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EXPLORING THE INDOOR ENVIRONMENT OF HERITAGE BUILDINGS AND ITS ROLE IN THE CONSERVATION OF VALUABLE OBJECTS

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Abstract

This study is an attempt to monitor the indoor microclimate and the microbiological contamination of some indoor objects inside a wooden Orthodox church. Standard microbiological techniques were used for the isolation and identification of the fungi present in the dust of the superficial surface of the paintings chosen to be investigated for biodeterioration. Samples were taken from approximately 1 cm^2 of the surface of the analysed paintings (cotton canvas, wood, on primer) using the cotton swab method. The cultures of fungus isolated from the studied paintings were identified based on their morphological and microbiological characteristics. The identity of isolates was established, based on the smear microscopic examination, using the lactophenol blue cotton staining procedure. Based on the morphological characteristics of conidiophores, the following fungal genera were determined to be present in the dust of the studied paintings: *Streptomyces* sp., *Arthrographis* sp., *Beauveria* sp., *Aspergillus* sp., *Penicillium* sp., *Alternaria* sp., *Cladosporium* sp., and *Streptomyces* sp. The current state of paintings, influenced in time by temperature, humidity, brightness, microbial contamination, and other factors, was investigated and mapped. The detailed analysis contributes to the conservation stage of the historic monument investigation, enhancing the existing data in the environments destined for the conservation of valuable objects. The continuous monitoring of the indoor microclimate, together with the maintaining of good hygiene, cleaning conditions and proper ventilation, could successfully contribute to the slowing down of painting degradation within the wooden church monument.

Key words: historic wooden church, contamination, microclimate, painting

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1. Introduction

Research into the control of indoor environments in heritage buildings (museums, churches etc.) led to several methodologies being proposed towards establishing a European standard for church heating systems favourable to artworks preservation (Bichlmair and Kilion, 2011; Camuffo et al., 2001, 2007, 2010; La Gennusa et al., 2005; Larsen, 2007; Maroya et al., 2015; Rohdin et al., 2012). Several research groups have studied the control of indoor environments in heritage buildings, specifically with regards to temperature, humidity and carbon dioxide fluctuations (Schelle, 2002: Varas-Muriel et al., 2014). Theoretical and practical studies concerning preventive conservation undertaken by Broda and Mazola (2016); Gargano et al. (2017); Lucchi et al. (2018), and Lech et al. (2015) also analysed the microflora present on historical textiles.

In Romania, many studies have dealt with the above-mentioned topic, among which are those of Dăneasă (2013), Herbel (2015), Ilies et al. (2018a; 2018c), and Indrie et al. (2019), whose detailed analyses of Romanian wooden churches have expanded the existing body of data for the conservation stage. Auner et al. (2005) explored technology applied to the restoration, and for protection against the biodegradation, of the wood from heritage buildings. Bucsa (2014), Bucsa and Bucsa (2006, 2009), Bucsa and Halasz (2013), and Sandu et al. (2001) have, in researching old paintings, evaluated the (bio)degradation of the wooden support in heritage buildings.

The aims of the study were to investigate the environments of a heritage building. The current paper presents a study on the preventive conservation of wooden churches in Romania.

2. Methods

With respect to the historic wooden church temperature and the relative humidity in the air, CO_2 monitoring was done using the Klimalogg Pro data logger and NOVA 5000, over the period of October to December 2018 (using eight sensors) (Fig. 1b), in the historic monument of the wooden church. Temperature scanning was done with a thermal imaging camera FLIR I7, and a Digi-Sense data-logging luxmeter was used for illuminance investigations.

The geographic information system (GIS) was used for the spatial analysis, visualisation, analysis, and interpretation of the available data (Biali et al., 2014; Ilieș et al., 2016, 2018b; Johnston et al., 2001; Longley et al., 2005; Onețet al., 2018; O'Connor et al., 2010). The indicators analysed were temperature, humidity and brightness, with the values obtained being incorporated into a pre-existing database developed in ESRI ArcGis 10.6. The spatial interpolation method was used in the study, with the data in the immediate vicinity being compared with a reference point examined.

In order to analyse the areas affected by degradation, their mapping was considered using the digitization method. In this way, simulations of the spatial distribution of temperature, humidity and luminosity were made to stabilise the causal relations existing between the degraded areas, in order to identify the necessary measures required to be taken for the preservation of the painting that forms an integral part of the historical wooden church monument (Figs. 2-4).

