Monitoring cultural heritage buildings via low-cost edge computing/sensing platforms: the Biblioteca Joanina de Coimbra case study

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ABSTRACT

Climate change and higher level of pollutants are affecting our heritage affect the conservation abilities and endangering centuries old buildings and artifacts. Governments and conservation agencies alike are scrambling to monitor and prevent disasters that would result in the loss of precious cultural artifacts. Sensing technologies, on one side, and new restoration techniques on the other, are in being used in this effort however they result in high costs and complex installation logistics. In this paper we present a pollution monitoring study for the *Biblioteca Joanina*, a baroque library situated in University of Coimbra that has been inducted in the UNESCO world's heritage list in 2013. In contrast with current practices the study has been conducted using a low-cost sensing platform, namely CANARIN II, built in a joint effort by the Sorbonne Université, the Macao Polytechnic Institute and the Asian Institute of Technology (Thailand). Our study shows that is possible to use low-cost platform for cultural heritage monitoring and preservation and how it can support decision makers in execute simple policy changes and yet achieve substantial impacts in the preservation efforts.

CCS CONCEPTS

• **Applied computing → Environmental sciences**;

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KEYWORDS

Heritage conservation, urban sensing, edge computing, fog computing

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After the introduction of Decree Law n. 78/2006 April 4, in Portugal, the indoor air quality (AIQ) has become a social need and national buildings, offices, libraries and shops started to tackle the airborne pollutants problem. Some sites in particular, such as old libraries and ancient museums need further attentions to manage 'the invisible killer', as has been coined the air pollution by the World Health Organization (WHO) [14], assuring the visitor an healthy location and guaranteeing the correct preservation of works of art and cultural heritage [7].
This represents the first action to manage a phenomenon in a different context than industrial and urban ones.
Several invasive techniques are available in modern building such as air conditioning (HVAC) and heating monitoring, but different strategies must be implemented in historical sites where their structure is part of the heritage, maintaining contaminants levels at low concentrations for human health [6]. Since most museums or libraries cannot afford dedicated complex monitoring systems, the Internet of Things (IoT) represents a promising, cost-efficient, not-invasive approach to measure air pollutants. [9][8]
In this context, in June 2017 we started a monitoring campaign into the XVIII century Baroque library of the University of Coimbra - also called Joanina Library (Portuguese: Biblioteca Joanina) - placing several our sensor stations inside the building. From 2013, the historic centre of the city, including the University of Coimbra and its library, were declared a World Heritage site by UNESCO [12]

making them one of the most visiting sites in Portugal drawing the attention of local and foreign tourists.
In particular nine Canarin II (a sensor for detecting particulate matter, as a pollution monitor [10]) have been installed in the three floors of the library, gathering different parameters 24/7 providing a collection set of data, useful by third parties to assess their own air pollution models.
In this paper, we present a preliminary campaign results from the sensors stations deployment between Summer 2017 and Spring 2018.

1 THE SPATIAL CONTEXT

The Joanina library is located in the heights of the historic center of the University of Coimbra (UC), 120m above the sea level. It was built between 1717 and 1725, and the decoration works lasted for another three years. [2]
It consists of three floors: the Noble floor, the Intermediate floor and the Academic Prison.
The noble floor is the heart of the site and stores circa 40,000 books; it's rich in decorated ceilings and walls, ancient wooden bookshelves with golden details. The Intermediate floor has workplace tables and some cases as a small exhibition [5].
The Academic Prison, worked from 1773 until 1834 [11] and it had a souvenir shop until Summer 2018.
The library is daily open, with 180 visitors each hour maximum: 20 minutes shifts with 60 people, receiving more than half a million tourists in 2017. Visitors are accepted from 9h00 to 13h00 and from 14h00 to 17h30 in Winter and from 9h00 to 19h30 in Summer.
Last average rainfall amount in Coimbra varied between 5.5mm in July 2017 (3 days) and 449mm in March 2018 (26 days). The average outdoor temperature was 26°C in Summer and 10°C in Winter. The average wind speed was 5.1mph in August 2017 and 8.1mph in March 2018. [4]
A peculiarity of this library is the presence of bats inside of it. Despite thinking of them a source of risk for the book collection inside, the bats "are essential for the maintenance of the books since they eat bookworms" but "they leave a thin layer of droppings over everything" [3] that requires daily maintenance and cleaning.

