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Contribution of an environmental monitoring system to evaluate the potential effect of urban air pollution

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Abstract

The growth of the world's population has been followed by the increase of residents living in urban areas, which very often results in additional pressures concerning space, ecosystems, infrastructures, facilities and the way of life. The impact of pollutants, emitted into the atmosphere, on materials is enormous and could be irreversible. The effects of the air pollution in façades and on the structural systems lead to unexpected costs for the buildings maintenance and may be avoided if pollution monitoring systems exists.
This work presents a methodology to evaluate, on a regular basis, the potential impact of air pollution on historical buildings. It uses a monitoring system to collect samples of particulate matter (PM_{10} and $PM_{2.5}$), particulate matter concentration levels and weather parameters. It is possible to act, in time, for the preservation and protection of this historical heritage by joining all of these data. This methodology could complement the studies of the environmental impact assessments on the historical buildings from the outdoor air pollution sources and contributes to the preservation and protection of the historical buildings. This work is being applied in the Portuguese midsized city of Vila Real, where the urban pollution assessment and their effects in urban historical buildings was considered the main goal.

Keywords: Air pollution; Historical buildings; Particulate matter; Preservation; Protection

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1. Introduction

The preservation of cultural heritage has become an increasing concern over the past decades, since it includes priceless cultural assets of identity and memorial value (Grøntoft, 2017). The desire to preserve historical constructions often contrasts with many factors that endanger them, putting cultural heritage at risk (Watt *et* al., 2009). In recent years, despite the improvement of air quality in urban areas, the way the conservation of cultural heritage is thought has changed and the concern over the degradation of materials exposed to atmospheric pollution has become a reality (Di Turo *et* al., 2016). The past two centuries have witnessed the degradation of built heritage, not only as an consequence of natural weathering and aging, but also as a result of an ever growing industry and social evolution and economic life, which compromises air quality and global environmental conditions (Ghedini *et* al., 2011)

The European Council has recently stated the vulnerability of cultural heritage to climate change, highlighting the impacts of climate and pollution acting together, causing increased pH in precipitation and changes in pollutant deposition, which leads to effects such as stone recession, blackening of materials, corrosion of metals and bio-colonization (Sabbioni *et* al., 2008; Silva *et al.* 2010).

Although many international regulations to control air pollution have had a positive effect on global emissions, the transport sector continues to act as a negative contribute, particularly in urban areas with high volumes of traffic (Silva *et* al., 2016). Motorized vehicles are still a source of harmful pollutants such as nitrogen oxides, sulphur dioxide and particulate matter, and the exponential increase of registered vehicles means that it is still a challenge to achieve the required levels of air quality. This trend leads to exceedance in pollutant concentrations according to European Union (EU) established limits (EEA, 2015; EEA, 2016).

The damage caused by air pollution, combined with natural weathering, has been studied for many years, with different forms of degradation being analyzed in different ways and environments (Watt *et* al., 2009).

Accelerated ageing laboratory tests, in a scientifically controlled environment, are often used in the context of material degradation. However, these may fail to consider the full complexity of environmental parameters (Watt *et* al., 2009). Despite its higher time-consumption, resorting to field exposure tests is common, in order to validate analytical formulations that can be used in practical decision-support exercises such as the definition of efficient urban planning, heritage management and pollution mitigation strategies (Grøntoft, 2017).

Monitoring, evaluating and assessing the cities air quality and the effects related to the cultural heritage is very important allowing to act in time to prevent irreversible losses (Silva *et* al., 2016).

This work presents a methodology to evaluate, on a regular basis, the potential impact of atmospheric pollution (particulate matter) on historical buildings. It uses a monitoring system to collect samples of particulate matter and then analyzes its composition and assesses the degree of degradation risk. This study was applied at the Portuguese midsized city of Vila Real, where the urban pollution assessment and their effects in urban historical buildings was considered the main goal.

2. Effects of Particulate matter on the building materials. A literature review

Particulate matter is a term that represents a wide range of chemically and physically diverse substances that can be described by size, formation mechanism, origin, chemical composition and atmospheric behavior (Tidblad *et* al., 2009; Watt *et* al., 2009). The particles concentration in the atmosphere varies across space and time and is a function of the source of the particles and the transformations that occur to them as they age and travel (Watt *et* al., 2009).