For the isolation of microorganisms from the paintings:

● samples were taken from approximately 1 cm^2 of the surface of the analysed paintings (cotton canvas, wood, on primer) with the help of sterile cotton swabs (Cifferi, 1999; Fernandes, 2006);

● the cotton swabs dipped in 1 ml of sterile distilled water; which was then inoculated into the Sabouraud agar with chloramphenicol for the fungi isolation;

● inoculated plates were incubated at 25°C;

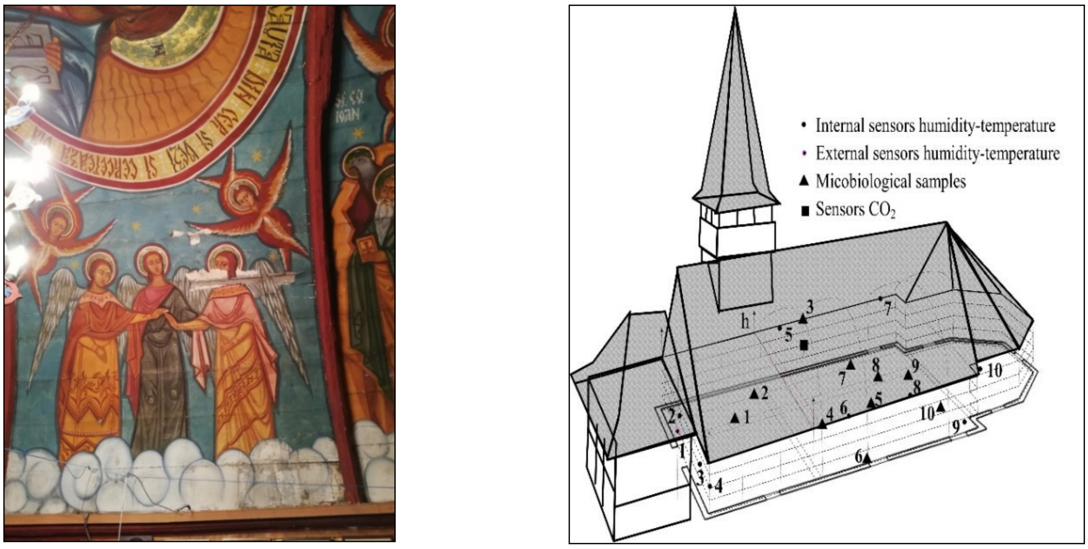
● the cultural and morphological characteristics of fungal colonies were observed, and the fungal isolates were identified by means of the microscopic examination of the morphological characteristics involved, using the lactophenol cotton blue staining procedure (Borrego et al., 2012; Garcia and Isenberg, 2010).

Case study. The Orthodox wooden church of Saint Martyrs Constantin Brâncoveanu and His Sons, on the University of Oradea campus, Romania, has been listed as a national historical monument since 2010 (BH-II-mB-20958 m). The church, which was built (1760-1762) with wooden beams, has a plated and repainted interior, so that it no longer retains its original appearance (Baias et al., 2015; Ciferri 1999, Godea et al., 1978; Ilieș et al., 2011, 2013, 2014). Among the objects of interest in the wooden church are the paintings on the interior walls. Three case studies have been considered, consisting of examinations of the paintings on cotton canvas, wood and primer (Fig.1a).

The painting in the church monument has been done in tempera on a thin layer of primer-distemper paint, as well as using the 'al secco' painting method on dry plaster. In the area of contact between the beams, an additional primer layer was applied, so as to prevent cracks from aging the wood.

3. Results and discussion

Microbiological samples from the dust of the paintings were collected and analysed. The mapping of the studied paintings emphasises the areas damaged due to the influence of temperature, humidity and brightness over time, as well as the influence of the anthropic factors (the existence of a pinch on the joint of the dropped canvas, the deformation areas, etc.). The observations were made to establish the damaged areas and those that are vulnerable to damage (Figs. 2-4).



(a) (b)

Fig. 1. (a) Wall picture on wood, in the interior of the historic wooden church; (b) Three-dimensional sketch of the wooden church with the locations of monitoring sensors for: temperature, carbon dioxide (CO_2) and microbiological samples

