchi

1.1 Introduction

Air pollution is a serious problem that affects everyone and that causes serious health risks. There are various sources that contribute to it but some sectors contribute mostly. One of these sectors is road transport. According to a research of the EEA (European Environment Agency) of 2019, as can be seen in figure 1, road transport is the main responsible for the NO_x emissions (figure 1) and has also a relevant impact in the other pollutants generation.

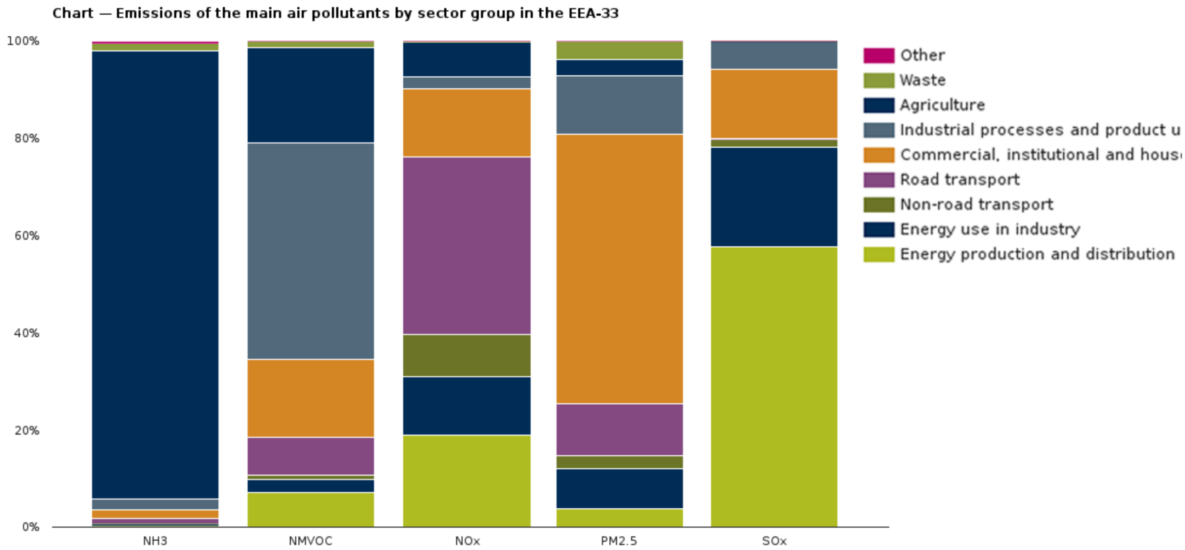


Figure 1: emissions of the main air pollutants by sector group [1]

According to the World Health Organization there are "4.2 million deaths every year as a result of exposure to ambient (outdoor) air pollution" [2]. In particular, "air pollution has a devastating impact on children's health", in fact "both Ambient Air Pollution and household air pollution contribute to respiratory tract infections that resulted in 543000 deaths in children under 5 years in 2016". [3].

Moreover, the relevance of this theme grows when dealing with metropolitan cities. Particularly due to the intensive traffic jam and to the presence of factories in peripheries, big cities are the most affected by air pollution. In this contest, the most in danger are pedestrians and children in particular.

Given this scenario, there is a growing interest in monitoring the concentration of major pollutants in the air, for this reason, several nations and international organizations have developed an AQI (Air Quality Index) to have a reference standard in monitoring air pollution. Often, those AQI differ place-by-place, for instance, the

United States AQI [4] evaluates carbon monoxide (CO) and sulfur dioxide (SO2) which are not considered by the EAQI (European AQI) [5].

Anyway, based on the AQI, a lot of websites and mobile applications have been developed to let people monitor the status of the air in the world. One of the most famous is probably the “Air Visual” [6] web-site which, using the U.S. AQI, gives to users a map of the spreading of air pollution all around the world. These applications refer to the official data released by national organizations which are often calculated by means of stations spread across the country or the city that capture high-quality data about air pollutants, then an average value from two or more stations is used to represent a given area.

1.2 Project overview

This project, which is called “Q-Air Gotchi”, has the purpose of monitoring the concentration of major air pollutants at the outdoor space of the “Aldo Palazzeschi” Secondary School in Turin. The collected data is used to calculate an AQI which is shown to students through an avatar, like a TamaGotchi (project’s name is derived from this application), in a monitor inside the school. The avatar has different “emotional status” according to the value of the calculated AQI, better is the air quality, lower the AQI value and happier is the avatar. The AQI used as reference to calculate the air quality is the IPQA (Indice di Previsione della Qualità dell’Aria) that is the standard used by the “Città Metropolitana di Torino”, it defines five levels of air quality: great, good, acceptable, bad and slack.

Starting from IPQA we modified it, so that we have the pollutant’s values determined by an adding or decreasing factor that contribute to the real one according to some eco-actions performed by the students (i.g. carry out recycling in an appropriate manner, going to school by Public Transport, biking or walking).

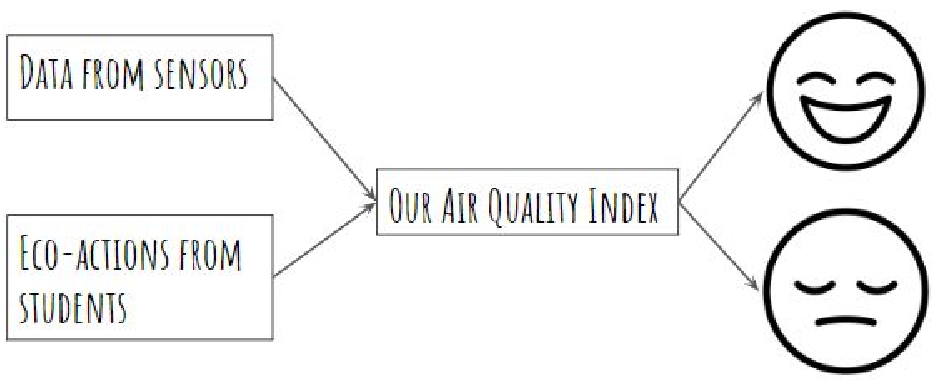


Figure 2: how the AQI works in this project

1.3 Project goals

The aim of the project is to sensitize students and their parents about the “air pollution” theme. Using our specific developed algorithm, we want to show them how they can directly influence and affect the air quality. Moreover, by involving them actively into the project, it could stimulate a “healthy competition” among students.

It’s important to notice that the main difference between this project and the most spread applications that make similar work, apart from the modification of the AQI, is that those kinds of web services use an AQI value that is not strictly representative of specific location, it’s an overview of a big area such as a city. This project, instead, wants to monitor only the area of the “Aldo Palazzeschi” school, and shows the AQI value of the air breathed by each student and not a generic mean that sometimes people don’t care about.

1.4 Project Requirements

The first fundamental requirements we needed to fulfil was to involve the students in the project, we did that by letting them choose the avatar and suggesting every week to fill some questionnaire.

Another important requirement of this project is that it has no scientific goals. The idea behind the “Q AIR GOTCHI” is not to have a full monitoring of all pollutants, in order to perform a scientific study, so we decided to build a low cost system easily replicable, and we display just the avatar health status avoiding the values of air pollution which could have lead to a public alarm for the families.

To stress the importance of how everyone's behaviour influences the air that we breathe, the concentration of the air pollutants is taken with a greater frequency during periods in which students go in and out of school. During such periods, students are more vulnerable since they are exposed to outdoor conditions and the pollutants concentration near the school is worse than in other moments. The latter is due to the fact that most parents accompany their children to school with the car, this way, parents' behaviour directly influences children's health status in a bad way.

Another important project requirement is an appropriate coordination with the school. This has been really fundamental to carry out the project, besides some bureaucratic aspects, the school has an important role in order to involve students and their families into the project. This aspect will be treated in more detail in chapter 2.

1.5 Timeline

The project timeline has suffered several changes from the original one we have presented at the beginning of the project. This is due to several reasons and can be easily seen through the Gantt chart (a chart that illustrates the project schedule) we have prepared during the project evolution. The first reason is that several tasks have been modified or added following the meetings with the school reference professor. For example, as can be seen in figure 3, which is the first Gantt chart we have prepared, there is no task about parent or student survey. This is because the idea of those came after some of the aforementioned meetings. Moreover, as in all projects, tasks have been shifted or adjusted in time due to delays or organization problems.

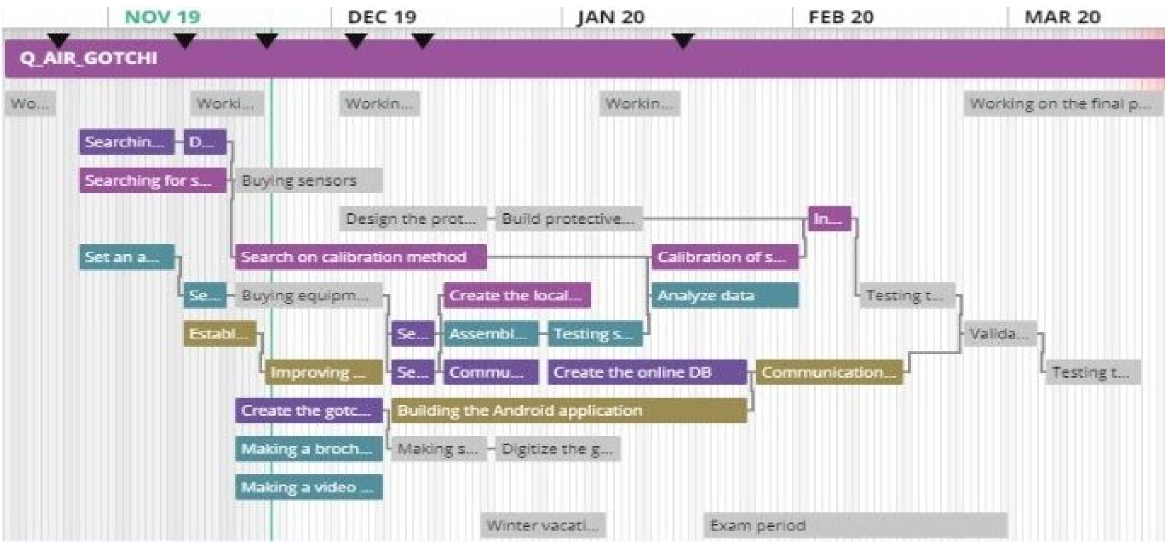


Figure 3: original Gantt chart of the project

In addition, some tasks not related to our work, such as the buying of the equipment and sensors, have required more time than expected. These problems have caused shifting and stretching in time which are really evident by comparing the Gantt chart in figure 3 and the one in figure 4, which is one of the last presented.