Particulate matter is much more complex to classify, when compared to other type of pollutants, because it is a mixture rather than a single substance (Vidal *et* al., 2019). It may include dust, soot and other tiny bits of solid materials produced by many sources, including burning of diesel by trucks and buses, incineration of garbage, construction, industrial processes and domestic use of fireplaces and woodstoves (Watt *et* al., 2009).

Particulate matter is, in general, a hygroscopic substance, increasing the possibility of corrosion to occur (Tidblad *et* al., 2009) by involving a large number of chemical reactions and, often more importantly, it is the source of the black matter that makes buildings dirty (Watt *et* al., 2009). Airborne particulate matter includes any material that can be transported through the atmosphere by wind and air movements, including particulate matter up to 1 mm in diameter, although most particles in the ambient atmosphere could be significantly smaller than this (Watt *et* al., 2009).

Particulates can also be corrosive when containing acidic aerosols and considering the catalytic role of carbonaceous particles in the formation of nitric and sulphuric acid (Screpanti and De Marco, 2009). Additionally, in coastal areas, where corrosive substances such as chlorides are present, the risk of corrosion is even greater, especially in environments with a high relative humidity and temperature (Vidal *et* al., 2019).

Particulate matter is, additionally, the main cause of soiling, as it may contain carbonaceous particles, which are the main cause of stone darkening (Watt *et* al., 2009). This is more pronounced in porous stones, as porosity influences particle penetration, but also from rainwater, disabling its washout effects (Kucera and Fitz, 1995).

The sulfates and nitrates are the main chemical compounds present in the particulate matter composition that affect the building materials. The environmental pollution effects on the materials of the sulfates and nitrates are summarized on Table 1.

Table 1. Main effects of the chemical compounds on the historical buildings materials (Watt *et* al., 2009).

Chemical compounds	Main effects	Building materials affected
Sulfates and Nitrates	Corrosion	Metals (cast iron, carbon steel, zinc, copper, bronze and aluminum)
	Corrosion	Glass
	Loss of material and increase in porosity, gypsum formation	Concrete and mortars
	Stone decay, soiling and darkening	Stone elements

3. Methodology

The development of the present study will rely on SMMART Vila Real (in English "Municipal System for Monitoring Air, Noise and Traffic for the city of Vila Real") developed by CTAC/University of Minho (Silva *et* al., 2016). In this work, two infrastructure of SMMART Vila Real has been used: 1) The web platform that integrates the services of acquisition and analysis of the collected data; and (2) The mobile unit for the acquisition and collection of environmental data.

The mobile unit (Figure 1) takes measurements in a specific location of the city (GPS technology), and transmits them through wireless communication to the web platform. On board of the mobile unit the devices are installed to monitor noise, air pollution (particulate matter), traffic counting, meteorological, multimedia, communication and positioning.

The mobile environmental monitoring station carries out measurements in different points of the city that are part of the urban monitoring network. In the urban monitoring network, a set of data is collected and transmitted to the analysis center (air pollutants concentrations, meteorological data and time of the measurements), through a router installed inside the mobile unit that is connected to the analysis center. The particulate matter is also collected for posterior physical and chemical analysis in laboratory, intending to identify the potential risks to the historical buildings.

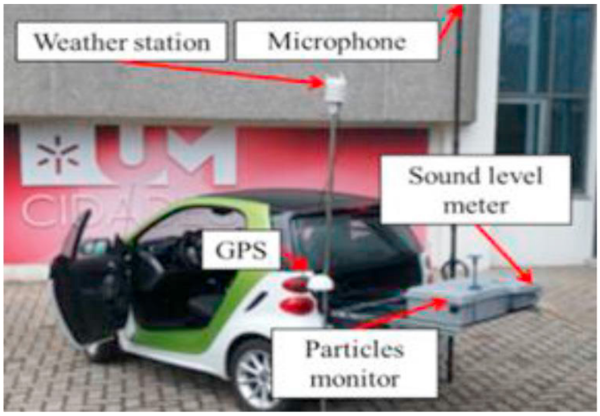

Figure 1. The mobile monitoring unit (Silva *et* al., 2016).

The PM monitor is a device for measuring real-time aerosol mass readings in the air, in an outside environment. This equipment takes measurements of the following pollutants simultaneously: PM_{10}, $PM_{2.5}$ and Total Suspended Particles (TSP), using a light-scattering laser photometer method. The meteorological station collects the following weather parameters: air temperature (ºC), wind speed (m/s) and wind direction (in degrees).

