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# Protecting Art and People: Environmental Monitoring of Beata Vergine dei Miracoli Sanctuary for Health and Heritage Conservation

Antonio Spagnuolo[1,2], Andrea Bergomi[3], Carmela Vetromile[1,2], Antonio Masiello[2], Noemi Mantile[1], Mattia Borelli[3], Chiara Andrea Lombardi[3], Valeria Comite[3], Paola Fermo[3], Carmine Lubritto[1]

[1] *Department of Environmental, Biological and Pharmaceutical Sciences and Technologies and MAReA Centre, University of Campania "Luigi Vanvitelli", Via Vivaldi 43, 81100, Caserta.*
*antonio.spagnuolo@unicampania.it, carmela.vetromile@unicampania.it, noemi.mantile@unicampania.it, carmine.lubritto@unicampania.it*
[2] *Energreenup srl; info@energreenup.it*
[3] *Department of Chemistry, University of Milan, Via Golgi 19, 20133, Milano, Italia*
*paola.fermo@unimi.it, valeria.comite@unimi.it, mattia.borelli@unimi.it, andrea.bergomi@unimi.it, chiara.lombardi@unimi.it,*

***Abstract*** **– This research article discusses the importance of environmental monitoring to ensure the health and well-being of humans and ecosystems, with a specific focus on cultural heritage sites, which are susceptible to damage by pollution and microclimatic conditions. The Beata Vergine dei Miracoli sanctuary, a notable cultural heritage site in Italy, was studied to analyse the environmental quality of the site and any changes in environmental conditions during the COVID-19 pandemic. The study monitored different environmental parameters from 20 January to 11 April 2023. The data collected were evaluated, and the results were compared with previous campaigns. This study highlights the importance of environmental monitoring in cultural heritage site conservation, particularly in response to global challenges like climate change and pandemics.**

## I. INTRODUCTION

Environmental monitoring is essential to ensure the health and well-being of human beings and the ecosystem. In recent years, the importance of environmental monitoring has increased considerably, as pollution and climate change have become major challenges to be confronted [1]. The awareness on pollution-related damages is also increasing due to the effects on the works of art. It is in fact known that air pollution and bad microclimatic conditions can cause mechanical ruptures in response to strong temperature and relative humidity variations, colour changes due to chemical reactions, soiling due to particulate matter deposition; the effects can be synergic [2][3][4][5].

For this reason, several museums around the world started to put forth measures to ensure optimal microclimatic conditions within the indoor environments hosting important works of art. However, museums are not the only sites in which artifacts of artistic and historical interest may be found. Sanctuaries can also be the home to numerous works of art such as frescoes, sculptures, and paintings. However, there is currently no legislation defining limit levels for air pollutants or microclimatic parameters to ensure proper conservation conditions, leaving these sites essentially unmonitored.

In this regard, studies conducted in the sanctuary of the Beata Vergine dei Miracoli in Saronno (VA), Italy, represent one of the first attempts to evaluate environmental conditions in sites other than museums [6,7,8,9]. This sanctuary, is an important spiritual and cultural heritage site, visited by thousands of worshippers and tourists every year. It was decorated by some of the most renowned and influential artists of the time, such as Bernardino Luini and Gaudenzio Ferrari [10]. Therefore, the indoor air quality of this site needs to be closely monitored to ensure a safe and healthy environment for the people and for the works of art.

Indeed, initial studies conducted in previous years highlighted non-ideal microclimatic conditions within the sanctuary [6,8,9]. Thermohygrometric parameters (temperature and relative humidity) were often outside the ranges recommended in the UNI 10829 "Goods of historical and artistic interest. Environmental conservation conditions. Measurement and analysis" technical standard [6]. Also, the large influx of people during religious ceremonies, guided tours and other activities caused air pollutant (PM and NOx) levels to rise above the suggested limits in the Ministerial Decree D.M. 10 May 2001 "Guidance document on technical-scientific criteria and museum functioning and development standards" for the

proper conservation of artifacts in museum environments [6,8].

In this study, we aimed to analyse the environmental quality of the Beata Vergine dei Miracoli sanctuary and through the monitoring of different environmental parameters. The monitoring period starts on January 20th 2023 until April 11th 2023. The data collected during this period were compared with those collected during the 2021 monitoring period to assess whether there had been any changes in the quality of the indoor environment during the COVID-19 pandemic [6,7]. Different periods will be considered in the comparisons with the 2021 campaign: the main one will be the most overlapping with the new campaign, other periods considered will give an idea of the results of the observed parameters trends.