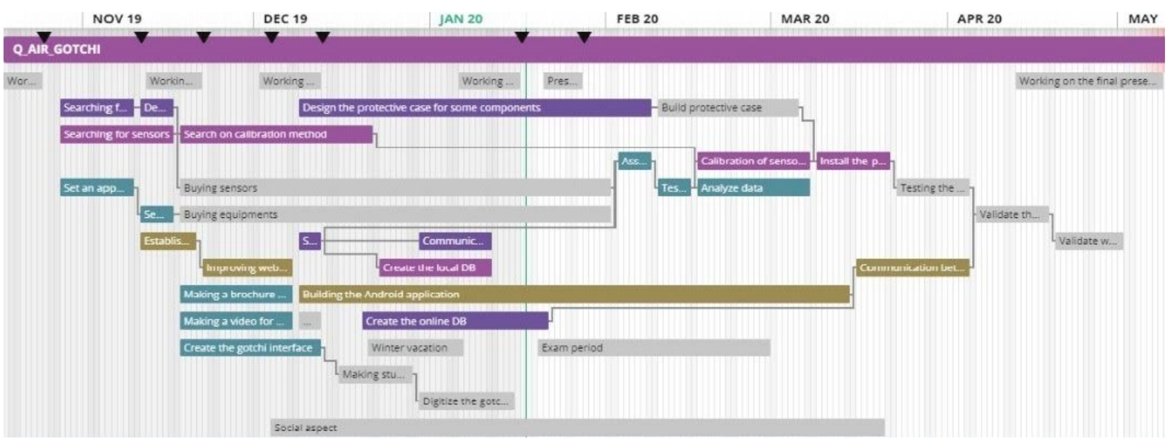


Figure 4: one of last Gantt charts presented

At the end of the project, another significant change in the Gantt chart was due to the emergency situation caused worldwide by the spreading of the COVID-19. Because of it, our project has faced some modifications, those were not structural changes, the idea behind it and its technical organization has remained basically unchanged.
According to the situation we acted this way:

1. since school was closed before we were able to present the project to students on a meeting through a specially prepared video, it has been uploaded on the web-site we have created for this project (more in following chapters);
2. since we decided to let the students choose the avatar, the surveys prepared were uploaded on the web page too instead of being filled in manually;
3. since it was not possible to install the sensors in the school, we placed the acquisition system in one of our homes;
4. we couldn't install the screen in the school, so the avatar status is shown on a web-site and on an Android application;
5. we couldn't buy the O_3 sensor, so our AQI referred only to the other two sensors (PM_{10} and NO_2);
6. we had to change the way in which data, the so called "eco-actions", were collected from students;
7. We couldn't attend a radio presentation of the project organized by school Professor Manella who conducts a radio program on a local station.

1.6 Workflow

The project has been carried out according to the following steps:

- Meeting with reference teacher of the school
- Create a video presentation for students
- Create a brochure to publicise our work
- Had a meeting with parents and teachers to explain the project and its goals
- Make an inspection of the site where to install the sensors
- Create a survey for parents
- Create a survey for students, where they can choose the avatar
- Create a questionnaire for students that will affect the avatar health status
- Get data from sensors
- Elaborate data and calculate the IPQA
- Modify avatar health status according to a specific designed algorithm
- Create a Website as main user interface and upload avatar with its relative data
- Create an Android App based on the website

All these general steps can be visualized through the workflow in figure 5.

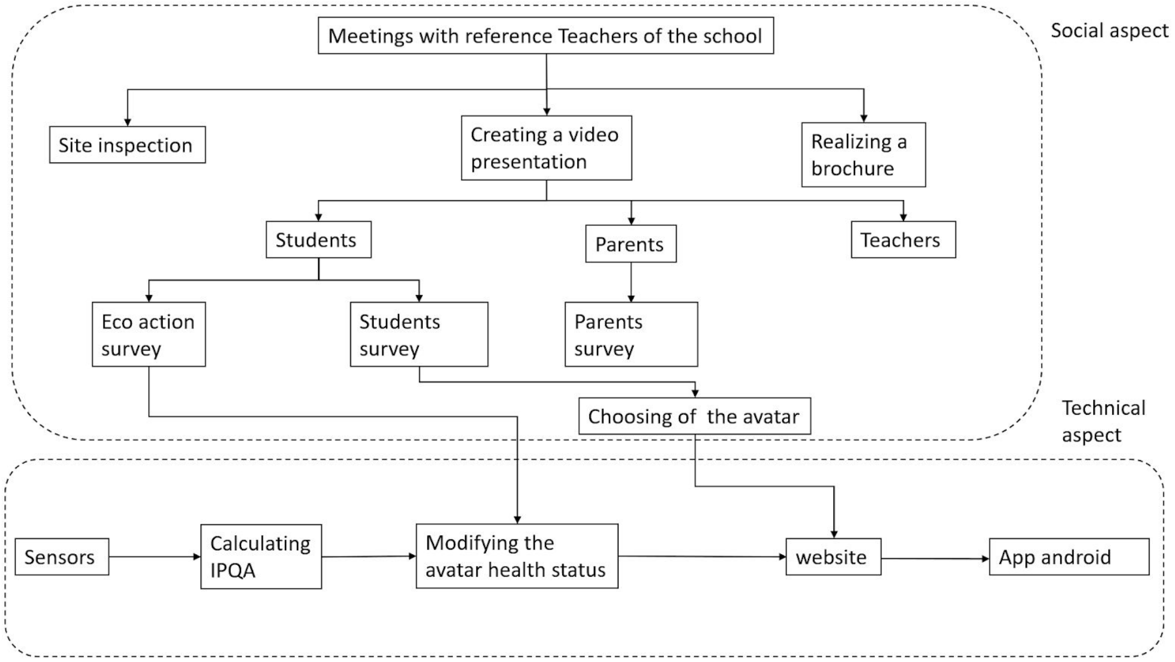


Figure 5: workflow of the project

This scheme allows us to show how we interfaced with the school and how we connected the social aspects with the technical part of the project.

2.Cooperation with the school

2.1 The teachers' coordinator

The coordination with the school has been fundamental. We needed complete cooperation in terms of contacting students and their parents and to use the school's infrastructure in order to install our prototype at the entrance of the school and show the state of pollution to students. Moreover, during the project evolution, some aspects have also been modified and adjusted following some meetings between the school and us.

In particular, in order to have direct contact with the school, a teachers' coordinator for the "Q AIR GOTCHI" project has been chosen, the Professor Manella. We had our first meeting with him in which we explained the project and what we expected from the school in more detail. During this meeting we used the school's suggestions in order to have a greater impact and achieve a bigger participation in the project. Apart from this first one, we had several meetings with the teachers' coordinator in order to evaluate the project evolution and discuss more aspects and the next steps to be carried out. Thanks to professor Manella, it was decided to present the project to the other teachers, student's parents and students.

Going on with the project, due to the emergency situation of the COVID-19, ulterior online meetings were needed to outline how to develop the project in a new situation. The school's coordinator was responsible, as our intermediary with the students, of conveying information and coordination in the new situation.

2.2 Video presentation for the school

In order to present our work to the students we have decided to create a short animated video where we explain the project goal and their own contribution to the project in a simple manner. The video was made with Animakers and its duration is about two minutes.

We had scheduled a meeting with students in the first week of March, in order to present them the video, clarify every doubt and answer their questions. Due to Covid-19 pandemic situation, we had to change our plan according to safety measures and social distancing. Hence, we decided to communicate with students remotely and upload the video on our website and provide access for students.

Figure 6: screen of the video from the web page

2.3 Brochure

In order to advertise and explain our project's goal, we created a Brochure. This way, we could show the possible avatars and moreover, share our contacts and the link to the questionnaire with a QR code.

Figure 7: brochure

During the meeting with teachers and parents, we handed out the Brochures (figure 7) to give them our idea and clarify their doubts about the ways they can cooperate in this regard. Unfortunately meeting the students and distributing the brochures didn't happen due to COVID-19 emergency situation, so we decided to ask the principal to inform students with some memos through official channels.

2.4 Meeting with teachers and student's parents

One of the first steps of the project was to present it to the teachers. During this presentation we described the project and it became evident how the teachers were interested and how they were willing of contributing to it.

Originally, the idea was that teachers had to collect the "eco-actions" performed by students once every two weeks, involving them in the project and making them too an active part of it.

Subsequently, we made a project presentation to students' parents. Despite the low participation from parents, the ones present were really impressed by it. Since the project was related to their children's health, they were curious about how it was developed. We also expected them to be actively involved in the project.

