Multipurpose Urban Sensing Equipment – An EPS@ISEP 2018 Project

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Abstract. This paper describes the development of a Multi-purpose Urban Sensing Equipment, named Billy, designed by a multinational and multidisciplinary team enrolled in the European Project Semester (EPS) at Instituto Superior de Engenharia do Porto (ISEP). The project is set to design, develop and test an interactive billboard in compliance with the relevant EU regulation and the allocated budget. The Team benefited from the different background, multidisciplinary skills and the newly acquired skills of the members, like marketing, sustainability and design ethics, in activities both inside and outside of the University. The challenge was to design a multi-purpose urban sensing and displaying equipment to inform citizens of nearby environmental conditions. The Team decided to design a system to monitor and display the temperature, humidity, air pressure and air quality of leisure areas, featured with a proximity detection sensor for energy saving. Billy will not only monitor and display this local information, but also the air quality determined by other billboards placed in other locations, creating a distributed urban sensing network. The system has been successfully prototyped and tested using the ESPduino Wi-Fi enabled micro-controller, different sensors and displays (screen and map-based). The results show not only that the prototype functions according to derived specifications and design, but that the team members were able to learn, together and from each other, how to solve this multidisciplinary problem.

1 Introduction

EPS challenges students from multiple educational backgrounds and nationalities to join their proficiencies [5] to solve multidisciplinary real-life problems in close collaboration. On the 26th of February 2018, ISEP assembled its EPS students into four groups, including the current team composed of Maarten van der Most, from Netherlands, 22 years old, studying Industrial Engineering and Management; Wouter Smit, also from Netherlands, 26 years old, studying Industrial

Design; Damien Cordeiro Marques, from France, 20 years old, studying Mechanical Engineering; Maria Bagiami, from Greece, 23, studying Environmental Engineering; and Mostafa Farrag, from Scotland, 20, studying Electrical Power Engineering. The Team chose to develop an interactive billboard to monitor and display the temperature, humidity, air pressure and air quality of leisure areas. By working together in a multidisciplinary team, the Team members had the opportunity to learn from each other and collectively, and achieve further than they would have individually.

Poor air quality has a negative impact on the quality of life. It causes many health issues, such as breathing or cardiovascular problems. These issues are even more critical in urban areas where there is often a poor air quality as a result of modern way of life [2]. The air in cities is polluted with small harmful particles. However, people are not fully aware of the actual level of air pollution. Although there are smart phone applications which provide related information, there is still a great lack of knowledge about this topic, as there is no system or object providing real and trusted local information. This is the Team's vision regarding the design of a smart billboard: a trusted equipment which informs and empowers people knowledge on how to improve air quality. This will not only benefit the public, but also governments by helping them to comply with the European Union (EU) rules [3].

In order to contribute to the minimisation of these problems, the team decided to build a connected billboard to provide citizens with real time air-related data concerning current and remote locations. The billboard was designed to measure local temperature, humidity and air pressure, estimate the local air quality, show the estimated air quality of the connected remote locations, display useful information and advice on how to improve air quality. The final objective of Billy is to raise the public awareness by offering as much information and advice as possible and, thus, contribute to the improvement of the air quality and the reduction of health related problems.

The team searched for similar equipments and performed several studies on marketing, ethics and sustainability to design Billy as a smart billboard. Billy not only collects and shares information about the current local time, weather and air pollution, but informs on how to reduce the carbon footprint and on upcoming local activities. To design and develop Billy, the team had to integrate what they learned in their individual field of study. Billy main potential clients will be governmental bodies and local public authorities.

This paper is organised in six sections, including this introductory section. Section 2 describes existing types of billboards; Section 3 details the background studies performed; Section 4 presents the design and development of the prototype; Section 5 reports the tests and results; and Section 6 draws the conclusions.

2 Billboards

A billboard is a large outdoor advertising structure (a billing board), initially found in high-traffic areas such as alongside busy roads and presenting large

(a) Painted billboard [6]

(b) Human billboard [7]

(c) Mobile billboard [11]

(d) Digital billboard [4]

Fig. 1: Types of billboards

advertisements to pedestrians and drivers and distinctive visuals, billboards are highly visible in the top designated market areas. Typically showing witty slogans, billboard advertisements are designed to catch public attention and create a memorable impression very quickly, leaving a lasting impression on readers. They have to be short and easy to read because cars can drive by at high speed. This section presents the different purposes of billboards, leading to the team's decision to create Billy.