2 MONITORING CAMPAIGN

Initial environmental conditions studies started at the end of the 20th century and in last years the Rectorate of the University started "a research project focused on the accurate characterization of the indoor environmental conditions within the Baroque library and on the assessment of risk situations, both for heritage and health issues" [5].
In early 2017, a preliminary environmental analysis has been done by the Department of Mechanical Engineering of the University of Coimbra. [5] Subsequently we started a new monitoring campaign led by the Macao Polytechnic Institute in collaboration with the Sorbonne Université, at the beginning of June 2017, placing first three Canarin II in the noble floor, focusing on Particulate Matter (PM) concentrations. In particular, we put one sensor on the mezzanine floor close to the main entrance, one at the bottom of the main entrance and one to the door to the intermediate floor. They are constantly plugged to the library power source even if electricity is available on during opening hours; Rechargeable lithium batteries are installed to extend data availability during the night.
Until November 2017, tourists used to enter from the main big door at the noble floor, then the administration decided to let them enter from the academic prison/souvenir shop to mitigate the impact of the dust from the main courtyard in front of the library.
After November 2017 other six stations have been installed:

- One in the academic prison, close to the new entrance;
- One inside, at the intermediate floor, on a table;
- One outside, at the intermediate floor, laced to a window grid;
- Three more in the noble floor, covering all the area: two on the floor and one on the mezzanine wooden floor.

Collecting data in in the whole area of the library makes it possible to identify which different factors play a role in the PM trend into the different floors. Along with air pollutants, other aiding parameters are gathered and presented in Table I:

Measure	**Sensor type**	**Unit of measure**	**Monitoring interval**
Temperature	Thermistor	°C	Every 60 sec
Humidity	Thermistor	%	Every 60 sec
Air Pressure	Piezoresistive sensor	hPa	Every 60 sec
$PM_{1.0}$	Light scattering optical analyzer	μg/m^3	Average value from 30 samples achieved in 30 seconds
$PM_{2.5}$	Light scattering optical analyzer	μg/m^3	Average value from 30 samples achieved in 30 seconds
PM_{10}	Light scattering optical analyzer	μg/m^3	Average value from 30 samples achieved in 30 seconds

Table 1: Measurements details and monitoring intervals

In Autumn 2018 some FLIR Lepton 3.5 thermal cameras will be installed inside the sensor stations to:

- Check the relationship between heat sources and pollution
- Track the bats behavior inside the library

3 ARCHITECTURE

Canarin II [1] is a powerful low-cost, low-power Arduino/Linux single board running an ARM® Cortex-A9 microprocessor and a Cortex-M4 I/O real-time co-processor. Its design, code and architecture are the joint result between Sorbonne Université, the Macao Polytechnic Institute (MPI) and the Asian Institute of Technology (AIT - Thailand). It detects PM_{10}, $PM_{1.0}$ and $PM_{2.5}$, air pressure, temperature and relative humidity, in an indoor environment.