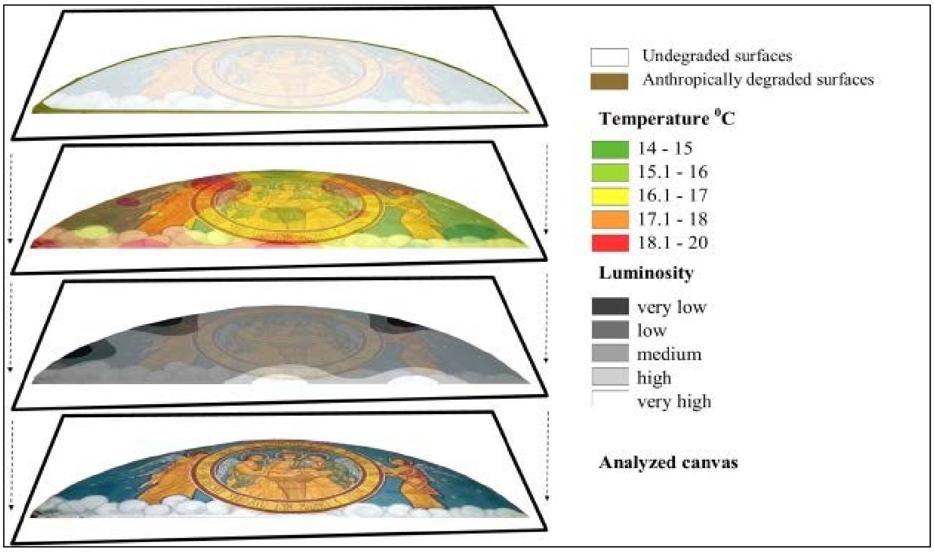


Fig. 2. Case study 1 - Painting on canvas

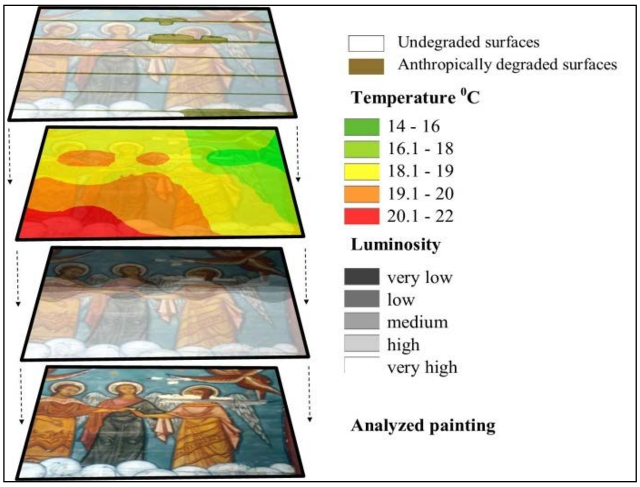


Fig. 3. Case study 2 - Painting on wood

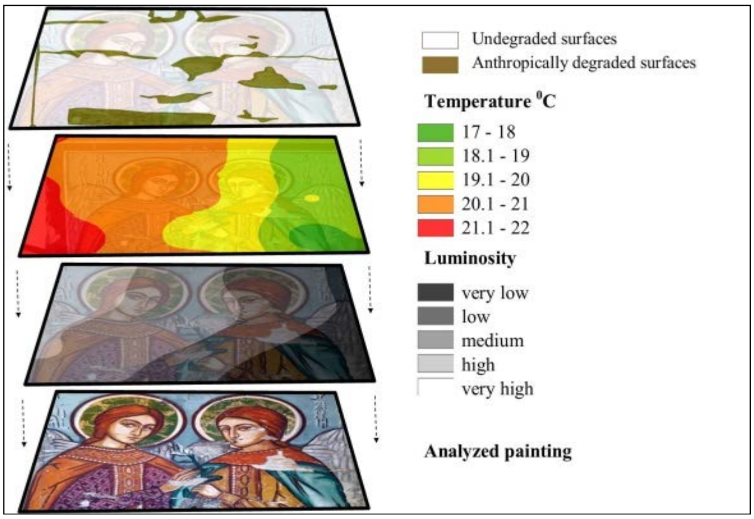


Fig. 4. Case study 3 - Painting on wood and primer

Concerning the concentration of CO_2 inside the historic wooden church, the values are within the acceptable range of parameters up to 600 parts per million (ppm) (Hedrick et al., 2010) throughout the day. During the regular Sunday liturgical service, the level of carbon dioxide exceeds the threshold of 1000 ppm, with it, in some cases, even exceeding 2000 ppm (Fig. 5). A level of CO_2 above 1000 ppm could adversely affect those attending the liturgical service with sleepiness, headaches, excessive sweating, and balance disorder (Hedrick et al., 2010). Maximum CO_2 values have been recorded during Sunday services between 09h00 and 10h00, when from 50 to 60 people have gathered inside the church. After the liturgical services, the level of CO_2 tends to drop sharply, returning to normal values from about 12h00 to 13h00 (Fig. 5).