Figure 8: meeting with teachers

2.5 Site Inspection

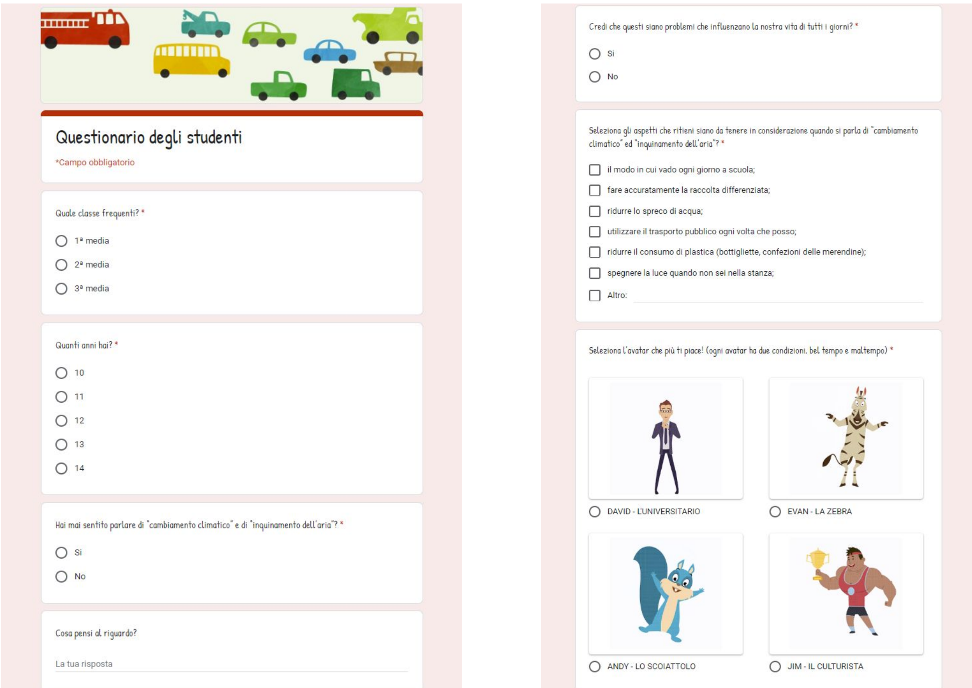
To install sensors in the school, a meeting with professor Manella was scheduled in order to be able to place them in the right position and acquire as much data as possible.

During this meeting it arose that one of the main problems was the electricity needed to power the electrical equipment placed outside, moreover, the communication between inside and outside components with school WiFi was not reliable. For this reason, we thought of a cabled connection for Ethernet and power by using the standard PoE (Power over Ethernet) but the cost of this operation was too high (about 300€) for the school. We decided then to evaluate a system powered by a solar panel paired with a software capable of maintaining data in case of discontinuity of the WiFi signal and able to send the data once the connection was re-established.

Figure 9: school's main entrance

2.6 Student survey

After having presented the project to the students by uploading a video on the project website, a survey was prepared for them.


Questionario degli studenti

*Campo obbligatorio

Quale classe frequenti? *

- 1ª media
- 2ª media
- 3ª media

Quanti anni hai? *

- 10
- 11
- 12
- 13
- 14

Hai mai sentito parlare di "cambiamento climatico" e di "inquinamento dell'aria"? *

- Si
- No

Cosa pensi al riguardo?

La tua risposta

Credi che questi siano problemi che influenzano la nostra vita di tutti i giorni? *

- Si
- No

Seleziona gli aspetti che ritieni siano da tenere in considerazione quando si parla di "cambiamento climatico" ed "inquinamento dell'aria"? *

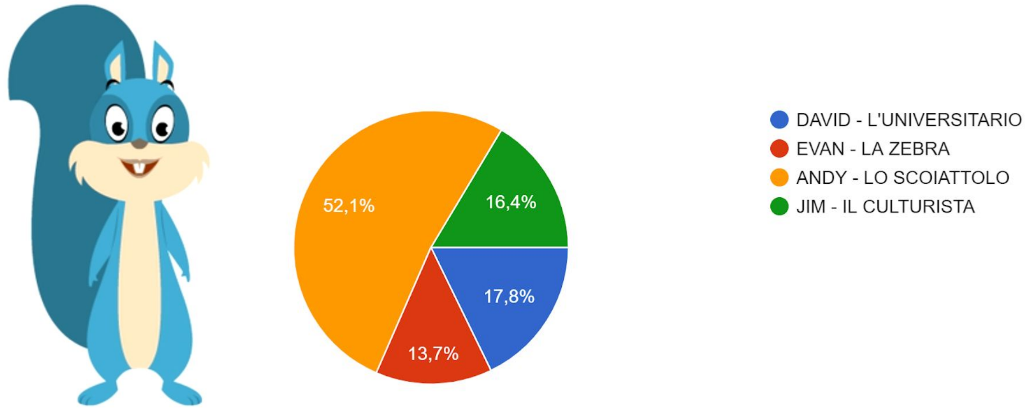
- il modo in cui vado ogni giorno a scuola;
- fare accuratamente la raccolta differenziata;
- ridurre lo spreco di acqua;
- utilizzare il trasporto pubblico ogni volta che posso;
- ridurre il consumo di plastica (bottigliette, confezioni delle merendine);
- spegnere la luce quando non sei nella stanza;
- Altro:

Seleziona l'avatar che più ti piace! (ogni avatar ha due condizioni, bel tempo e maltempo) *

- DAVID - L'UNIVERSITARIO
- EVAN - LA ZEBRA
- ANDY - LO SCOIATTOLO
- JIM - IL CULTURISTA

Figure 10: student survey

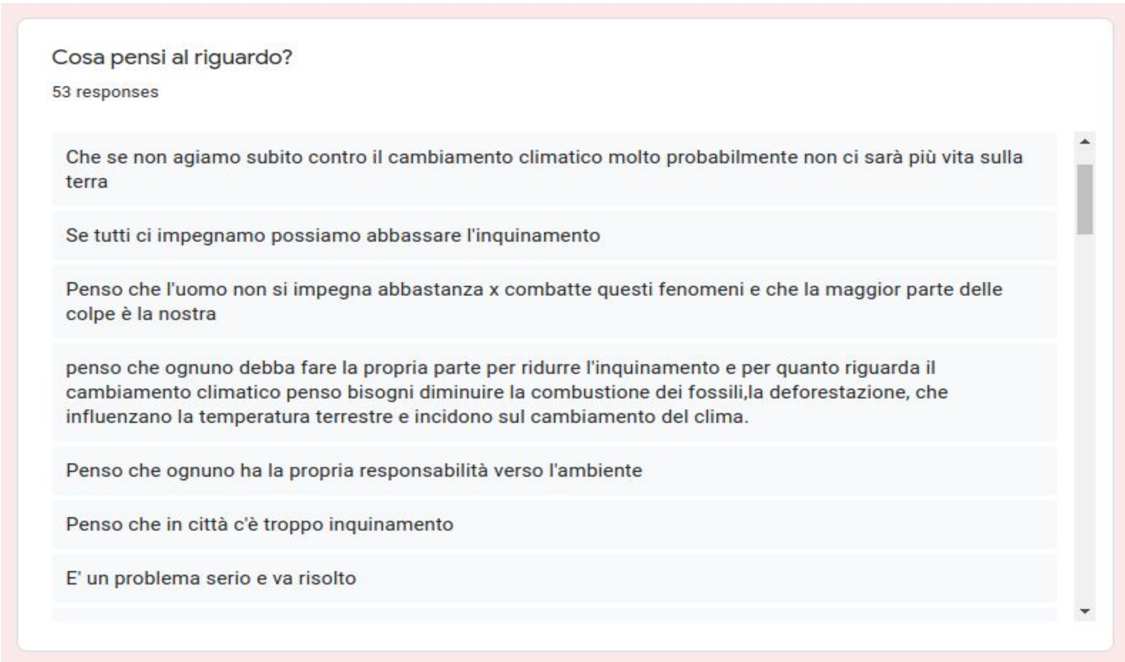
The aim of this survey was to understand how they perceived the "air pollution" theme and to let them choose the avatar based on their preference. For what the avatar choice is concerned, four different ones were selected by us and were shown through the web site for more than two weeks. We experienced the participation of 83 students in this survey, which was very satisfactory in terms of remote communication. As it can be seen in figure 11, more than 50 percent of students voted for Andy avatar which has been shown here.



a) b)

Figure 11: a) chosen avatar; b) results of the survey

Also in this survey, we provided an option in order to collect student's feedback about air pollution throughout a short writing in addition to the multiple fixed answers provided by us. We came up with an interesting participation of 53 students with some sentences that showed their awareness and importance in this matter. Some sentences are reported in figure 12.



Cosa pensi al riguardo?

53 responses

Che se non agiamo subito contro il cambiamento climatico molto probabilmente non ci sarà più vita sulla terra

Se tutti ci impegnamo possiamo abbassare l'inquinamento

Penso che l'uomo non si impegna abbastanza x combatte questi fenomeni e che la maggior parte delle colpe è la nostra

penso che ognuno debba fare la propria parte per ridurre l'inquinamento e per quanto riguarda il cambiamento climatico penso bisogni diminuire la combustione dei fossili,la deforestazione, che influenzano la temperatura terrestre e incidono sul cambiamento del clima.

Penso che ognuno ha la propria responsabilità verso l'ambiente

Penso che in città c'è troppo inquinamento

E' un problema serio e va risolto

Figure 12: student's response to air pollution idea

2.7 Parent survey

A separate survey was prepared for parents, in order to involve them and get their feedback about some air pollutants related factors in families. This one was composed of several questions about the habits and properties of the families related to the air pollution theme (i.e. number of cars owned in the family, how they accompany their children to school).

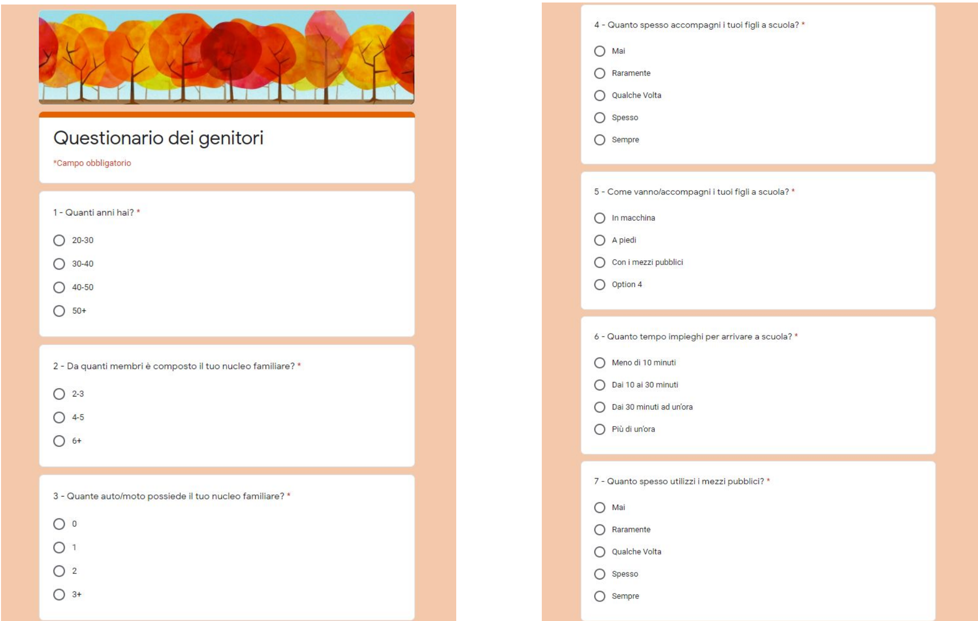


Figure 13: parent survey

The aim of this survey was to compare the answers of the questionnaire before the project started and after its development in order to have an overview on the impact of the QAir Gotchi on them. Thanks to the school's coordinator who had explained in depth this aspect to the students' parents, we received 82 responses in this survey. We then collected the results that allowed us to make some considerations:

- majority of parents are worried about their children's health and think that it's necessary to stress the importance of the air pollution theme;
- most parents bring their children to school by car since they do not have any other solution.