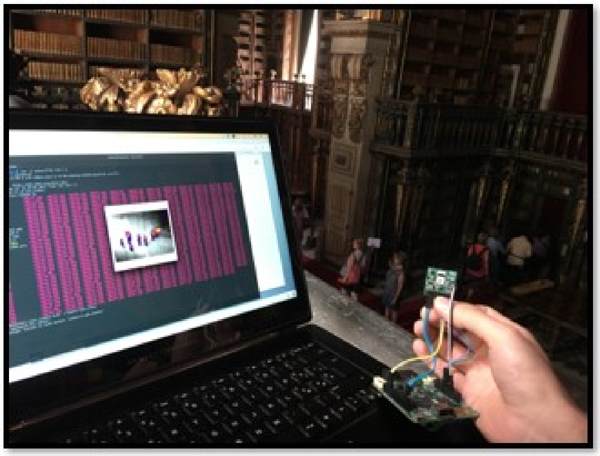

Figure 1: A thermal camera demo inside the library

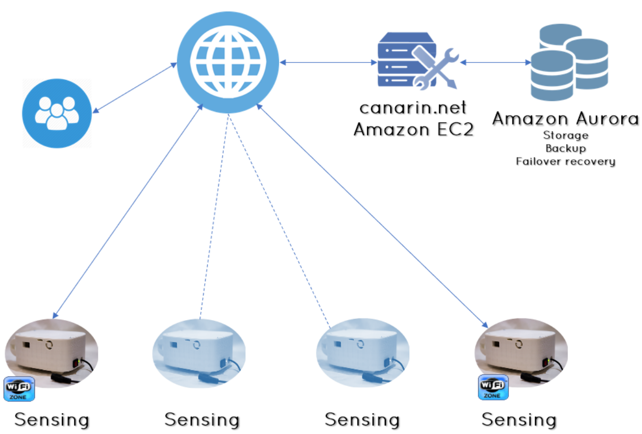

Figure 2: Canarin II architecture

From its previous version [10], Canarin II has been enhanced with a new firmware and new sensors. In particular it has:

- More storage capability: all the systems are equipped with 32GB SD cards;
- WiFi now supports WPA2-Enterprise and 802.1X Simplified
- PM sensor software is improved gaining refined values;
- The Linux kernel and its packages are updated and maintained

Canarin II's core runs an Arduino-like sketch on the real-time coprocessor that coordinates every sensors mentioned before. The hardware is based on in-house printed circuit board (PCB) that encapsulates the board, the wiring and the sensors' sockets. Around it, a 3D printed polylactic acid (PLA) box has been designed to tangle the PCB and the 6800mAh lithium battery together. Its size is 19x15x7 cm and it weighs about 900g.
The communication relies on *Eduroam* Wi-Fi offered by the University of Coimbra nearby, even if the board also supports GSM network using the EAP-SIM (EAP Subscriber Identity Module) authentication framework by means of a USB SIM reader; in the current setting *Eduroam* has been preferred.
The communication protocol is based on a customized UDP; every Canarin II interacts with a server that runs on a Amazon EC2 instance, which manages the packets and stores the sensors values into a MySQL database (Amazon Aurora). Amazon Aurora ensures fail-over recovery and DB daily backups.

During the closing hours, since the library doesn't provide power supply, the lithium battery inside every canarin let the sensors sample during the night. In the morning the power has restored and all the data, stored into the SD card, are uploaded to the server.

Range $PM_{2.5}$	Air Pollution Level	%
0 - 12.0	Good	56,42
12.1 - 35.4	Moderate	36,54
35.5 - 55.4	Unhealthy for sensitive groups	4,65
55.5 - 150.4	Unhealthy	2,30
150.5 - 250.4	Very unhealthy	0,06
250.5 - 500.4	Hazardous	0,03

Table 2: Air quality level in the Noble floor from Nov 2017 to Jul 2018

4 PRELIMINARY DATA ANALYSIS

This paper presents some preliminary results obtained during the campaign started on Summer 2017 (still active).
Particulate matter - and others parameters - are monitored in four different scenarios:

- In the noble floor - upstairs, on the mezzanine wooden floor by Canarins #2, #4, #6, #7, #8
- In the noble floor - downstairs by Canarins #5, #8
- In the intermediate floor/prisons by Canarins #9, #1
- Outside by Canarin #3

Up to August 2018, we collected 5,574,959 samples between PM_{10}, $PM_{1.0}$ and $PM_{2.5}$.
As shown in Table II, in the noble floor we detected good air pollution level in 56.42% of the time, according to US-EPA 2016 standard [13] thats defines air quality level (AIQ) into six categories:

- Good: $PM_{2.5}$ [0 - 12.0]
- Moderate: $PM_{2.5}$ [12.1 - 35.4]
- Unhealthy for sensitive groups: $PM_{2.5}$ [35.5 - 55.4]
- Unhealthy: $PM_{2.5}$ [55.5 - 150.4]
- Very unhealthy: $PM_{2.5}$ [150.5 - 250.4]
- Hazardous: $PM_{2.5}$ [250.5 - 500.4]

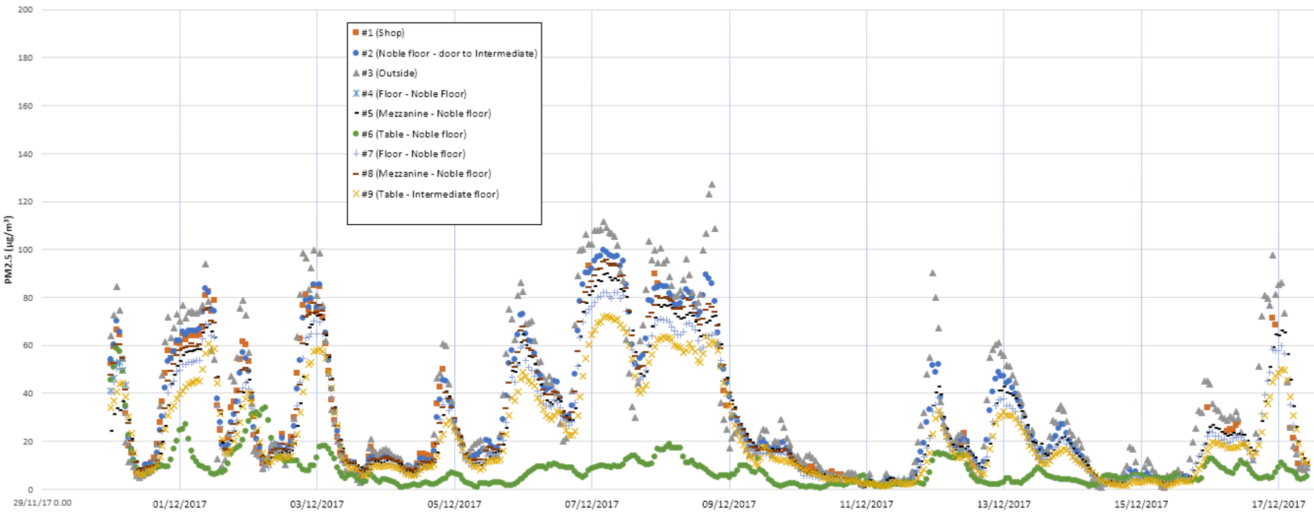

Figure 3: All Canarins $PM_{2.5}$ concentrations values from 30 November 2017 to 18 December 2017