Figure 1 illustrates the most common types of billboards:

- Painted billboards: This traditional billboard displays a painted message or advertisement.
- Human billboards: The human billboard is a person who displays an advertisement. The person can just wear a T-shirt with a message, carry a small billboard or also "wear" the billboard. Frequently, the person will spin, dance or wear costumes with the promotional sign to attract attention.
- Mobile billboards: A mobile billboard, also known as "truck side advertising", is used for advertising on the side of a truck or trailer. Unlike a typical billboard, mobile billboards are able to go meet their target audience.
- Digital billboards: A digital billboard is a billboard that displays changing digital images. Imagery and text are created using computer programs and

software. Digital billboards are primarily used for advertising, but they can also be adopted by public services.

3 Background Studies

The team decided to create Billy, a smart billboard, to collect and share publicly information on the weather and pollution, using IoT cloud. For sustainability reasons, the team chose to use wood as building material and a solar panel as renewable energy source. This section will present different background studies conducted by the team to define the proposed solution.

3.1 Marketing

Since the European Union has set the maximum allowed air pollution, the team decided to create a public product to display the air pollution and advise on how to improve the air quality in their area. Consequently, the team chose to target city councils and offer a multipurpose urban sensing equipment. Billy stands out from its competitor because it provides: (*i*) information about local and remote air pollution, indicating the spatial distribution of urban air pollution; and (*ii*) advice on how an individual can improve the local air quality. The team has decided to use a differentiation strategy. The product will be promoted with direct marketing to the decision making entities of the city councils in Europe as a solution to measure air pollution, informing inhabitants with local information [10] on air pollution and how to mitigate it [1].

3.2 Eco-efficiency Measures for Sustainability

Engineers must adopt sustainable development practices when designing new products. Thus, the team took equally into account the environmental, economic and social aspects of sustainability in order to design a sustainable billboard. Based on this study, the team chose to use environmental friendly materials, *e.g.*, natural materials or materials which can easily be recycled and are not harmful to the environment. The team opted to display the air quality for social reasons and to use a power supply unit composed of a solar panel and battery for environmental and economic reasons. Moreover, by informing the public on how to protect against air pollution and on how to improve the air quality, the team increases the efficiency of billboard, making it even more sustainable [9].

3.3 Ethical and Deontological Concerns

In the ethical and deontological analysis, the team considered the production, servicing and recycling of Billy. The focus of the company will be on honesty, respect and high standards in every step of the production process, including choosing suppliers and components, selling and marketing the product and providing a warranty of two years, even if it increases costs. In the case of breakdown, the company will collect Billy from the customer to reuse or recycle the parts. Team Billy will not use suppliers for whom it is unsure if they use child labour. In terms of environmental ethics, the decision to adopt a solar panel and a battery reduces the usage of fossil fuels.

4 Project Development

4.1 Pre-defined Requirements

The project proposal specified the mandatory use of the International System of Units, sustainable materials, low-cost hardware solutions, open source software and technologies, the compliance with the European Union (EU) Machine Directive (2006/42/CE 2006-05-17), EU Electromagnetic Compatibility Directive (2004/108/EC 2004 12 15), EU Low Voltage Directive (2014/35/EU 2016-04-20), EU Radio Equipment Directive (2014/53/EU 2014-04-16), EU Restriction of Hazardous Substances (ROHS) in Electrical and EU Electronic Equipment Directive (2002/95/EC 2003-01-27), and a maximum budget of 100.00 €.

4.2 Functionalities

The main functionality of the billboard is to publicly display the temperature, humidity, air pressure and the air pollution. Billy is designed to sense these parameters, process the readings and display the results individually.

