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Air quality assessment in cultural heritage: the case study of the Amalfi historical center (Amalfi, Salerno, Italy)

Daniele Sofia[1,4], Maria Ricciardi[2,3], Oriana Motta[3], Antonio Proto[2]

[1]DIIN-Department of Industrial Engineering, University of Salerno, Via Giovanni Paolo II, 132, 84084, Fisciano, Italy, nlotrecchiano@unisa.it, dsofia@unisa.it
[2]DCB – Department of Chemistry and Biology, University of Salerno, Via Giovanni Paolo II, 132, 84084, Fisciano, Italy, aproto@unisa.it, mricciardi@unisa.it
[3] Department of Medicine and Surgery, University of Salerno, via S. Allende, 84081 Baronissi, SA, Italy, mricciardi@unisa.it, cpironti@unisa.it, omotta@unisa.it
[4]Research Department, Sense Square Srl, 84084, Salerno, Italy,

***Abstract* – Air pollution is a serious problem for the preservation of cultural heritage. In fact, the iteration works of art with atmospheric pollutants leads to their degradation. To define the impact of air quality on artifacts, it is necessary to measure the pollutants' levels through an air quality measurement system. In this study, the levels of particulate matter (PM10, PM2.5 and PM1) near the Amalfi Cathedral (Amalfi, Salerno, Italy) were measured by using the Sensy sensor. The analysis of the data recorded by the Sensy sensor was useful in identifying the air quality in an area that is very crowded with tourists from around the world. By analyzing the data collected by the sensor, researchers were able to assess the air quality in the area and evaluate the potential impact of air pollution on the cultural heritage sites in the region.**

I. INTRODUCTION

Numerous studies and research have been conducted to protect architectural artworks from air pollution. For example, a study conducted in Florence evaluated the effect of air pollution on the facade of the Basilica of Santa Croce, an important religious and cultural building of the Italian Renaissance. The research revealed that pollutants, such as particulate matter, can accumulate on the facade of the basilica and cause irreparable damage to building materials, such as limestone. [1]

The harmful effects of indoor and outdoor pollution can also have a significant impact on artworks. Air pollution and climatic factors work synergistically to accelerate the natural deterioration processes of the materials that make up the artworks. The specific types of degradation that occur depend on the composition of the materials that make up the monuments and the climatic, environmental, and topographical characteristics of the territory with which the assets interact. [2,3,4]

In the troposphere, which is the part of the atmosphere that is in contact with the Earth's surface, there are naturally occurring organic and non-organic compounds, including nitrogen oxides, sulfur, and atmospheric dust. The latter is composed of a variety of metal-based substances that can be classified as an inert powder. In urban environments, there is a greater formation of nitrogen oxides and particulate matter, largely due to the combustion of petroleum derivatives, especially diesel engines. This imbalance also contributes to the formation of strongly oxidizing substances, such as ozone, which in turn contribute to the formation of new pollutants of secondary origin. [5,6]

In closed environments, airborne particulate matter is produced by combustion, such as from candles, cigarettes, and fireplaces, and is mainly below one micron in size. Therefore, in places such as churches, museums, and historical buildings where there are often candles, incense, or a high number of tourists, it is essential to limit the sources of pollution due to small combustions and to have good ventilation to avoid the accumulation of pollutants for both the people who work there and for the artistic works therein.[7]

Italy is home to most of the world's historical-artistic heritage, with over 60,000 cultural assets registered on the national territory. However, in recent decades, the historical-artistic heritage has undergone greater deterioration than what has been observed in the past. Atmospheric pollution is considered one of the most important contributing causes of this process. The main causes of material degradation can be natural, such as frost, saline crystallization, microclimate, and temperature changes, as well as anthropogenic, mainly represented by atmospheric pollution [8, 9, 10].

Atmospheric pollution modifies the chemical, physical, and biological properties of the air, inducing more or less serious alterations to human health and artifacts. The impact of atmospheric pollution on inert materials such as monuments is significant and irreversible due to the lack of self-defense systems and the disposal of toxic elements, which are instead present in humans. [11,12]

Therefore, it is important to implement effective measures to protect historical-artistic heritage from the harmful effects of atmospheric pollution. This can be achieved through the use of appropriate materials and coatings, regular cleaning and maintenance, and limiting the sources of pollution in the surrounding environment. Additionally, it is essential to raise public awareness about the importance of preserving these cultural assets for future generations.[13]

The deposition of particulate matter on the surfaces of artifacts of historical and artistic interest is not a simple phenomenon of absorption on the surface. The powders are often cemented in a physico-chemical process that includes the deposition of a veil of water and chemical reactions between the material and the acids contained in this corrosive solution, thus becoming an integral part of the material. These reactions can also affect deeper layers of the material. [14] As for particulate matter, its effect on historical artifacts is given by the fouling determined by the deposit of carbonaceous particles on the monument surface. This occurs in areas protected from rain and physical stress, determined by climatic and microclimatic factors[16, 17].

