An integrated approach to the preventive conservation of cultural heritage: indoor biological environmental monitoring
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1. Biological aerosol as risk of biodeterioration
In indoor environments as libraries, archives, museums etc, the biological component of air, so called biological aerosol or bioaerosol, may be a potential cause of biodeterioration in cultural heritage and may have an important role on human health, operators/restaurators/visitors, for possible allergenic effect of certain classes of biological particles. Indoor air contains a great number and variety of biological particles, they come from various sources. The sources of indoor pollution, which are added to those outdoor, are primarily represented by human activity, the presence of dust, the type and mode of maintenance of air conditioning, when present, from artefacts infected, the use of materials and products not suitable for conservative interventions. Most of the biological particles are microorganisms such as bacteria, fungi and their spores, viruses, algae and protozoa, but also spores of Bryophyta, Pteridophyta, lichen propagules, algal cells, pollen grains and Protozoan cysts. The airborne biological particles can settle on surfaces at different speeds depending on their size, if they find favorable nutritional and environmental conditions, can survive and multiply and become responsible for the biodeterioration of materials they are made of the cultural heritage, with significant cultural losses and economic expenses for disinfection and decontamination of cultural environments and restoration. The dust is one of the main vehicles of microorganisms and allergens in indoor environments. Cultural artefacts, in especially those of organic nature (books, drawings, textiles, photographs etc.) are subject to the attacks of specific groups of fungi and some categories of bacteria, and they are recognized as the most cause of biological alterations. The deteriorated artefacts show specific morphological characteristics depending on the microbial species involved, their physiological conditions, the nature of the material and microclimatic conditions. Many factors are involved in the process of biodeterioration; physical or mechanical processes cause disintegration and irreversible transformations, while chemical processes, resulting by metabolic mechanisms, cause the deterioration or decomposition of materials and external damages, associated with the production of pigments (various types of stains, foxing, etc.). The indoor environment can thus be a source of risk and/or damage to artefacts which is essential for an accurate diagnosis on the biological contamination and environmental exposure towards of operators and users. It is the
fundamental premise for the evaluation of environmental quality, risk management and the study of the biological mechanisms of degradation processes for cultural heritage. The environment is like a container inside of which are located artefacts and it is also an open thermodynamic system, characterized by elements and variables that interact between them, as microclimatic parameters and pollutants, such as biological particles, and determine the “health” of the cultural property. The approach to the analysis of biological risk is of considerable complexity since one must consider many factors involved: different types of cultural heritage of organic nature, different environments in which they are preserved and/or exposed, the multiple work rooms and the different activities and procedures of conservation and restoration.

For the definition of biological risk and its management, is fundamental to the study of air quality environments for storage and/or exposure through biological monitoring and sampling of surfaces (cultural property and furniture) for the evaluation of their contamination degree. The biological quality of air in a preservation environment is directly influenced by environmental factors and microclimatic, which determine and maintain the optimum conditions for the development and proliferation of microorganisms. Therefore essential complement to the campaigns of biological measurements are those microclimate to evaluate the correlation with the microbial concentration.

Environmental biological monitoring has a duplicity of purpose: on one hand allows you to acquire several knowledge on exposure to biological risk factors in respect of cultural property and on the other towards the health of the operators involved in the conservation and restoration, allowing to identify the presence of microorganisms potentially biodeteriogens and dangerous to the health of operators and users. These data, correlated with those microclimate (especially temperature and relative humidity), allow to identify the critical factors that may favor the development of microorganisms and to set up corrective strategies.

In recent times has emerged a particular focus on the study of methods and techniques of investigation and prevention of biological risk in the area of cultural properties. The importance of preventing biological risk in cultural heritage has been laid out by the Italian Ministry of Cultural Heritage in the “Atto di indirizzo sui criteri tecnico-scientifici e sugli standard di funzionamento e sviluppo dei musei (Guidelines on technical and scientific criteria, and operating and development standards for museums)”. Assessing biological risks is particularly important since indoor pollution may cause diseases and discomfort to operators and users. The Italian act “Decreto legislativo n. 81/2008” prescribes that risk assessments for biological agents be carried out in all work environments, including those related with the conservation and restoration of cultural property.