The COVID-19 pandemic has led to a significant reduction in human activities, including tourism, industrial and transportation activities, and commercial activities. As a consequence, there has been a reduction in environmental pollution. The environmental quality of this sanctuary and its surroundings are therefore of particular interest, given that it is possible to observe the effects of reducing human activity during the COVID-19 pandemic on the pollution levels and environmental parameters.

The results of this study will also be useful to establish environmental monitoring protocols in cultural heritage sites and evaluate the effectiveness of measures to reduce environmental pollution.

## II. MATERIALS AND METHODS

For the project, a smart object has been designed and assembled for the non-invasive control of indoor environmental parameters of the site. The station is equipped with a microcontroller with custom firmware equipped with Bluetooth-GPRS dual telecommunication channel and operating in Start-Go-Stop mode. The collected data are sent to a remote cloud and visualized through a web application. The monitoring station is equipped with a microcontroller, a multi-in-one air quality module integrating several sensors, including a laser dust sensor, electrochemical sensors for ozone, carbon monoxide, TVOC grade, and nitrogen dioxide, as well as temperature and humidity sensors. A micro-fan inside the station is switched on for a pre-set time and frequency to establish an equilibrium with the environment to be monitored. The monitoring station has several strengths. Firstly, it has small dimensions, which make it possible to install the station in areas where the space is limited. Secondly, it is highly customizable, allowing the addition or removal of sensors depending on the type of monitoring to be carried out. By customizing the sensors, it is also possible to detect pollutants that might otherwise go unnoticed, providing even more accurate and comprehensive measurements. The station is thus versatile, being adaptable to different contexts and environmental conditions, and represents an efficient and economical option for air quality monitoring. The device was placed in proximity to the "Last Supper" sculptural group, which is one of the most important works of art that can be found in the Sanctuary. This sampling site was chosen, not only due to the relevance of the artwork, but also because this sculptural group is next to the main altar where all the ceremonies are celebrated and small guided tours are often organized for worshippers and visitors.

## III. RESULTS AND DISCUSSION

### *A. Temperature and relative humidity*

Figure 1 depicts temperature and relative humidity trends observed throughout the sampling period. Temperature naturally fluctuates in response to external conditions, gradually increasing as spring approaches. Similarly, humidity behaviour is also influenced by external factors.

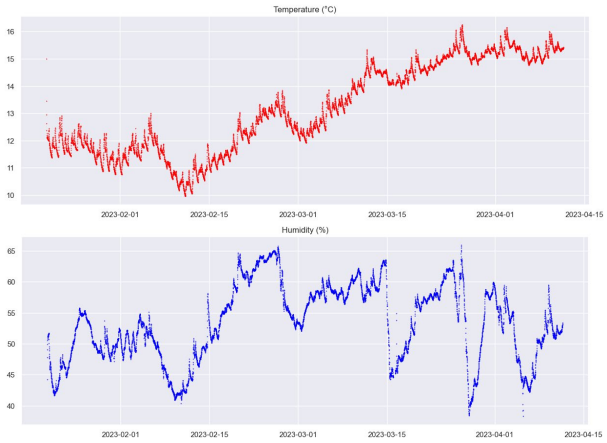



*Figure 1: Temperature (red line) and Humidity (blue line) trends*

Within the monitored periods, temperature values oscillate between 10 and 16°C, which is within the recommended range in the UNI 10829:1999 technical standard for mural paintings (10-24°C), but outside the one recommended for painted wood (19-24°C). These results are in line with the measurements carried out in 2021 [6], where the number of overrun days was greater for painted wood, as opposed to wall paintings, occurring mainly in the colder months of the year. Similar results were also obtained for relative humidity, with oscillating values between 40 and 60%.

Furthermore, upon observing the maximum daily temperature and humidity variation in Figure 2, it was found that the former adhered to the guidelines set by the UNI 10829 standard for painting on wood. However, the latter exceeded the limit on approximately 48% of the sampled days. Similar results were obtained between February 23rd and April 11th, 2021, with no overrun of the maximum daily temperature variation limit, but the

maximum daily humidity limit was exceeded in 47% of the sampled days. Looking at a wider time range for 2021, from the same starting date until August 28th, only one overrun day was recorded for $\Delta T_{max}$ while $\Delta RH_{max}$ exceeded the limit on 57% of the days [7]. It is important to note that the percentage of $\Delta RH_{max}$ overruns is not a monotonically increasing function but is greatly affected by short-term variations.