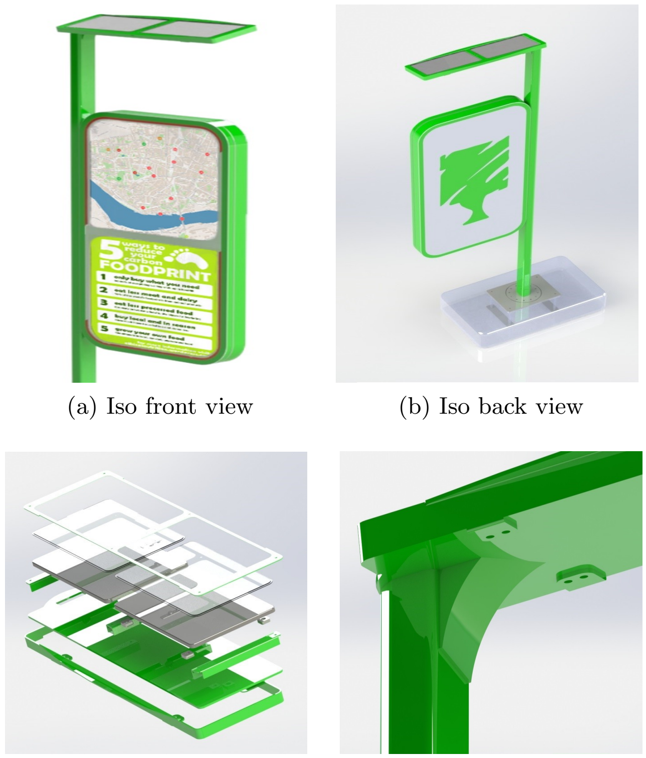
The map-based display is colour coded to indicate low, normal and high values of the air quality, using green and red light-emitting diodes (LED). The map of the enlarged urban area is dotted with green, amber and red LED over the locations of the billboards deployed in the urban area. It additionally displays complementary information about the air quality, health and safety, and public activities to assist citizens in keeping a high standard life style. Finally, Billy was designed to be echo-friendly as it is solar powered. It includes a photovoltaic system and a battery to sustain its operation day and night.

4.3 Design Structure

The structure of the product, which was drawn in SolidWorks, was divided into the top, middle and bottom part to make it easier to develop and assembly.

The top part holds the sustainable energy source – the solar panels – which powers the system. These solar panels are wired to the power unit through the hollow stand of the billboard. This part has several requirements: (*i*) be waterproof; (*ii*) be robust and vandal proof; (*iii*) be easy to assemble and disassemble for maintenance; (*iv*) be easy to recycle; (*v*) protect the solar panels; and (*vi*) be easy to clean. To strengthen the structure, an additional piece was developed and attached to the top part and to the stand of the billboard. It makes the structure more robust and vandal proof and contributes to an attractive design.

The middle part – the core of the billboard – has to: (*i*) be attached to the stand of the billboard; (*ii*) be watertight; (*iii*) have ventilation to make sure



(a) Iso front view (b) Iso back view

(c) Middle assembly (d) Top attachment

Fig. 2: 3D Model of the structure

the warmed up air can escape; (*iv*) be dust proof (on the inside); (*v*) be easy to open, close and dissembled for maintenance; (*vi*) house the control system, the map-based display with the LED indicators and the text-based display to inform and advise people, e.g., on how to reduce their ecological footprint.

The bottom part or stand is intended to hold the other parts. The bottom part has a few important requirements: (*i*) be robust to hold the complete structure; (*ii*) be vandal proof; (*iii*) be adjustable to the deployment area (to position it as well as possible); (*iv*) be fitted as different parts to build the product up at the location where it should be installed.

4.4 Control System

The billboard is equipped with a control system to implement the identified functionalities. The power unit includes a photovoltaic solar panel for power supply and a battery for energy saving. The ESPduino micro-controller, which includes a Wi-Fi module, is responsible for reading, communicating and displaying the local sensor values in the organic light-emitting diode (OLED) display and on the map-based LED display as well as for obtaining and displaying the remote air quality on the map-based LED display. While the proximity detection sensor and gas sensor are directly connected to the ESPduino, the humidity, temperature and air pressure sensors are connected through a signal conditioner to adapt the sensors signals to the micro-controller input requirements. The billboard is connected to an Internet of Things (IoT) cloud platform (ThingSpeak) to save and share information through the public Wi-Fi network. The values are displayed on the LED display, using different colours to indicate the air quality status. Figure 3 displays Billy's conceptual diagram.