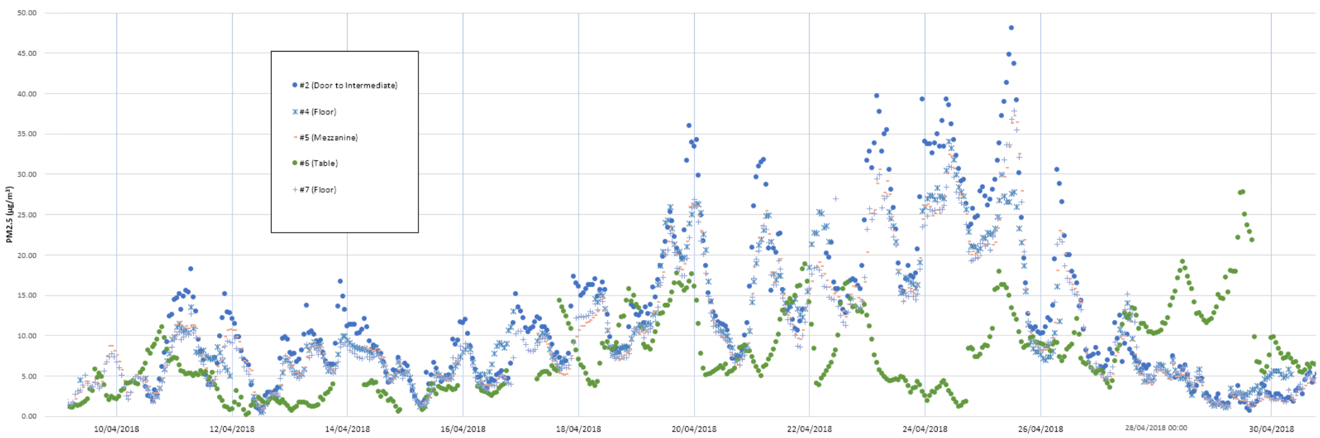

Figure 4: Noble floor Canarins $PM_{2.5}$ values from 9 April 2018 to 30 April 2018

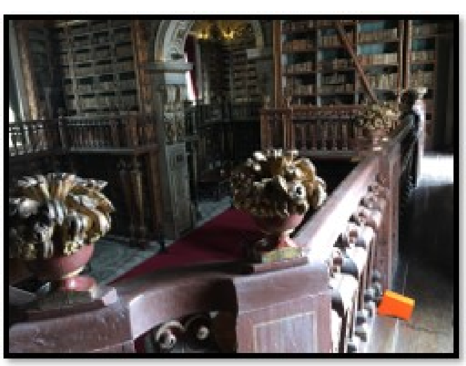

Figure 5: Canarin #5 on the mezzanine floor

Figure 3 presents the $PM_{2.5}$ concentration trending in the time window between 30 November 2017 and 18 December 2017. At the first glimpse, the reader could see how all the sensors tend to follow the same trend even if not all the Canarins are in the same spot. High values peaks are present during the night, after the closing time.

The Canarin outside the window (#3 - grey triangle) detects the highest values and it defines the trend maximum boundaries while the Canarin on the table in the Noble floor has the lowest values. The latter does not seem to 'follow the trend', probably due to a malfunctional PM sensor. In our past experience, we checked that some sensor in a batch could lead to underestimated values.

In Figure 4, on the other hand, it shows the behavior focused on the noble floor from 9 April 2018 to 30 April 2018: the sensor close to the passage to the intermediate floor shows the highest values; in fact this is a spot in front of the tourist tour, inside the

library. In this time window, the sensor on the mezzanine matches the sensors on the floor: the different height does not affect much the values. Canarin #8 was off on April.
From the two trends it can be state that the concentrations of particles on December are much higher than the ones in April. Therefore, it remains unclear whether this is related to the house heating in cooler months as December that may influence the air pollution in Coimbra; consequently much particulate matter might enter into the library with tourist tours.

5 FUTURE DATA ANALYSIS

Further data analysis will be done, to prove if there is a correlation between tourists and PM values inside the library. We will also correlate other sensors with PMs like temperature/PM or humidity/PM together with some forecast measures like rain and wind speed. Link between number of people inside and PM values will be study. Plus, a whole-year analysis will allow a comparison between different seasons and weather.

6 FINAL REMARKS

This paper proposes an indoor pollution study for the UNESCO heritage Biblioteca Joanina in Coimbra, Portugal. The study was performed using a low-cost edge based sensing platform and enabled the library managers to understand how to modify the paths of tourists in order to reduce the PM in the library. We also noticed an higher than expected impact of the outside pollution into the library likely due to the ancient doors and window that do not represent a bearer for the $PM_{2.5}$ or PM_{10}. In our next step we plan to develop a privacy-aware tracking technology to enable the correlation between PM values and the actual paths taken by the tourists. This will require to build a distributed computing systems to perform the necessary machine learning tasks in a distributed fashion.

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