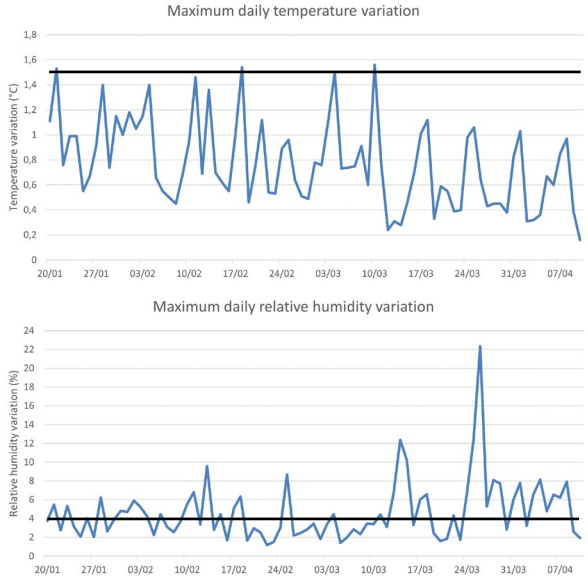
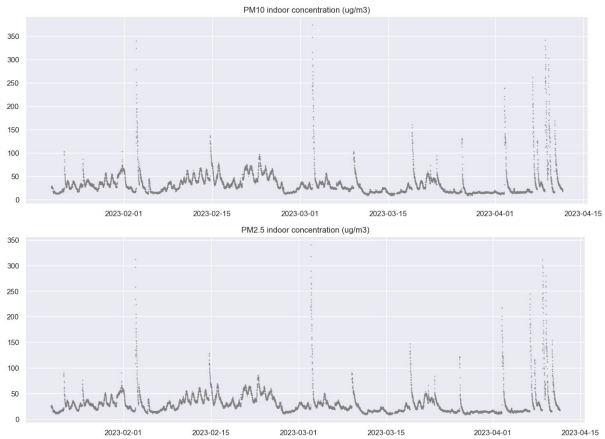



*Figure 2: Maximum daily temperature and humidity variation*

### *B. Particulate Matter*

PM10, PM2.5 and PM1 show fairly constant values over time, as can be seen from the figures below, except for peaks in concentrations associated with specific events occurring within the Sanctuary (Fig. 3).



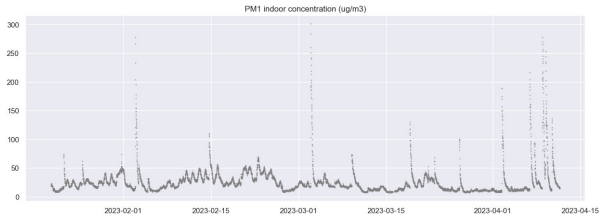




*Figure 3: concentration trends of (from top to bottom) PM10, PM2.5, PM1.*

For PM10, the average over the period is around 30 $\mu g/m^3$ and there are no particular variations between the different months (Fig.4). This value corresponds to the upper recommended limit indicated in the D.M. 10/05/2001 for the protection of artworks. In 2021, from March 23th to April 11th, the PM10 average, estimated with a P-DustMonit, was 23 $\mu g/m^3$ [6], therefore not significantly different than the value obtained in this study.

As in [6], PM1 (particles with a diameter less than 1µm) almost always accounts for more than 50% of the PM10 concentration, with an average value during the reference period of approximately 20 $\mu g/m^3$. Given that the smaller particles are the ones that are most harmful to human health, but also to cultural heritage, this result further supports the conclusion of non-ideal microclimatic conditions within the sanctuary.

Moreover, despite the average value being in line with the recommendations for museum environments, the peaks in concentrations reached levels far above 30 $\mu g/m^3$ (Fig. 4).

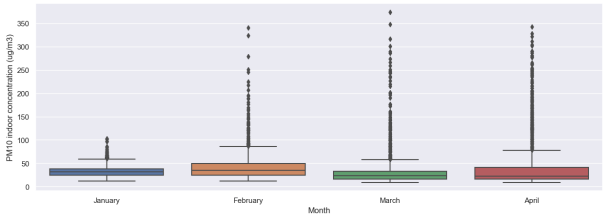



*Figure 4: Boxplots of monthly particulate matter (PM 10) concentrations.*

Interestingly, the anomalous peaks almost all correspond to Thursdays, Saturdays, and Sundays (Fig.5). In fact, in these days religious services that are scheduled within the sanctuary cause the presence of more people and different sources for particulate matter, such as the burning of candles and incense [6, 11].