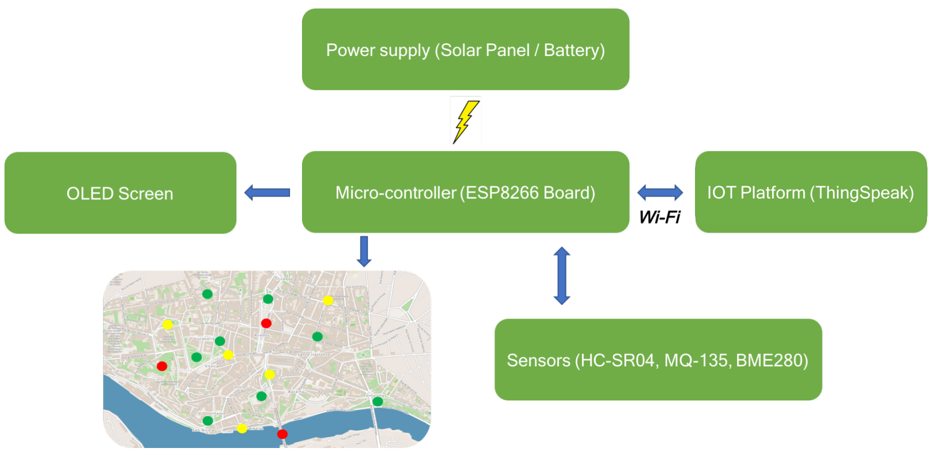


Fig. 3: Conceptual diagram

Table 1 holds the maximum expected voltage, current and power consumption per component. Considering that the prototype will display the air quality

Table 1: Power budget

Component	**Voltage** (V)	**Current** (A)	**Power** (W)
Green LED	1.8 – 2.2	0.040	0.088
White LED	2.4 – 3.6	0.040	0.144
Red LED	1.8 – 2.7	0.040	0.108
MQ-135	5	0.150	0.750
BME280	1.2 – 3.6	0.000	0.000
Solar Panel	5	0.600	0.300
ESP8266 board	5	1.000	5.000
HC-SR04	5	0.015	0.075
OLED	3.3 – 5.0	0.020	0.100

of up to two locations (2 sets of red and green LED), it will need a power source capable of providing a current higher than 3.885 A and a power of at least 14.076 W. Based on this analysis, the team selected of a power source with 4.0 A and 27 W.

The control algorithm starts by initialising the parameters and configuring the micro-controller and, then, implements the control loop. This continuous loop performs the following tasks: (*i*) sensor data acquisition and display (OLED); (*ii*) uploading of local air quality to ThingSpeak; (*iii*) downloading remote air quality (remote sites) from ThingSpeak; and (*iv*) map-based air quality display.

The MQ135 measures the concentration of CO_2, NH_3, NO_x, benzene and alcohol in parts per million (ppm). According to [8], if the concentration value is below 500 ppm, the air quality is good and, otherwise, the air quality is bad. Consequently, the green LED illuminates when the concentration value is below 500 ppm and, otherwise, the red light illuminates.

5 Tests and Results

The experimental set-up, which was assembled in a breadboard, includes the ESPduino micro-controller, the gas sensor (MQ-135), the humidity, temperature and air pressure sensor (BME280), the ultrasonic range sensor (HC-SR04), the OLED screen and a set of two of each red, white and green LED. Figure 4 displays the experimental set-up. The sensors were connected to the ESPduino

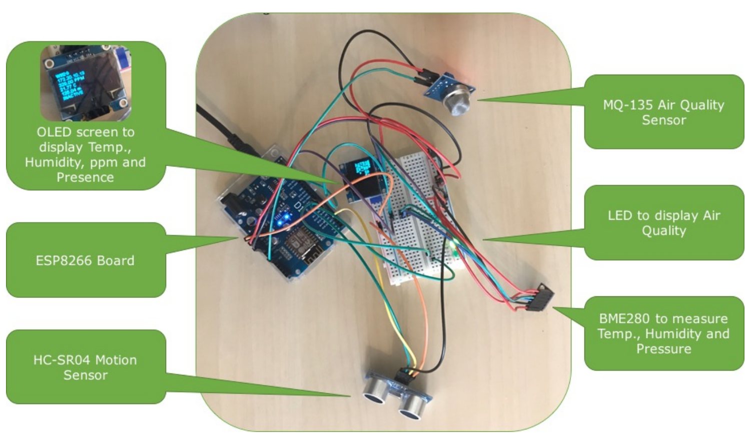


Fig. 4: Experimental set-up

(Arduino) as follows: (*i*) the MQ-135 is connected to A0; (*ii*) the OLED, HC-SR04 and BME280 are connected to the Arduino via I2C interface; and (*iii*) the LED are directly plugged to the Arduino GPIO interface.

Figure 5 displays the assembled prototype. It includes the main map-based LED display, the OLED and the complementary information panel bellow, advising people how to reduce their footprint. The different LED report the air quality of the different areas (green for good and red for bad). The OLED provides the following information: (*i*) the Internet Protocol (IP) address of the device connected to the Wi-Fi; (*ii*) the concentration of the measured gases in ppm; (*iii*) the temperature in °C; (*iv*) the relative humidity in %; (*v*) the pressure in hPa; and (*vi*) the output of the presence detection sensor.