Some other quantitative results can be seen in figure 14.

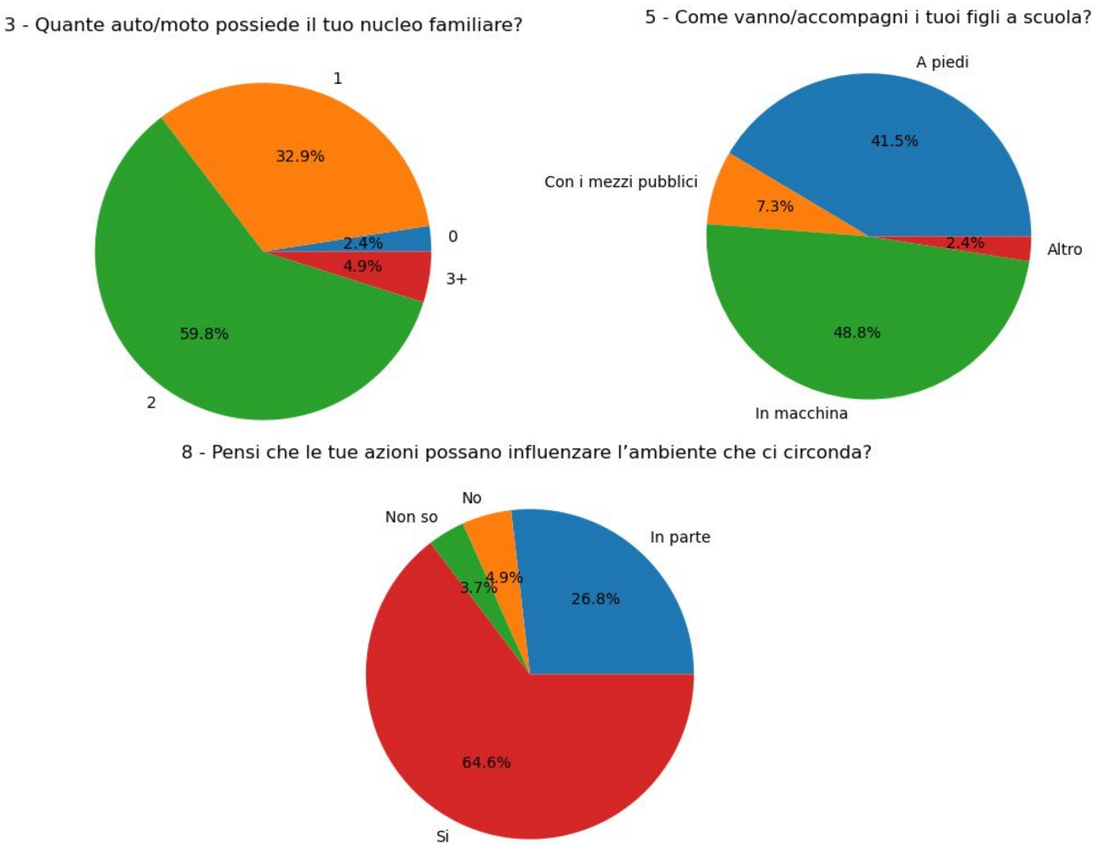


Figure 14: some results of the parents survey

In order to get reliable data and be sure that only students and their parents could access the surveys, we implemented an authentication method in the survey section of the website which allowed only the ones that had a password provided by us to enter this section (figure 15).

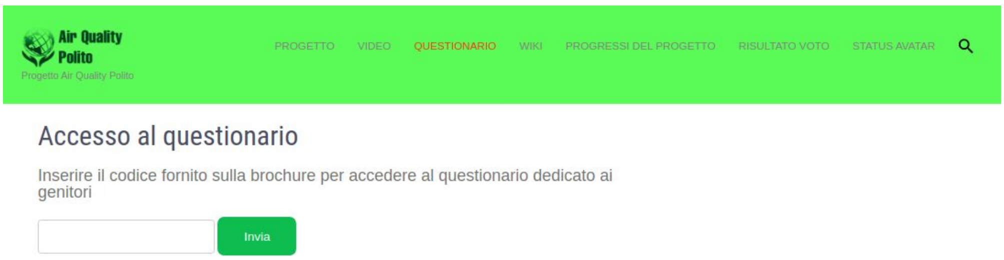


Figure 15: some results of the parents survey

From the results related to our small control group we drew another consideration about car ownership. As it can be seen by analysing survey data, despite being aware of the risk and the implication for the environment that a regular use of the car imply, most of the parents still consider it the main and only option for transportation.

2.8 Good actions by students

The eco-actions of students were collected through a survey on the web site. This survey was composed of a few questions needed to detect the behaviour of the students. Each answer is associated with a vote which modifies the avatar health status (IPQA algorithm in section 3.3.2.1).

In particular, the questions were related to their everyday habits. The idea was to transmit a sample of the actions that can help having a more eco-friendly behaviour. Those actions were chosen in accordance with Professor Manella. Obviously, this aspect has been partially modified due to the lockdown. Initially, questions were inherent also to the way students come to school and their behaviour inside it. The objective was to collect answers from students of every class, this way, by showing the status of the avatar and the results of the eco-actions performed by the different classrooms, a “healthy eco-competition” could have been born among students.

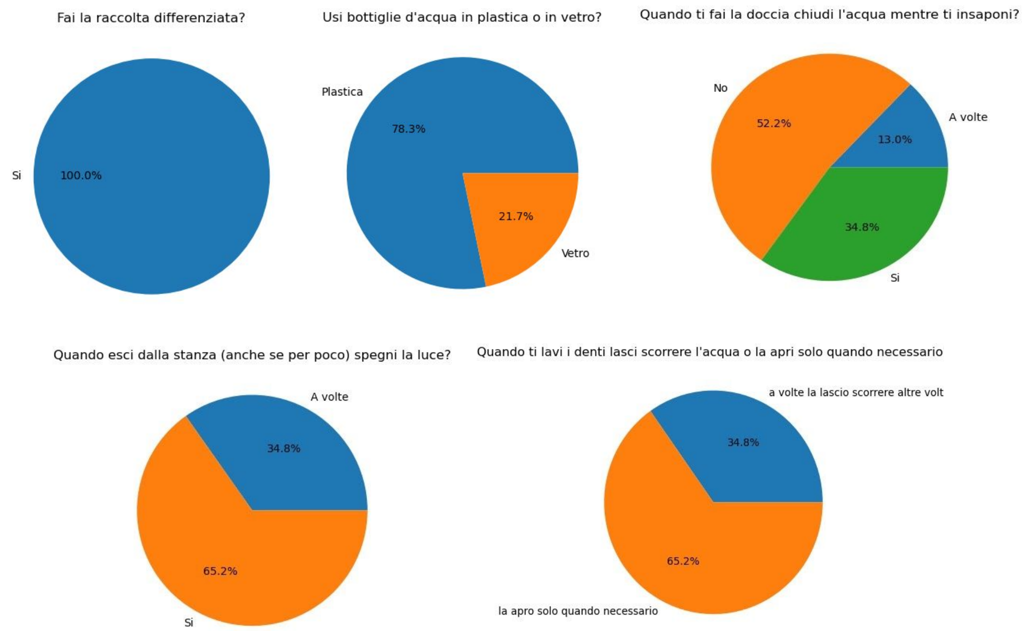


Figure 16: results of the eco-actions inserted by students

Looking at the 50 responses given by the students (figure 16), we can see that recycling has become a milestone in our society, but the reduction of plastic bottles usage remains a far goal. In this sense, some school initiatives could be of great impact on students to discourage the usage of plastic bottles. In the end, it has to be noticed that water wasting is not perceived as a bad habit to be fought.

Obviously, the eco-actions inserted in the survey are not directly linked to the concentration of pollutants in the air, since secondary school students cannot heavily impact it (i.e. by driving a car or choosing the source of energy for their house), but the eco-actions we have selected still remain a good indicator of their approach to a wise usage of resources.

3.Technical project description

3.1 Project scheme

The project scheme, as can be seen from figure 17, is divided in several segments that work as distinct modules and interact among them. This way of structuring a project is called modularity and it is pretty standard and well-founded. By developing it this way since the beginning we ensure evolvability end extendibility with small architectural impact.