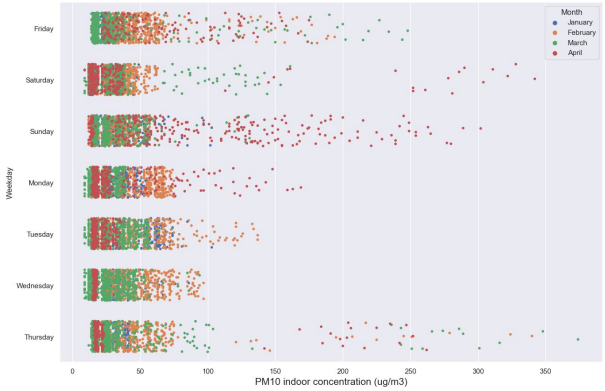



*Figure 5: PM10 concentrations divided by day and month of acquisition.*

### C. Nitrogen Dioxide

The trend in nitrogen dioxide concentration over time is shown below (Fig. 6).

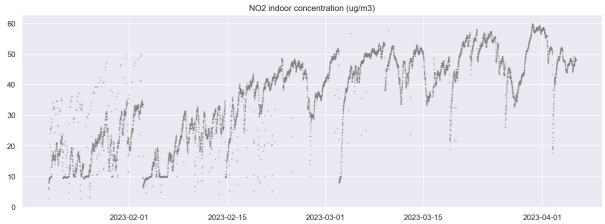
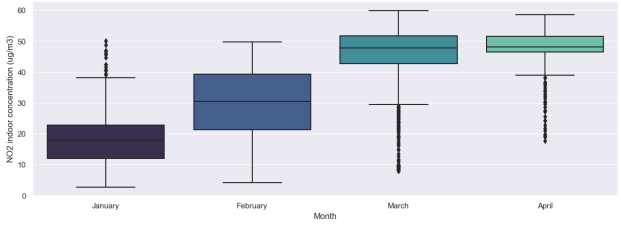



*Figure 6: trend of $NO_2$ concentration*

Thanks to the use of a continuous monitoring device, it was possible to observe the daily variation of nitrogen dioxide and not only the average over the entire period, as was done with passive sampling techniques employed in the previous campaigns [6]. Indeed, it is possible to observe a gradual average increase in the concentration of this air pollutant from January to April, with concentrations between 10 and 60 µg/m$^3$, as shown in the graphs in Figure 7.



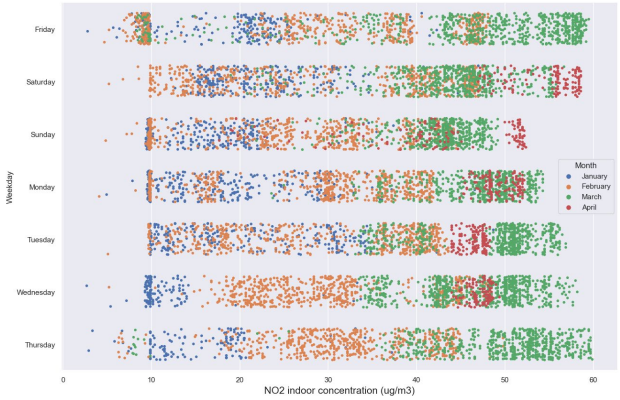




*Figure 7: (from top to bottom) Boxplots of monthly nitrogen dioxide ($NO_2$) concentrations; $NO_2$ concentrations divided by day and month of acquisition.*

Doing a comparison with 2021, $NO_2$ concentration measured with diffusive passive systems was significantly different than the one found with the station objective of the work. The concentrations observed in December 2021 [6] were in line with the values observed in January 2023, whereas the concentration observed in February and March 2021 were significantly lower (5.2 µg/m$^3$, 6.7 µg/m$^3$) than the values observed in this study for the same period. Despite these considerations, all the observed values are above the recommended limit of 5 µg/m$^3$ indicated in the D.M. 10/05/2001. In this regard, the measurements carried out in this study highlight a worsening of the situation with respect to 2021.

The most common sources of nitrogen dioxide are outdoor ones and include all combustion processes. Since vehicular traffic was highlighted as the main source of outdoor pollution affecting the indoor areas of the Sanctuary [6], an increase in the levels of nitrogen dioxide within the sanctuary could indicate an increase in this activity from 2021 to 2023.

## IV. CONCLUSIONS

In summary, this study aimed to analyse the environmental quality of the Beata Vergine dei Miracoli sanctuary through the monitoring of different environmental parameters using a smart monitoring station. The collected data were compared with those collected during the 2021 monitoring period to assess any changes in the indoor environment during the COVID-19 pandemic. The results showed that the monitoring station was efficient and highly customizable, allowing for the detection of pollutants that might otherwise go unnoticed. The temperature and relative humidity trends showed that both are naturally influenced by external conditions. Additionally, the average concentration of PM10 was around 30µg/m$^3$, and there was a gradual increase in $NO_2$ concentration over time. The findings of this study are crucial for establishing environmental monitoring protocols in cultural heritage sites and evaluating the

effectiveness of measures to reduce environmental pollution.

## V. REFERENCES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