At present there is no reference standards that indicate the threshold limit values for exposure to microorganisms, but only guidelines concerning the limits of biological aerosol concentration issued by some American health organizations and governmental organs are available. So far various methods are used for the assessment of biological pollution of the indoor environment.
in cultural heritage area and still are not available standard methodologies. This article describes a biological environment monitoring integrated system, for museums, libraries and archives, developed as a contribution toward the definition of a model standard of methodologies for assessing the biological quality of cultural heritage environments.

**1.1 Integrated system for biological environmental monitoring**

This system for biological environmental monitoring is based on a model of methodologies for measuring microbial air and surface contamination, as well as allergens, representing the starting point for studying the complex “environment-artefact-humans”, and can lead to a better understanding and prevention of biological risks both to cultural materials and to the health of operators and users. This approach belongs to a wide research project which involves multidisciplinary experts also on microclimate, particle monitoring and Computational Fluid Dynamic (CFD) simulations.

The methodological protocol includes: 1) air microbial sampling; 2) surface microbial sampling; 3) sampling of particulate in the dust; 4) microclimate monitoring.

1) For air monitoring, both active and passive sampling are used. Active sampling: DUO SAS 360 impactor (Surface Air Sampler), that measures the concentration of viable particles in the air is used. The sampler is positioned at one meter above the floor and at one meter away from any physical obstruction, the aspiration is 200 L of air, and RODAC plates of 55 mm diameter are used. Tryptone Soy Agar (TSA) for bacteria isolation and Sabouraud Dextrose Agar (SDA) + chloramphenicol for fungi isolation are utilized. The results are expressed as colony forming units per cubic meter (cfu/m³).

Passive sampling: Petri dishes, with a diameter of 9 cm to determine the Index of Microbial Air Contamination (IMA), measure the rate at which particles settle on surfaces. This value corresponds to the number of colony forming units (cfu) counted on a Petri dish, left open for an hour at one meter, from the floor and about a meter away from walls or any obstacles. Results expressed as IMA can be expressed as cfu per square decimeter per hour (cfu/dm²/h).

2) Biological sampling of surfaces (cultural property and furniture) is carried out with a non-destructive and non-invasive technique, using nitrocellulose membranes filters, with a diameter of 47 mm that measure the Microbial Buildup (MB) and Hourly Microbial Adhesion (HMA). The MB indicates how many microorganisms have accumulated on a given surface during an indefinite period of time prior to the sampling. The membrane was pressed on the surface for 20 seconds and then transferred to Petri dish containing culture medium. The HMA corresponds to the number of microorganisms that fall on a given surface during a period of one hour. Samples are collected leaving a nitrocellulose membrane on the tested surface for one hour, after samples are transferred to Petri dishes. The results for MB and HMA are expressed as cfu/dm², as suggested in ISO 14698-1.

The Petri dishes for the detection of bacteria are incubated at 36 ± 1°C for 48 h and those for fungi are incubated at 22 ± 1°C for 120 h.

3) Sampling of particulate in the dust: a sampler spore trap (type Hirst), posi-
tioned on the floor, with a flow rate of 10 L/min, for the evaluation of the temporal distribution of the particulate for a period of 24 hours and for direct detection of viable and non-viable fungal spores with the microscope are used. The spore trap is also used to identify pollens. The count is performed according to the methods defined in UNI 11108/04 and the indications formulated by the Italian Association for Aerobiology.

The integrated system we describe has been applied: 1) in Parma at the Pilotta Palace during the Correggio exhibition; 2) at the Palatina Library; 3) at the Magnani Rocca.

Thanks to a funding by Cariparma Foundation, the integrated system has been applied at the Sala De Rossi at the Palatina Library in Parma. The results are being drawn up.

1.1.1. Experience at the Palatina Library

The biological monitoring was performed in two periods of the year, in summer (in July) and in winter (in December). The sampling was performed at 1 m height (12 sampling points), at 2 m height (12 sampling points) and at 4 m (2 sampling points).

A wide variability of environmental contamination was observed in the different sampling points. In the sampling performed in July the highest levels of air bacterial contamination were found at 2 m height (median: 315 cfu/m³), for IMA at 1 m height (median: 8 IMA), the lowest at 4 m (median 165 cfu/m³), while for IMA at 2 m (median: 5 IMA). As for microfungi, the highest median value was recorded at 1 m and 4 m (50 cfu/m³), while the lowest at 2 m (25 cfu/m³); as for IMA both at 1 m and at 2 m the median was 1 IMA, while at 4 m the median was 0.5 m. The highest value of air bacterial contamination was recorded at 2 m f(660 cfu/m³), and 1 m for the IMA (35); fungal contamination showed the highest value at 1 m for both cfu/m³ (120) and for IMA (3).