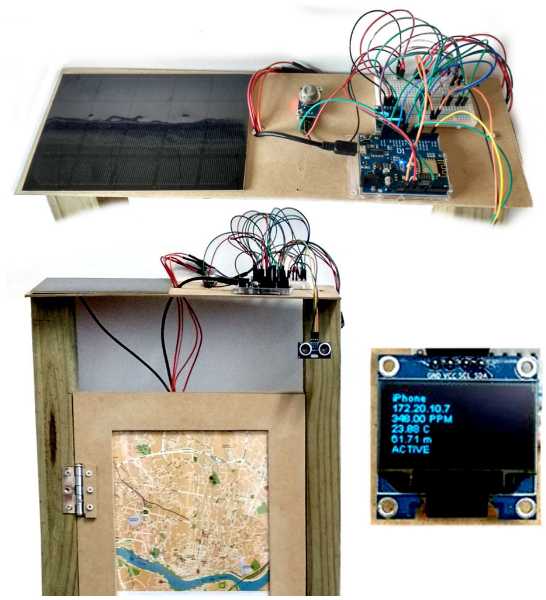


Fig. 5: Prototype

5.1 Tests

The Team performed a set of functional tests to ascertain whether 'Billy' complied with the requirements and was ready to be transformed into a product for release in the market. The tests were performed as follows:

- Temperature & Humidity Sensor: the sensor was placed near a cold source (cloth with ice) to lower the temperature and near a heat source (warm damp cloth) to raise the temperature and the humidity (warm damp cloth);
- Air Quality Sensor: the sensor was placed near a gas source (kettle) to see if it detects gas and lights up the LED (green is low and red is high);
- Proximity Detection Sensor: the sensor detected an object within the detection desired zone. First, in calibration mode, the sensor was adjusted to cover the desired distance and, then, was switched to regular mode;
- Photovoltaic panel: the solar panel was placed outdoor and the voltage and current charging the battery monitored.

Table 2 summarises the functionalities tested. First, the OLED test involved sending and displaying "Hello World" on the screen. Second, the temperature, humidity and air pressure (BME280) test comprehended reading and displaying the three values on the screen. Last, the gas (MQ-135) test consisted of reading the values and lighting the four LED accordingly.

Table 2: Functionalities tested

Ref	Component	Test
DISP	OLED Display	Draw strings and pictures
Wi-Fi	Wi-Fi on board	Connection to WLAN
BME	BME280 sensor	Temperature acquisition
SR04	HC-SR04 sensor	Motion detection
MQ135	MQ-135 sensor	Air quality measurement
LED	LED	Light the LED on
IOT	IoT Cloud	Communication with ThingSpeak

5.2 Results

Table 3 displays the expected and achieved results of the functional tests. The expected results of each test were defined beforehand. The actual results matched the expected results, which means that the parts tested were working properly.

Table 3: Results of the functional tests

Part	Test	Expected result	Result
DISP.01	Draw a string	String displayed	Yes
DISP.02	Draw a picture	Picture displayed	Yes
Wi-Fi.01	Connect to Wi-Fi	@IP displayed	Yes
BME.01	Acquire temperature	Temperature displayed	Yes
BME.02	Warm the sensor	Temperature raise displayed	Yes
SR04.01	Acquire distance	Distance displayed	Yes
SR04.02	Establish proximity	System activated/deactivated	Yes
MQ135.01	Acquire ppm values	ppm values displayed	Yes
MQ135.02	Breath over	ppm values increase displayed	Yes
LED.01	Specify a colour code	Corresponding LED on	Yes
IOT.01	Send data toIoT Cloud	Value displayed n the dashboard	Yes
IOT.02	Get ppm values from IoT Cloud	Light LED accordingly	Yes
UAT.01	Connect to Wi-Fi	OLED displays @IP	Yes
UAT.02	Detect presence	OLED activation	Yes
UAT.03	Measure temperature	OLED displays temperature	Yes
UAT.04	Measure ppm	OLED displays ppm value	Yes
UAT.05	Send data to IoT Cloud	Data displayed on IoT dashboard	Yes
UAT.06	Display air quality of other bills	Download data and light LED	Yes

6 Conclusion

The goal of this project was twofold: (*i*) to design, develop and test a proof of concept prototype of Billy; and (*ii*) prepare engineering undergraduates for their future profession. The latter is achieved by providing a multicultural, multidisciplinary and collaborative learning experience where distinct visions of the problem need to be integrated to reach the final team solution.