Physical stress takes into consideration some parameters such as the wetting time (evaluable as the annual period in which the relative humidity is higher than 80%), the ambient temperature frequency oscillation around 0°C, and the freezing of the material. [18] To verify the effects of atmospheric pollution on cultural heritage located outdoors, monitoring campaigns are carried out to measure the main pollutants. Then, attempts are made to correlate the pollutant concentrations measured with the absorption by the monuments [19, 20].

It is essential to carry out regular monitoring campaigns to evaluate the impact of atmospheric pollution on cultural heritage. [21 -25] This can help identify the main pollutants responsible for the degradation of the materials and take effective measures to protect them. Furthermore, it is important to raise awareness among the general public and stakeholders about the importance of preserving our cultural heritage and the role that each one of us can play in achieving this goal [26-35].

II. MATHERIALS AND METHODS

The cathedral in Amalfi (Salerno, Italy) with its glittering gold mosaic facade and colorful Majorca-tiled dome, dominates the main piazza (Figure 1).

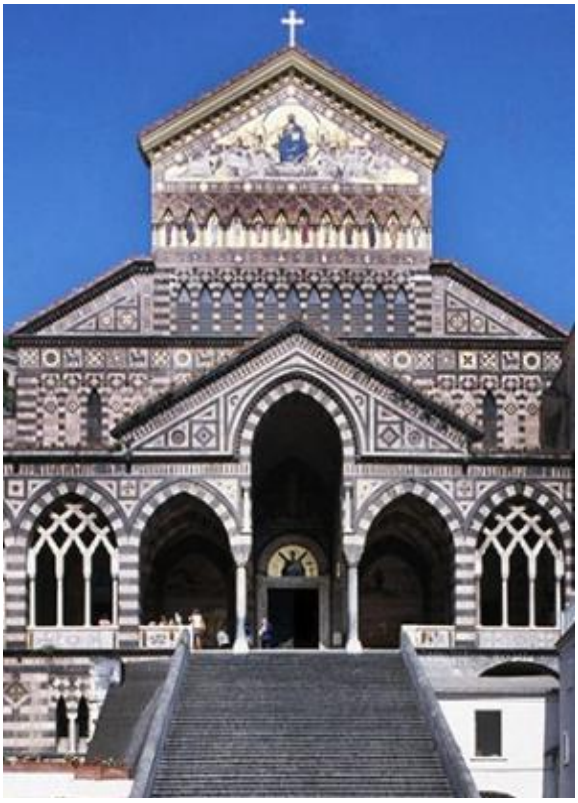

Fig. 1. Photograph of the Amalfi Cathedral (Amalfi, Salerno, Italy).

Construction on the cathedral began in the 9th century, and centuries of additions and renovations are revealed in the mashup of Moorish and Norman Romanesque styles present. Climb the 62 steep steps in front to admire the enormous bronze doors that were cast in 11th-century Constantinople. Inside, the crypt holds the relics of St. Andrew the Apostle, the patron saint of Amalfi. Through the cathedral’s portico, you can enter the Cloisters of Paradise, a 12th-century arcade bordered by 120 columns surrounding a garden. This peaceful space was created as a burial place for the noble families of Amalfi.

To monitor the airborne pollutants levels, five sensors (figure 2) were installed at different points: one near the cathedral, the other in a more distant part of the town of Amalfi. These Sensy (S1) sensor are developed by Sense Square (WIPO 2018/225030AI). They are laser scattering sensors that allow the continuous measurement of PM10, PM2.5 and PM1 particles with a high temporal resolution and microclimatic parameters such as temperature, atmospheric pressure and relative humidity. The sensors characteristics are reported in table 1.

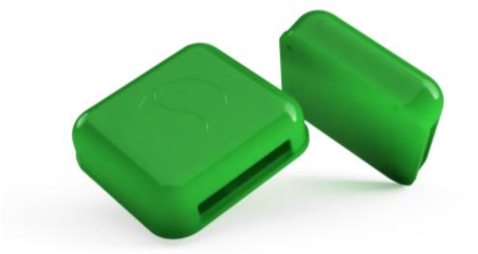

Fig. 2. Sensy – www.sensesquare.eu - Pollution sensor

Table 1. Sensor's characteristics.

Topic	Param.		Techn.
Climate	Temp.	±0.3 °C	Band-Gap
	Relative Humidity	±2%	Capacitive
Particulate	PM10	±5 μg/m^3	Laser scattering
	PM2.5	±5 μg/m^3	Laser scattering
	PM1	±5 μg/m^3	Laser scattering

Fig. 3. Installation maps

The Sensy monitoring stations were installed at strategic points in the Amalfi area, chosen based on the presence of potentially relevant pollution sources such as vehicular traffic or industrial activity. The stations recorded levels of various air pollutants such as PM10 and PM2.5 fine particles, ozone, nitrogen dioxide, and carbon monoxide, with a sampling frequency depending on the specific technical specifications of the stations.