The data collection process requires some procedures to be followed. As this is a mobile station for monitoring urban environments, it is essential to take measurements at different points of the city. To monitor the potential effect of PM's on cultural heritage, a dedicated monitoring network was created, that includes points near the historical heritage buildings, with vulnerability to air pollution. The following buildings were considered (Figure 2):

- Casa de Mateus;
- City Hall Square (Camilo Castelo Branco Square);
- Carvalho de Araújo Boulevard (São Domingos church);
- São Pedro Square (São Pedro church).

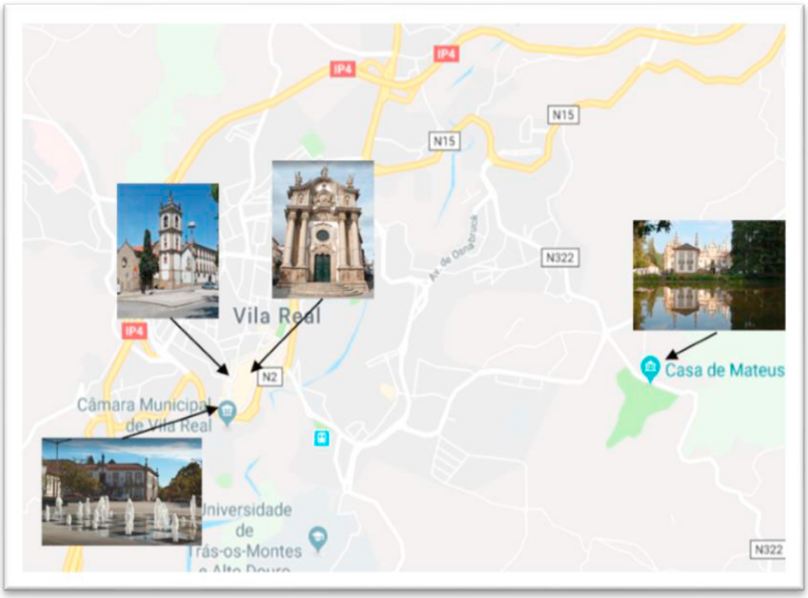

Figure 2. Monitoring network, point's location.

The choice of monitoring sites was made with the aid of the PM concentration map for the city of Vila Real. This map was developed by Silva *et al.* (2016) using a pollutant dispersion model AUSTAL2000 developed by the German National Environmental Protection Agency. This model has been used by several authors to produce horizontal concentration maps of air pollutants (Gerharz *et* al., 2013; Silva, 2015; Paas and Schneider, 2016). The use of a pollutant dispersion model allows evaluating advantageously the way the PM's reach the buildings. Additionally, it is also important to estimate the quantities of particulate matter that hits the buildings and to anticipate the concentration levels present in the atmosphere at different scenarios. For instance, it is possible to study the effect of the wind direction and speed, for specific conditions, such as traffic flow variations and traffic composition. The use of long-term concentration maps (Figure 3) allows making a macro analysis of the built environment of the city and can be used to complement the other data sources. Analyzing Figure 3, it is possible to see the PM_{10} concentration that hits the historical buildings façades.