In the sampling performed in December the values of air bacterial contamination were higher, both by active sampling and by passive sampling, at 1 meter in height, with a median of 47.5 cfu/m3 and 8 IMA, while decreased at higher
levels: at 2 m (35 cfu/m³ and 4.5 IMA) and 4 m (37.5 cfu/m³ and 6 IMA). Fungal contamination, both at 1 m to 2 m showed a value of 10 cfu/m³ which decreased to 0 to 4 m. The highest value of IMA (IMA 2) was recorded at 1 m height. In general, in summer at all points and at all heights bacterial and fungal contamination values were higher than in winter.

As for surface contamination, in the sampling performed in July the highest value of AM bacteria (161 cfu/dm²) and fungi (75 cfu/dm²) were recorded on two different shelf at 1 m height; in December a maximum value of fungal contamination of 277 cfu/m³ was recorded on the cut of the book at 1 m height. The highest AMO value both of bacterial contamination (35 cfu/dm²) and fungal contamination (23 cfu/dm²) was observed on the cut of the book.

The most frequently isolated microfungi were Alternaria, Aspergillus, Penicillium and Cladosporium, which belong to genera of fungi biodeteriogens, which can potentially cause damage such as erosions, blemishes, pigmentation and changes in mechanical properties.

On the surfaces of the shelves and books examined the genera Aspergillus and Cladosporium were the most abundant, which must be added Pleospora herbarum and Rhizopus stolonifer; also these fungi belong to species biodeteriogens and are able to induce mechanical and aesthetic damage.

The analysis of all data collected in indoor environment will allow a comprehensive assessment of biological contamination of air and surfaces.

The results obtained represent a contribution towards the definition of standardized biological environmental contamination assessment methods that will help researchers define levels and environmental classes of biological contamination. The biological monitoring integrated with microclimatic analysis and CFD simulations represents a starting point to study the “environment-artefact-man” system and can lead to a better understanding and prevention of biological risks both to cultural materials and to the health of operators and visitors.

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References


**Abstract**

In cultural-heritage-related indoor environments, biological particles represent a hazard not only to artefacts, but also to operators and visitors. Biological environmental monitoring is essential to assess any potential risk to the integrity of cultural objects.
and human health. We propose an integrated approach to the study of biological pollution in indoor environments, such as museums, libraries and archives, based on a methodological model for measuring microbial air and surface contamination, as well as allergens which belongs to a wide research project which involves multidisciplinary experts also on microclimate, particle monitoring and Computational Fluid Dynamic (CFD) simulations. The proposed approach relies on the analysis of 1) airborne microorganisms with active and passive methods; 2) surfaces of artefacts with non-destructive and non-invasive techniques based on nitrocellulose membrane filters; 3) fungal spores with a spore trap (Hirst type) and microscope; 4) surface and airborne allergens with immunoenzymatic assays; 5) airborne particles, with a laser particle counter; and 6) indoor microclimatic conditions, with a data logger monitoring air temperature, relative humidity, air velocity and mean radiant temperature, all combined with infrared measurements of surface temperatures. Thanks to a grant by Cariparma Foundation, the proposed approach has been applied at the Palatina Library in Parma. For air microbial monitoring, a DUO-SAS 360 was used to measure the concentration of microorganisms in the air, expressed as cfu/m3 (colony forming units per cubic metre), while settle plates were used to measure the rate at which airborne microorganisms settle on surfaces (Index of Microbial Air contamination, IMA). For surface contamination, two parameters were measured using nitrocellulose membranes: the Microbial Buildup (MB, the total number of microorganisms accumulated on a surface in an unknown period of time prior to the sampling) and the Hourly Microbial Fallout (HMF, the number of microorganisms that settle on a specific surface during one hour). A spore trap sampler (VPPS 1000) was also used for direct detection at the microscope of fungal spores, both viable and nonviable, and to measure the temporal distribution of the particulate. The results obtained represent a contribution towards the definition of standardized biological environmental contamination assessment methods, which will help researchers to define levels and environmental classes of biological contamination. This integrated biological (air and surfaces) and microclimatic approach represents a starting point to study the environment-artefact-man system and can lead to a better understanding and prevention of biological risks both cultural materials and health of operators and visitors.