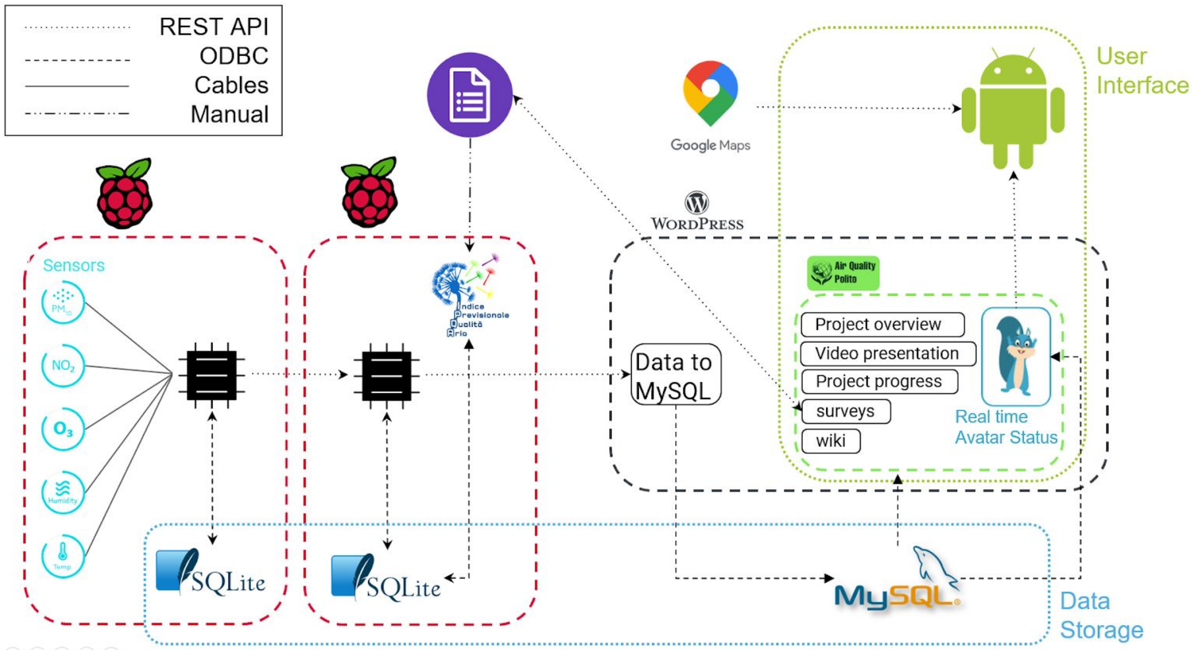


Figure 17: project scheme

3.2 Hardware

The hardware sector is composed of the following equipments:

- 2 Raspberry Pi, one version 3 and the other version 4;
- 1 Mics-2714
- 1 DHT-22
- 1 SDS011
- 1 ADS1115

Those will be furtherly analysed in detail in the subsequent subparagraphs.

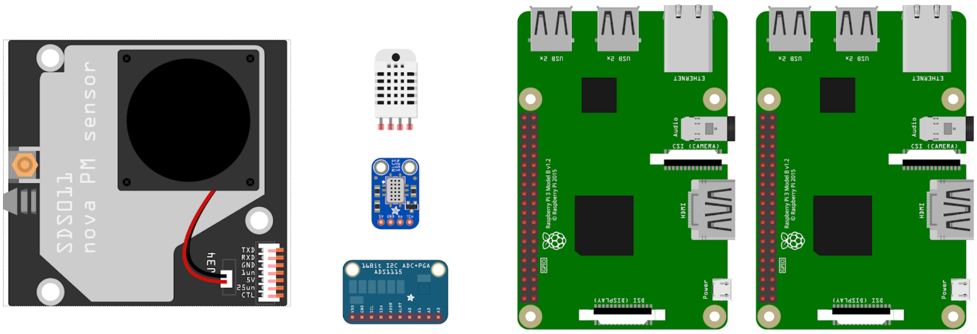


Figure 18: graphical representation of hardware used

In figure 18 we can see graphical representations of the equipment used.

3.2.1 Outside Raspberry

A Raspberry Pi had to be placed outside of the school; later on, we refer to it as the "outside Raspberry". It would act as a concentrator of data since all sensors are connected to it. A protective case was designed for it due to its exposed position.

3.2.2 Inside Raspberry

A Raspberry Pi stands at the main entrance of the school; later on, we refer to it as the "inside Raspberry". It works as the central unit of this project. Collecting data, calculating the IPQA, storing data in its database and sending them to the web application are among its duties.

3.2.3 DHT22

The DHT22 sensor provides temperature and humidity data. Those information are not relevant to the pollution calculation but are needed to give a complete overview about air quality. The pollutants concentration changes with different atmospherical characteristics.

Its measuring range is from -40 to +125°C with a ±0.5°C accuracy. The DHT22 consists of a humidity sensing component, a NTC temperature sensor or thermistor (Negative Temperature Coefficient; which means that the resistance decreases with increase of the temperature) and an IC on the back side of the sensor.

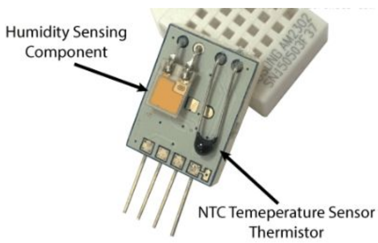


Figure 19: DHT22 inside

To measure humidity, it uses a sensing component which has two electrodes with moisture holding substrate between them. As the humidity changes, the resistance between these electrodes changes as well. This resistance delta is measured and processed by the IC which makes it ready to be read by a microcontroller.

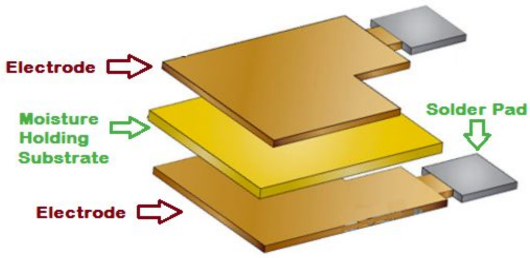


Figure 20: humidity sensing component

For temperature measures these components use a thermistor. These sensors are made by sintering of semiconductive materials such as ceramics or polymers in order to provide larger changes in the resistance in response to small variation in temperature.

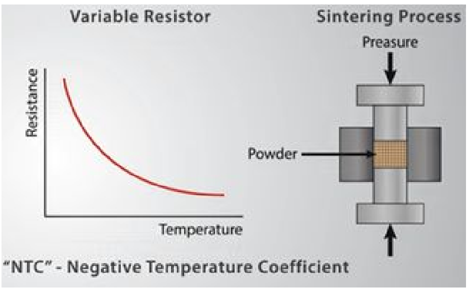


Figure 21: thermistor working principle

The DHT22 sensor has four pins, VCC, GND, data pin and a not connected pin which has no usage. We need to use a pull-up resistor of 5kΩ in order to enable the communication between the sensor and the Raspberry and to ensure a known state for a signal, which means to keep high the data line.

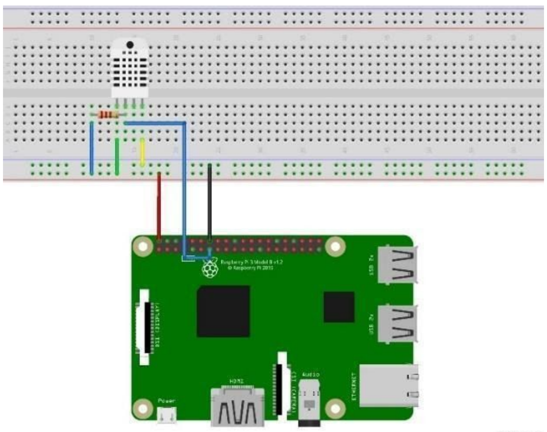


Figure 22: connection between Raspberry Pi and DHT22

3.2.4 SDS011

The SDS011 from INOVAFIT is a Particulate Matter sensor that monitors both $PM_{2.5}$ and PM_{10} concentration. The SDS011 has an accuracy of 70% for 0.3μm and 98% for 0.5μm [7]. It has a reduced size which makes it usable in several kinds of applications and scenarios.

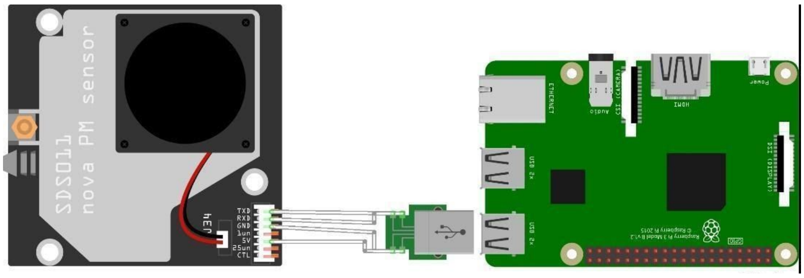


Figure 23: SDS011 sensor connected to the Raspberry Pi

This kind of sensor has a fan mounted on it that automatically blows the air in. In order to measure the value of dust particles found in the air, the SDS011 uses laser DLS (Dynamic Light Scattering) principle. Together with a great accuracy, this working principle has a pretty good response time that is below 10 seconds. The light scattering principle, as can be seen in figure 24, works as follows: when dust particles flow in the detecting area, the light emitted from the laser is scattered; a diode detects the light scattered and, by using an amplifier and an ACD (Analog to Digital Converter), the electric signal is analyzed in order to understand the concentration and size of the particles by using an ACF (AutoCorrelation Function).

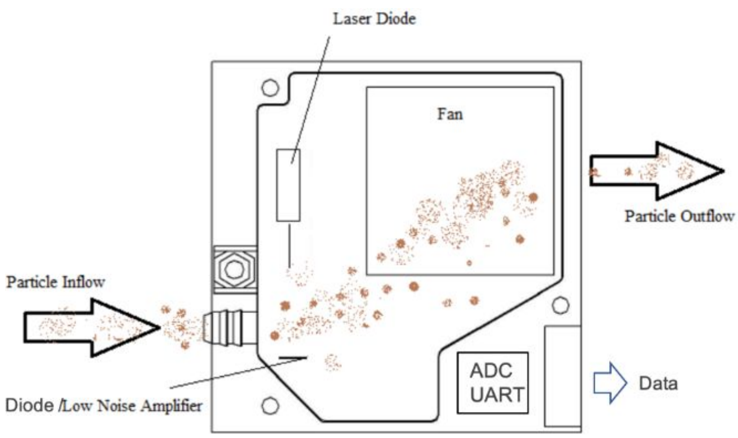
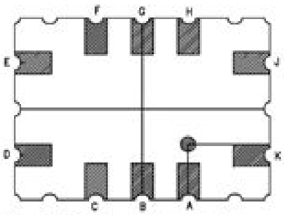


Figure 24: SDS011 working principle

Eventually it has a PCB (Printed Circuit Board) inside which controls all electrical operations and that performs calculations.