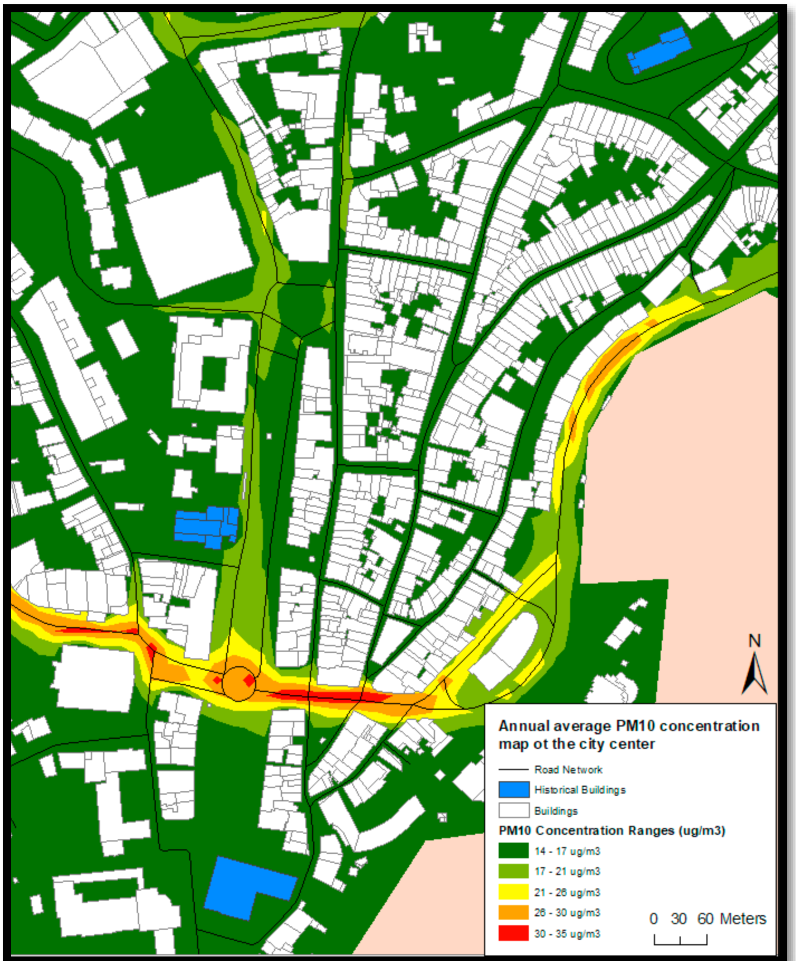

Figure 3. Long-term PM10 concentration map of Vila Real downtown area(Silva *et* al., 2016).

The particulate matter samples collection was performed by using polytetrafluoroethylene (PTFE) membrane filters with polymethylpentene support ring (2 µm porosity, Ø47 mm). The samples were evaluated in order to determine the type, chemical composition, morphology and size of the collected particles.

In order to obtain chemical and morphological characterization, the following techniques were used in the laboratory: Scanning Electron Microscopy (SEM), Energy Dispersive Spectroscopy X-rays (EDS), X-Ray Diffraction (XRD).

4. Discussion and Results

The particulate matter sources identified in the city of Vila Real are mainly from traffic, commercial and housing sources. Composition varies according to the sources and time of the year. For instance, in the winter the housing particulate matter sources are higher than in the summer, because of the burning wood systems. There is a significant contribution from the domestic sector (around 66%, in 2013) to PM_{10} emissions in the northern region of Portugal (CCDRN, 2014). The main contribution to emissions from this sector is the burning of biomass in domestic heating fireplaces. The significant contribution of emissions from this sector is also evidenced by some international authors (Basur *et* al., 2002) who reported that the emission of wood burning in the residential sector is even higher than the burning of fossil fuels on the road transport sector. Thus, the type of source must be taken into consideration as it is closely related to the composition of the released particles and therefore their potential impact on the building materials.

A factor that can be more important to the cultural heritage than the concentration levels may be the pollutants chemical composition. The particulate matter (according to its composition) could be more harmful to the materials that compose the cultural heritage buildings. Moreover, the effects may be higher to the cultural heritage buildings even if the concentrations are lower, but the chemical composition is more harmful.

The chemical composition analysis is made in laboratory, through the sample analysis collected at the monitoring network points. With the laboratory analysis, it will be possible to identify the following parameters: air pollutant sources and chemical characteristics of the compounds.

Joining all of the collected data (particulate matter concentration levels, chemical composition and the weather conditions), it is now possible to act creating actions in which the main goal it is the protection and preservation of the cultural heritage. With all these data, it is possible to make studies of the environmental impact assessments on the historical buildings from the outdoor air pollution.

This study does not consider the effects of indoor air pollution, which means that only the buildings structures affected by the outdoor air pollution are considered. However, on the future the indoor monitoring could be considered.

5. Conclusions

Monitoring and assessing the particulate matter on the surroundings of the historical buildings of the Vila Real's city using a monitoring system was the focus of this work.

In this study, the developed methodology proved to be an important tool to protect the historical buildings, according to all the type of relevant data that is able to collect, related to outdoor air pollution issues.

The mobile unit has shown that it can perform the tasks for which it was developed. The regular environmental monitoring campaign was successfully accomplished with the use of the mobile unit.

This methodology proves that it can be a supporting urban planning tool for the municipalities, because it provides important information about the particulate matter concentrations and the particulate matter chemical composition.

In the future, other air pollutants may be added to the monitoring system (for instance, NO_2 and SO_2), to improve the quality of the assessments and to collect another type of important data for the historical buildings protection.

The next step of this work will be the development of an analysis indicator to evaluate the potential impact of air pollution on the building degradation based on the laboratory chemical analysis of the particulate matter collected, the field measurements and the long-term air pollution concentration maps.

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