The port monitoring system was installed to evaluate the impact of maritime traffic on the air quality of the Amalfi area. The system recorded various parameters such as emissions of pollutants and their impact on air quality.
The data collected from the Sensy monitoring stations and the port monitoring system were analyzed to determine the main source of pollution in the Amalfi area and to evaluate the effectiveness of any pollution mitigation measures.

III. RESULTS AND DISCUSSIONS

The positioning of the monitoring stations was optimal for identifying the different sources of pollution. The stations were strategically placed in different areas of the study area, taking into account factors that could influence the dispersion of pollutants, such as wind direction and speed, the presence of obstacles, vehicular traffic, and emission sources.

Thanks to this appropriate positioning, it was possible to collect representative data on air quality in different zones of the study area and identify the main sources of pollution. In particular, the monitoring stations allowed for the detection of levels of fine particles PM10 and PM2.5, nitrogen dioxide, and carbon monoxide, which often exceed legal limits.

These results demonstrate the importance of positioning monitoring stations optimally to identify sources of pollution and evaluate the impact of pollution on the environment and public health. Moreover, this data can be used to develop pollution mitigation strategies and monitor the effectiveness of actions taken to improve air quality.

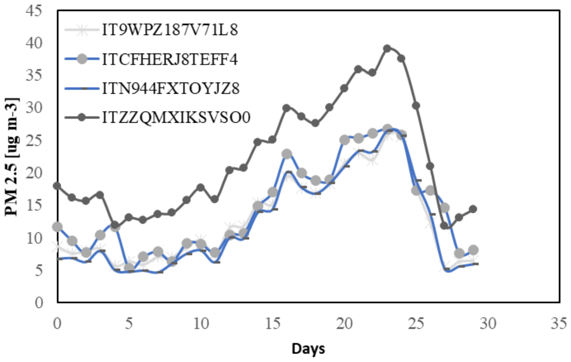

Fig. 4. PM 2.5 concentrations.

In Figure 4, the trends of PM 2.5 concentrations can be observed among different monitoring stations. It is evident that the stations display remarkable similarity in the recorded values over time. However, it is clear that the station closest to the port consistently exhibits higher levels of PM 2.5 compared to the others.

This observation raises important considerations regarding air quality in the vicinity of the port. The elevated levels of PM 2.5 concentrations could be attributed to various pollution sources in that specific area, such as maritime traffic, industrial activities, or other port-related operations.

PM 2.5 particles are particularly concerning as they are extremely small and can penetrate deep into the lungs when inhaled. This can lead to respiratory issues, eye irritations, cardiovascular diseases, and other adverse health effects.

The consistent presence of higher PM 2.5 concentrations at the station near the port highlights the need for targeted measures to address air pollution in that area. Specific actions may be required to reduce emissions from port activities, improve filtration systems, or introduce restrictions on maritime traffic.

It is important to note that analyzing trends in PM 2.5 concentrations is only part of the overall approach to assessing air quality. Other air pollutants and environmental factors, such as ozone, sulfur dioxide, temperature, humidity, and wind direction, need to be considered to obtain a comprehensive understanding of the situation.

Furthermore, it is essential to acknowledge that the selected monitoring stations may represent only a portion of the entire study area. Additional stations in different locations may be necessary to obtain a more comprehensive overview of the distribution of PM 2.5 concentrations and the specific influences of the port on air pollution.

In conclusion, the observation of PM 2.5 concentration trends in Figure 4 highlights significant similarity among the monitoring stations, but also consistently higher levels at the station closest to the port. This underscores the need for targeted measures to address air pollution in that specific area and the consideration of additional environmental factors and pollutants for a comprehensive assessment of air quality in the study area.

IV. CONCLUSIONS

The present study has shown that there are several sources of pollution that have a significant impact on air quality in the Amalfi area, particularly in the vicinity of the cathedral. Among the main sources, we have identified the port and vehicular traffic.

The analysis of data collected from Sensy monitoring stations and the port monitoring system has revealed that levels of fine particles PM10 and PM2.5, often exceed legal limits, especially near the main pollution sources.

Therefore, it is important to implement pollution mitigation measures to reduce the impact of human activities on the environment and public health. For example, incentives could be implemented to encourage the use of public transportation or promote low-emission transportation means such as electric bicycles.

Additionally, targeted measures could be taken to reduce emissions of pollutants from the port, such as installing filtration systems for ship engine emissions. Finally, it may be helpful to raise public awareness of the importance of reducing air pollution and the actions that individuals can take to contribute to environmental and public health protection.

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