3.2.5 MICS-2714

The MiCS-2714 is a compact MOS (Metal Oxide-gas Sensor) to monitor nitrogen dioxide (NO_2). A MOS works with the principle of chemi-resistance, this means that it's evaluated the change in electrical conductivity or resistivity of thin films when exposed to a target gas. In other words, gas molecules interact with the metal oxides which either act as a donor or acceptor of charge carriers (receptor function) and alter the resistivity of the metal oxide (transduction function). The NO_2 works as an acceptors of charge which increases the resistance of the thin film, being the material an n-type, and leads to an increase in resistivity; this means that the sensor resistance increases in the presence of NO_2. The silicon gas sensor structure consists of an accurately micro machined diaphragm with an embedded heating resistor and the sensing layer on top, the pin related to them are shown in the figure 25.



Pin	Connection
A	Rh1
B	Rs1
C	
D	
E	
F	
G	
H	Rh2
J	Rs2
K	

Figure 25: MICS-2714 pins

Following the datasheet of the sensor, we use two resistance in series (75Ω and 56Ω) between the input voltage (5V) and the pin H, and we connect pin A to the ground, to activate the sensor. In order to retrieve the data we generate a sensing circuit connecting pin J to the input voltage (5V) and using a load resistance of 22kΩ between pin B and ground to create a voltage divider and calculate the resistance of the sensor as follows:

$$R_{sensor} = R_{load}\left(\frac{V_{input}}{V_b} - 1\right)$$

where V_b is the voltage at pin B.

We send the voltage value to the Raspberry, which lacks an analogue port, using an analogue-to-digital converter, the ADS1115, through the I2C protocol.

The ppb of the NO_2 is given by the division of the Sensing Resistance measured (R_s) and the sensing resistance measured under controlled ambient condition (R_0). We made some tests in our home and took the mean from all the sensing resistance values measured as R_0 1 kΩ which is inside the limits supplied by the datasheet (0.8-22 kΩ).

In order to calculate the ppm used in the calculation of the IPQA we multiplied the ppb per 1.88.

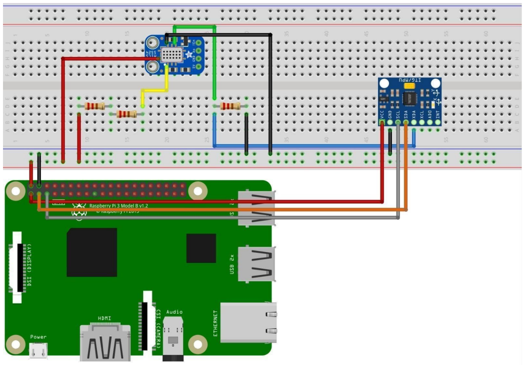


Figure 26: NO_2 sensor schema

3.2.6 Protective case

To install the whole system outside of the school, we designed two cases: one to protect the Raspberry Pi and the other for the entire system.
The first one fits very well the raspberry, leaving just the output doors open, in order to protect it from water infiltration, since the Raspberry Pi is much more fragile compared to the sensors, which are built to endure outdoor conditions.

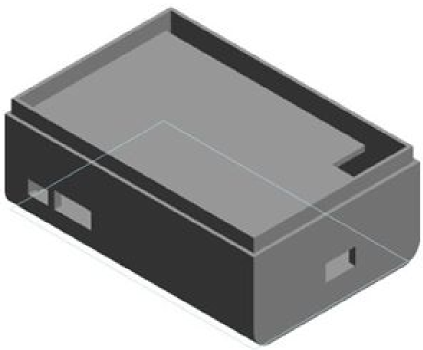


Figure 27: Raspberry Pi protective case

The case for the entire system has two floors, in the first one we should have put a battery which would have supplied the charge to the Raspberry, alimented by a solar panel. In the second floor, which has a section with different holes to allow air flow , we should have put all the sensors. The front of the case was designed to be removed and reattached by means of 4 blocks.

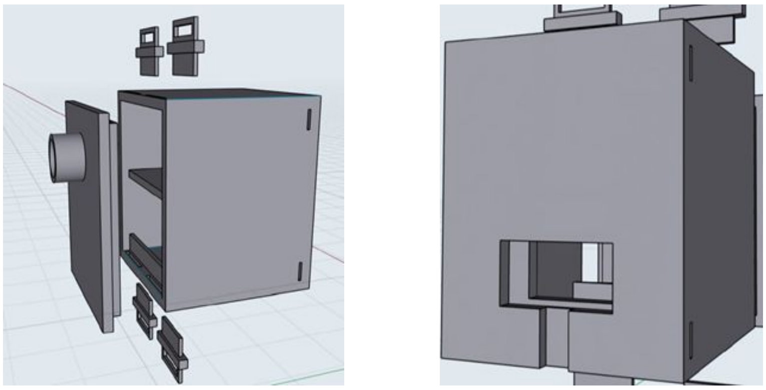


Figure 29: system case

These cases should have been 3D printed and positioned at the main entrance of the school, attached to a pole by metal clamp, but due to the limitations for the pandemic we weren't able to install that.

3.3 Software

For the software part of the project, we followed an object-oriented programming and microservice architecture. Object-oriented programming is a paradigm based on the concept of "objects", which can contain data, in the form of fields, and code, in the form of procedures. Microservice architecture is an approach to the development of a single application as a suite of small services, each running in its own process and communicating with lightweight mechanisms, this means that if a service crashes, it doesn't cause to stop all the procedure of a task.

3.3.1 Outside Raspberry

Following this approach, for each sensor, a class in order to collect data is developed separately. In the Outside raspberry we have 4 classes which are related to DHT sensor, PM sensor, NO_2 Sensor and O_3 sensor (which was simulated), all of these classes are managed by a single script which force them to collect data from the sensor each minute and store them in a local Database. Once the data is collected and stored, another script is in charge of sending this data to the inside Raspberry through REST (REpresentational State Transfer) Api (Application Programming Interface) protocol [8] by POST method.

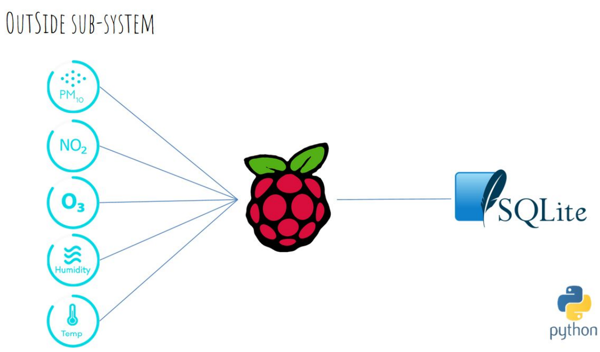


Figure 30: outside subsystem schema

3.3.1.1 Calibration and Testing of the sensors

The spreading of interest in the “air pollution” domain has considerably increased the availability of different sensors, especially low-cost ones on the market. Since this project was not a scientific study, we used low cost sensors which don’t provide accurate measurement. We still needed to be sure that our data was pretty close to the values measured by ARPA Piemonte, otherwise calibration of sensors was needed. The calibration of a sensor removes its bias and allows very accurate measurement by comparing obtained values with some standards or references.

Due to the already discussed modifications in the project caused by the sanitary emergency situation, we acquired data from sensors placed in one of our homes, but as expected data were not so similar with the ones published by ARPA. This is due to the fact that the concentration of pollutants in closed spaces is not comparable with the one in outdoor spaces. Hence, no calibration was possible since all studies and methodologies used in literature refer to an outdoor calibration of sensors.

3.3.2 Inside Raspberry

The inside raspberry is the central data processing unit and it’s devoted to the actuation of three main functions:

- Data Collection: a REST Api which is responsible for collecting data from outside Raspberry and store them in its local DataBase (DB), it accepts the request from the outside raspberry to send data;
- Calculation of IPQA value: all received data has to be validated firstly, which means all the needed values (PM, NO_2 and O_3 values) must be in the same period of streaming windows size that in our case is one minute. In other words, if one of the received values belongs to more than one minute ago window size, it’s not valid for calculation of IPQA. Consequently, if the data is valid, calculation will be done accordingly to the algorithm which is explained in the next section.
- Storing the values: Once the IPQA is calculated, these values and all sensor values will be sent to the online database over REST Api protocol by POST function.

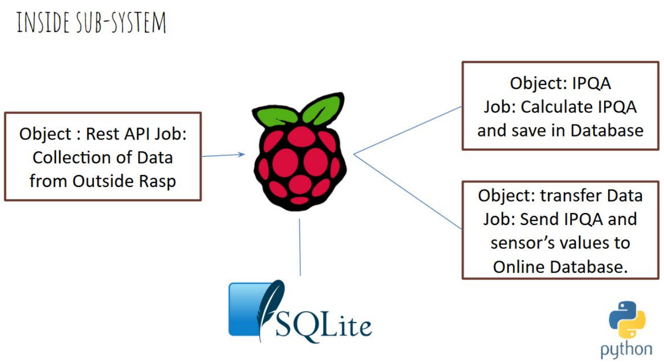


Figure 31: inside subsystem schema

3.3.2.1 IPQA algorithm

The IPQA is elaborated on the basis of the concentrations of three main pollutants which are particulate matter (PM_{10}), nitrogen dioxide (NO_2), and ozone (O_3), calculated by a modeling system managed by "Agenzia Regionale per la Protezione ambientale Piemonte" which, starting from the meteorological forecasts and the estimation of pollutant emissions, simulates the transport, deposition and chemical transformations of the same, providing a prediction of their concentration [9]. The The IPQA formula is the following:

$$I_{IPQA} = max\{I_{PM10}; I_{NO2}; I_{O3}\}$$

where the I_{PM10}, I_{NO2} and I_{O3} are the sub-indexes calculated as:

$$I_X = \frac{V_{Xmed}}{V_{Xrif}} 100$$

where V_{Xmed} is the average concentration of the X pollutant over 24h and V_{Xrif} is the daily limit value for the protection of human health [10].