Together with the increase in CO_2 levels during the liturgical service an increase of the temperature in the historic wooden church can also be observed (Fig. 5), which is mainly due to the activities of worship when many (approximately 60) parishioners are present. During the monitoring period (from 20.10.2018 to 10.12.2018), the average air temperature inside the wooden church was 21.1°C, with a maximum of 25.8°C being recorded on 22 October 2018 at 10h00.

The minimum temperature (6.3°C) was recorded on 01.12.2018 at 8h00. A factor that can affect the indoor microclimate is the outdoor environment. A minimum outdoor temperature (-8.8°C) was also recorded on 1 December 2018, two hours before the minimum temperature was recorded inside the wooden church, with the maximum temperature being 25.5°C, on 01.11.2018, at 16h00.

The relative humidity data collected from the eight sensors reveal an average of 44.3% of the measured values during the monitoring period. The increase in humidity levels inside the wooden church correlated with the holding of the liturgical services, with the maximum relative humidity (63%) being recorded during the liturgical service on 04.11.2018. The minimum humidity was recorded as being 25% on 01.12.2018 at 08h00 (Fig. 6).

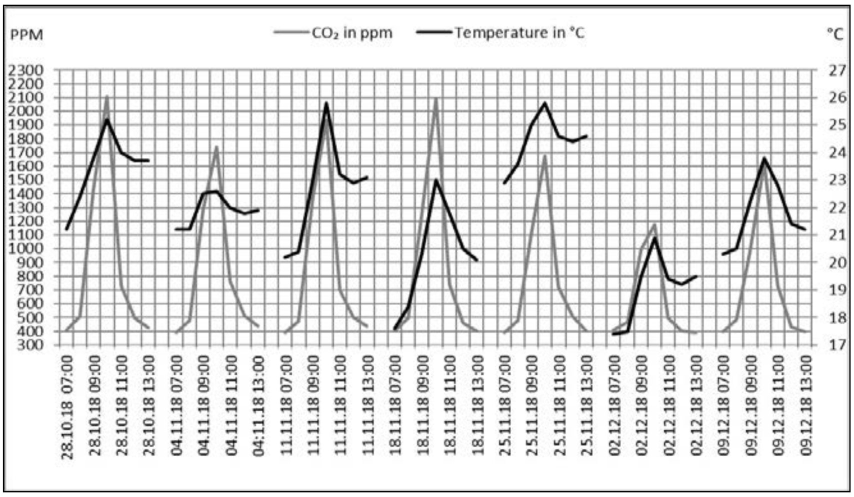


Fig. 5. The variation of air temperature and carbon dioxide (CO_2) in the historic wooden church during liturgical services, on Sundays, during the period (20.10.2018 – 10.12.2018)

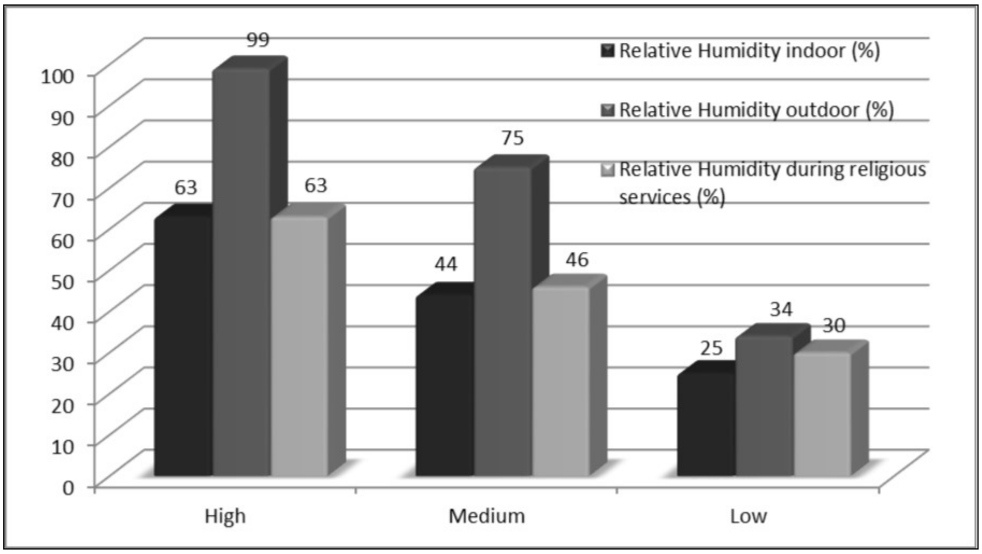


Fig. 6. The variation in relative humidity inside and outside the historic wooden church (20.10, 2018 - 10.12.2018)