Billy is a smart urban equipment intended to inform and raise the awareness of the public regarding the quality of urban air. In standalone mode, it displays the local temperature, humidity, air pressure and air quality as well as information and advice on how to improve the air quality and reduce related health problems. In addition, in network mode, it presents the air quality of connected locations. Currently, Billy meets most of the requirements set by the Team, and the members are on verge of concluding the development.

Collaborative learning is not always easy and, in a multicultural and multidisciplinary context, becomes even more demanding. The hardest challenge the Team faced was how to make the individual visions of the problem converge to a common solution since it was their first work and learning experience in a multicultural and multidisciplinary set-up. The Team members learned about themselves, from each other and together while participating in EPS@ISEP and staying in a new country, with its own culture and traditions. These are their testimonials:

– *"I'm grateful for having the opportunity to participate in the EPS@ISEP, it was an amazing experience to be in Porto learning many new things and meeting new people, while discovering Portugal and its culture. Within the EPS I have learned different information on different areas of studies. I'm glad working with team members who are willing to put 100 percent into their work to make our project to be standing out"* – Mostafa.
– *"EPS was for me a great opportunity to meet people from all over Europe and make friends and connections. EPS also enabled me to develop my skills and the best way to improve my English"* – Maria.
– *"The thing I liked the most about EPS was to learn to work with people from different nationalities and cultures. Before I did the project, I thought there were only minor differences between European cultures, but during the project I realised that every country has so many differences"* – Maarten.
– *"The European Project Semester was really good experience to learn about multiple cultures and their way of working, not only from Portugal, but also the different countries that your team members are from. Also, I loved to work on a project that is focussed on sustainable energy and materials and a solution for a problem that improves people's lives. It's a good structured project semester that has a lot to offer"* – Wouter.
– *"The European Project Semester at ISEP was a very rewarding experience. I'm used to work in team but it was the first time that I worked with people from different countries and backgrounds in a global project where we have not only to design an object but also think about marketing, management and sustainability. We are all coming from different cultures and working methods so we learned a lot from each other. I also learned different studies which I'm not specialised at such as sustainability and project management. This project also made me grow up, I'm now more tolerant and I trust more easily*

my team mates. As we used English to communicate, I'm now much more comfortable to speak this language than in the beginning. Even if I already knew some things about Portugal culture, history and language, working in Portugal give me the opportunity to increase my ability to speak this language and also to know new things thanks to some trips and visits" – Damien.

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References

1. CleanTechnica. Best Air Pollution Startups - Breathing Easy, "State of Pollution" Series. https://cleantechnica.com/2017/08/11/best-air-pollution-startups/, 2017. Accessed: May 2018.
2. European Council. The clean air package: Improving europe's air quality. http://www.consilium.europa.eu/en/policies/clean-air/, 2017. Accessed: May 2018.
3. James Crisp. 23 Pays de l'UE Violent les Règles de Qualité de L'air. https://www.euractiv.fr/section/climat/news/23-eu-countries-are-breaking-european-air-quality-laws/, 2017. Accessed: May 2018.
4. LEDtronics. LEDtronics: LED Displays — Digital Billboards — Media Facade. http://ledtronics.com.my/, 2018. Accessed: May 2018.
5. Benedita Malheiro, Manuel Silva, Maria Cristina Ribeiro, Pedro Guedes, and Paulo Ferreira. The European Project Semester at ISEP: the challenge of educating global engineers. *European Journal of Engineering Education*, 40(3):328–346, 2015.
6. Izms of Art. Izms of Art Live Billboard Painting. https://izmsofart.wordpress.com/2012/06/03/izms-of-art-live-billboard-painting/, 2012. Accessed: May 2018.
7. Pinterest. Human Billboard Advertising. https://www.pinterest.co.uk/pin/571675746426128706/, 2015. Accessed: May 2018.
8. Pravin E. Shinde and Vikram H. Javeri. Air quality monitoring system. https://www.slideshare.net/Pravin1993/air-quality-monitoring-system, 2014. Accessed: June 2018.
9. PVthin — Thin Film PV Technology. Life Cycle Analysis. http://pvthin.org/life-cycle-analysis, 2018. Accessed: May 2018.
10. Time. This Billboard Sucks Pollution from the Sky and Returns Purified Air. http://time.com/84013/this-billboard-sucks-pollution-from-the-sky-and-returns-purified-air/, 2014. Accessed: May 2018.
11. Truckbillboards. Truck Advertising on Billboards Long Island NY. https://truckbillboards.wordpress.com/tag/mobile-billboards//, 2018. Accessed: May 2018.