As already described, the avatar status is assigned based on the IPQA value modified accordingly to the eco-actions inserted by the students and properly transformed into a numerical value. This modification was developed throughout the following steps:

1. extracting data from online questionnaire (an excel file download by a google survey in our website);
2. assigning a value for each answer with a max score of 10 (table 2);
3. taking the mean;
4. transforming the mean in a percentage, by using the lookup table 1, that is then added to the calculated IPQA;
5. assigning a specific health status to the avatar according to the legend supplied by "Città metropolitana di Torino" (table 3).

0	1	2	3	4	6	7	8	9	10
+25%	+20%	+15%	+10%	+5%	-5%	-10%	-15%	-20%	-25%

Table 1: correspondence between mean and percentage in IPQA modification

Question	Do you perform recycling?	When you leave the room, do you turn off the light?	Do you use plastic or glass bottles?	When you wash your teeth, do you open water only when necessary?	When you do shower, do you close water while you lather?
Answer 1	Yes	Yes	Glass	I open only when necessary	Yes
Score	3,00	2,00	1,00	2,00	2,00
Answer 2	No	Sometimes	Plastic	Sometimes yes and sometimes not	Sometimes
Score	0,00	1,00	0,00	1,00	1,00
Answer 3	-	No	-	I leave it open	No
Score	-	0,00	-	0,00	0,00

Table 2: possible eco-action inserted by students with relative score

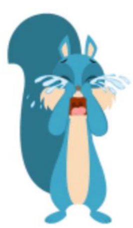
Air Quality	Pessima	Cattiva	Accettabile	Buona	Ottima
Avatar					
Status	very sad	sad	normal	happy	very happy

Table 3: all posibile avatar status

3.3.3 Raspberries configuration

Some consideration related to both Raspberry Pi:

All the scripts are written in Python language since it is one of the easiest ways to interact with sensors using a Raspberry Pi. Python 3.7 is used in the inside raspberry but in the outside raspberry we used version 2.7 due to the compatibility of the used sensors with the libraries that are provided in this version.

In case of power failure, the Raspberries will be restarted and they will run all of the scripts one by one in order to work automatically. This part is done by using a bash file which is responsible for executing all scripts with a sleep time of 1s to avoid collision; this bash file is run in rc.local of Linux system and it's executed by every reboot of the system.

A public class was developed to manage (insert, update, read and delete) data in the local database. In order to guarantee the safety of the connection between objects and database, ODBC protocol was used. In case of failure in transaction, an important feature of this class helps to rollback and keeps all data which were not sent.

3.3.4 Data Storage

In order to prevent losing data during transaction, in both the Raspberry Pi, a local RDB (Relational DataBase) called SQLite [11] is used; moreover, we store all the collected data on an online DataBase called MySQL [12].

3.3.4.1 SQLite

SQLite is a local database particularly suited for Raspberry Pi. It is really light since it's formed in just one single disk file. It doesn't need any configuration and is extremely portable between different hardware architectures. Its lightweight structure and portability are the reason why we have chosen SQLite as the local DataBase in the Raspberry.

Each raspberry store the data in its own local database to avoid losing them when the connection is lost. As soon as the connection is established, the raspberry tries to send data. We performed the policy of data storing in each raspberry for 7 days.

3.3.4.2 MySQL

The main reason behind choosing MySQL which is an open-source RDBMS (RDB Management System), is the fact that by using WordPress to create the web-site, a free-to-use MySQL enterprise edition was provided by the host. In this edition, a whole set of additional functionalities are provided which makes it more reliable and secure. In addition to being our database for the website, it also plays the role of our online DB where IPQA values are stored. Indeed, the values that determine the avatar status along with real-time temperature and historical data, are taken from this DataBase.

3.3.5 User Interface

3.3.5.1 The website

The website is developed through WordPress [13] which is an open source and free platform. This platform is written in the PHP scripting language and used MySQL as its database which is designed properly for this language. We used a specific template of WordPress to create our website along with various plugins (such as Google form, for surveys) to perform specific tasks.

The website with domain name of www.airpolito.it has been created in order to give a full overview of the project to the students and their parents. In this way, we could also submit them different surveys and retrieve new feedbacks. In Figure 32, the homepage of the website can be seen.

Figure 32: home page of the “Air Quality Polito” website

The web site is composed of context and information as below:

- Full description of the Q-Air Gotchi project;
- A progress page which is dedicated to some posts in order to bring up-to-date news about the development of the project;
- Questionnaire dedicated to students’ parents;
- Technical information about the Air Quality Index;
- The video of the project presentation to students;
- The survey dedicated to students;
- A form to let students insert their eco-actions, which is enabled periodically;
- Showing the real time avatar status;
- Our contact;

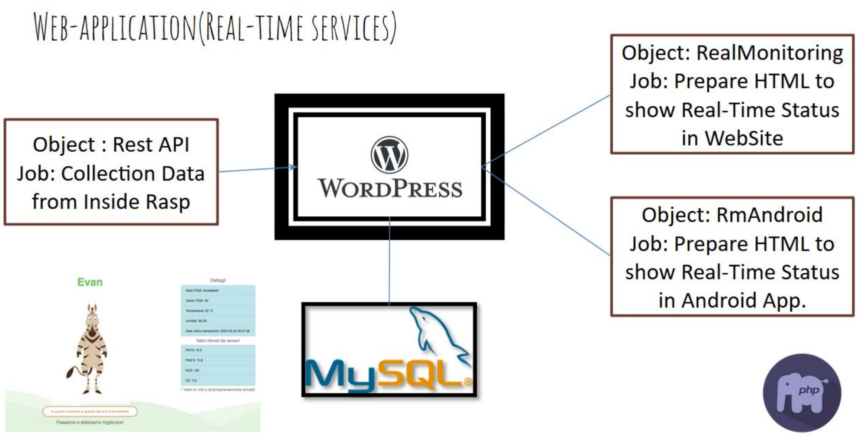


Figure 33: functions implemented on the Website

As you can see in figure 33, a REST Api is implemented in order to retrieve data from the inside raspberry through POST method and using ODBC protocol to store them in MySQL; We developed a class to manage data on the online database , such as the one used in raspberries (3.3.3), but in PHP language. In order to provide security on REST Api, we used a basic authentication (Auth V1.0), in which for each request (reading or inserting) username and password are mandatory.

The main function of the website is the real time monitoring of the avatar status, we created two different pages for the Web site and the Android App.

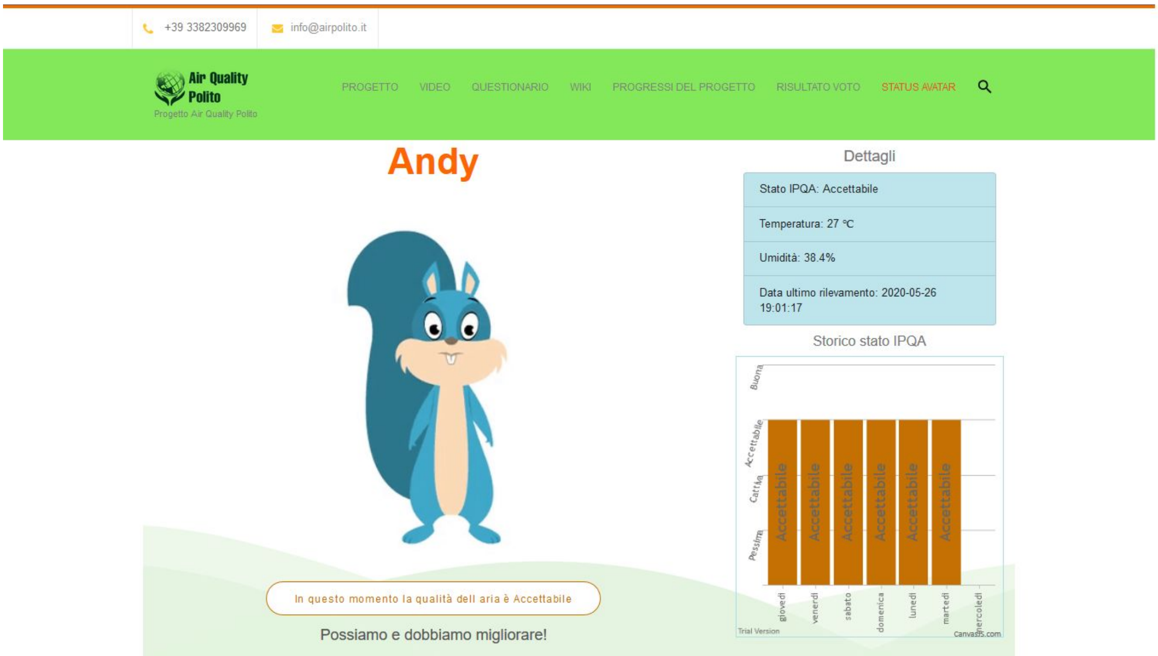


Figure 34: avatar real time monitoring

Some CSS and JavaScript files are provided especially for these two pages in order to have the same shape and scale. One of these CSSs is Bootstrap which is the most popular CSS Framework for developing responsive and mobile-first websites. The others Javascript are CanvasJS which is an easy to use HTML5 and Javascript Charting library. It runs across various devices including iPhone, iPad, Android, Windows Phone, Microsoft Surface, Desktops, etc. This allows us to create graphs for the data history that work across devices without compromising on maintainability or functionality.

Since we used WordPress as a template for our website, we were restricted to use default pages in the website. In particular, in the part of the avatar status we needed to create a custom page where we could put the file of the avatar statuses. In order to solve this problem we had to create a custom template which could be added to the original theme as an external template. We used this technique in implementing REST Api and showing status avatar.

3.3.5.2 The Android app

Due to the popularity of interacting through mobile phones among students and with the purpose of capturing their interest in this project, we developed an Android application named “Air Quality Polito” which has been published on the Google Play Store, with the same aims of the web site. Through it, students are able to: see the real-time avatar status, read about the project organization and read some information about the Air Quality Index we have chosen. In this sense, bringing the “Air Quality Polito” app in their everyday life, can be a way to truly influence and sensitize them about the “air pollution” theme.

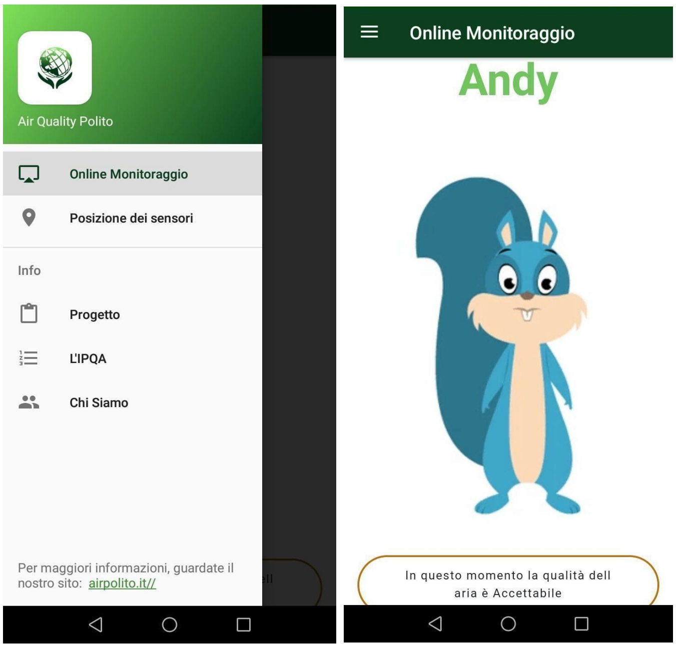


Figure 35: some screens of the application

To develop our application, we used Android Studio which provides the fastest tools for building apps on different types of Android devices. Android applications can be developed using the Java programming language and the Android SDK which was our choice.

The theme of the app is the one provided by Google in order to reach an optimal interaction with users (in terms of User eXperience, UX) and the Application Programming Interface (Api is a set of routines, protocols, and tools for building software applications) used is Android Lollipop (version 5.1 and Api level 22) which ensures an almost full compatibility of the application.

One of the latest platforms in android that is presented by google to improve compatibility, usage, velocity and new features is AndroidX. In this project, all the elements and widgets that we used are provided by this platform to guarantee the high compatibility of our application. In order to have more pages in application and navigating between them without lagging, we used fragments instead of activity to have fast replacing between the pages.

To show the avatar status, it has been used a WebView that allows to show a web page over the Internet (the page must be secured in SSL protocol) and it's a simple view which is connected to the corresponding page of the website.

One of the other sections is 'Location of Sensors' which is a map view that is connected to Google Map Api to retrieve an interactive and graphical map. Eventually, in order to put our application in the Google Play Store, we created a developing mode account. Before uploading, the application has been analysed by JIT-debugger in order to test its velocity and also, to prevent any future crashes; it was tested by 3 online robots to optimize the size of the application (from 8MB to 2.4MB).

After all of these procedures, we had to fill a registration form to upload the app and roll out. The most important features of this form were:

- Title and description of application;
- Graphic assets: manage app icon; screenshots; videos to promote app on Google Play;
- Type of application for categorization;
- Content rating for range of ages;
- Pricing and distribution, our app is free and it's available in all countries;
- Many other features relating to structure of application.

Finally, after uploading the first version of our application and waited about 7-8 working days, the version was accepted by Google and it was published on 20/04/2020.

As it can be seen in figure 36 which is exported from Google Play, our application experienced a significant rise in new and active users and it reached 25 active users at the beginning of May which is a really interesting for an university project.

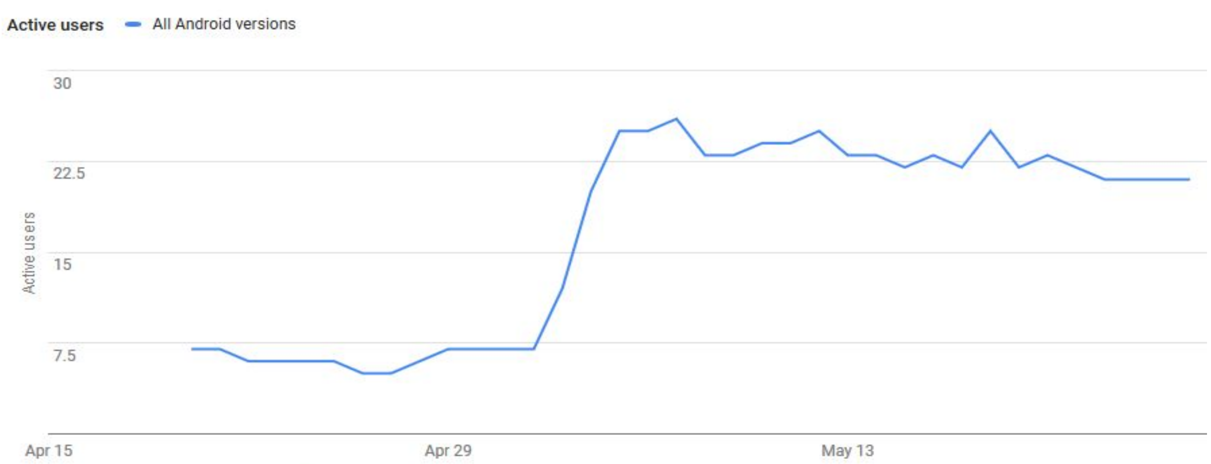
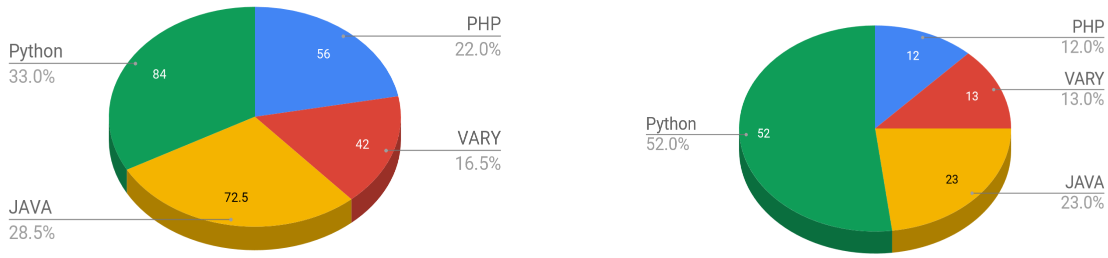


Figure 36: new user acquired

3.3.6 Coding effort

Thanks to PyCharm and Github, some interesting statistics about our project were obtained as it's shown in the figure 37; we worked over 250 hours for program, design and debug the project, time requested to design the algorithms or discuss about the technology is not included. In terms of lines of code, we wrote 7.229 lines in total with Python being used the most since the core is based on it.



a) b)

Figure 37: a) code hours; b) code lines

By comparison of these two figures, Python and Java were used in 75% of the project but it took about 60% of the total coding time.

4.Conclusions

4.1 Results

Despite the modifications due to the COVID-19 emergency, the project has been completed without any significant change to its initial configuration. We are currently collecting data from sensors and showing the results through the avatar.

On the technical side, we have registered that developing a low cost system for the air pollution monitoring is reasonable. Moreover, the technical scheme proposed here is a complete platform that could be adopted in different scenarios. In the end, this system is easy-to-install and doesn't require any maintenance from the final user.

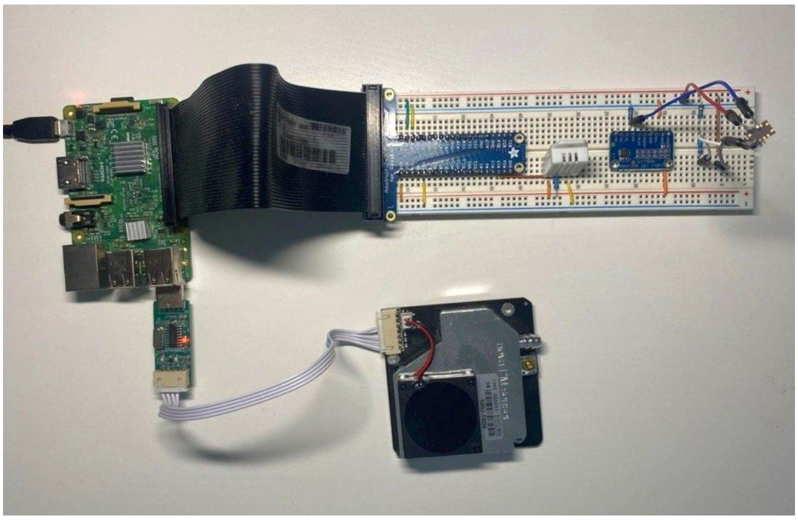


Figure 38: final prototype of our project

On the social side, we have registered a strong interest from students, teachers and parents about the air pollution theme. In particular, a good participation by students in the submission of eco-actions was registered. This allowed us to believe that future generations will have a deeper awareness of the world condition, from air pollution to climate change. As far as parents are concerned, a lot of advice was received from them during the parent survey, and they showed an active participation too, despite their behaviours not being completely eco- friendly. The main reason is probably that in the actual society there are not enough alternatives in the eco-friendly sense. For example, despite all initiatives and innovation in this sense, the usage of a car and so the usage of fossil fuel is still the main choice adopted. Often, this is a forced choice since there are not enough alternatives. Apart from these small peculiarities, interacting with them and with the teachers has been a good way to understand their point of view and so enriching ourselves.

4.2 Future developments

As expressed by the “Assessore all'Ambiente del Comune di Torino” in several interviews, there is a growing interest about the theme addressed by this project [14]. Turin, being a big city, is deeply affected by the air pollution problem. During the whole year, several times the municipality of Turin had to stop the movement of vehicles [15][16]. In this scenario, more and more schools are interested in installing a system like the one we have proposed to monitor the pollution in the surrounding of the school.

The scheme proposed for the Q AIR GOTCHI is pretty easy, it allows to have an endearing interface for students and let them interact with the system itself, moreover, it is easily scalable, it is a complete platform and, as already described, it is low-cost. All those characteristics bring the possibility of spreading this system in more and more schools creating a network of social environment connected by the air pollution interest. This could be a massive improvement in people's awareness about this theme.

Eventually, given the relevance of the air pollution theme, this project could be developed further in order to become a thesis project or, more in general, a bigger study on this subject.

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