One of the paintings investigated in the wooden church was on cotton canvas (Fig. 2). Cotton is a natural, polymeric, vegetable fibre, which is based on cellulose (Mâlcomete, 1995). The cellulose content gives cotton fibres suppleness, strength, elasticity, finishing ability, and specific chemical properties. Cotton fibre is hygroscopic, so the higher the moisture content, the more resistant the fibre becomes (to about 12%) (Bordeianu, 2005). Cotton can be degraded when it is exposed to ultraviolet light and to chemical and biological attack, as well as to contamination and mechanical stress (Golden, 2013). Cotton fibres should not be exposed to ultraviolet light, as it degrades the fibres over time, and, combined with other environmental factors (like humidity, temperature and mould), is likely to result in the loss of structural strength of the cotton canvas. The background colour of the painting has been influenced by natural light, which is non-uniform, with the lower part of the painting being extremely exfoliated (due to the contact between the beams being sensitive to temperature and humidity change) (Fig. 2).

The central part of the painting depicting the "Archangels Michael and Gavril" (on the right side of the iconostasis) (Fig. 4) is depicted in terms of the upcoming appearance of the wood. The influence of natural light was also observed on the non-uniform background colour (Fig. 4).

The wall painting (Fig.1a) was in a relatively advanced state of degradation, characterised by the loss of layers of paint down to the primer, plywood, or original wood layer employed in its making. The degradation was also observable at the contact between the beams, with their middle portion of wood having also suffered convex deformation, probably due to aging (Herbel, 2015). At the level of the painting's layers, degradation was recorded due to deposits of dirt on the surface. Traces of humidity were also present, because of the roof previously (before 2016) having required repair. As in the case of the other wooden churches (Herbel 2015), the wires of an electrical installation on the Nordic wall can also be seen, with it having been fixed with nails clamped into the painted grills. Degradation of the colour layers; scrubbing and erosion, including the loss of parts of the painting; metallic nails hammered in for hanging icons and curtains; cracks in the wood that led to cracks in the colour and primer layer; abrasion; and peeling, among other damage, were also seen.

Biological deterioration caused by microorganisms (bacteria and fungi) can lead to undesirable and irreversible changes in the properties of the composition or support material (i.e. in the organic, natural or synthetic substrates, consisting of cellulose, polycarbonates, metals, etc.). As various heterotrophic microorganisms can feed off the organic component of paintings (Wamedo et al., 2013), old churches can suffer biodegradation in the absence of systematic control of the prevailing microclimatic conditions. Biodegradation can penetrate the canvas, sometimes reaching the back of the paint layer, causing cracks and detachment, while cellulosic hydrolysis can create differences in the coherence between the paint layer and the canvas itself (Strzelczyk et al., 1987). In the case of paintings on wood, the degradation of the support can be different to that of the paint layer (Dhawan and Agrawal 1986; Makies, 1979). Egg distemper, emulsion distemper and linseed oil, in descending order, are most susceptible to biological attack. Paint layers tend to be more susceptible to biodegradation if heavy metals are present in some pigments (Dhawan and Agrawal, 1986).

Different fungal genes were isolated from the two paintings chosen for investigation for signs of biodeterioration inside the historic wooden church (Fig. 1a-b).

On the canvas painting, *Streptomyces* sp., *Arthrographis* sp., *Beauveria* sp., and *Streptomyces* sp. were isolated. The fungal degradation found was due to mechanical stress, the modification of compounds and enzymatic activity. The filamentous fungi can cause deterioration to oil paintings on canvas, by means of dissolving the cellulose fibres, causing discolouration of the support, and dissolving the glues used (Sterflinger 2010, López-Miras et al. 2013; Sterflinger and Guadalupe 2013).

The above-mentioned deterioration can cause severe infections, especially in people with low immunity (e.g. with AIDS infections, with a central venous catheter, or in receipt of oral treatment with corticosteroids, etc.) (Riviere et al., 2012). As the genus *Arthrographis* is a human pathogen, it can penetrate the body through the respiratory tract, or by way of trauma (Denis et al., 2016). Contamination with such fungi can lead to endocarditis, sinusitis, meningitis or keratitis, among other illnesses, and it can affect both immunocompromised and immunocompetent patients. For patients undergoing immunosuppressive therapy, systemic infection with *Beauveria* is possible (Henke et al., 2002). Concerning the presence of bacteria on the canvas paintings, both the *Bacillus* sp. and filamentous bacteria from the *Streptomyces* genus were isolated. Also, based on the microscopic techniques used, unknown bacteria strains, in the form of cocci and bacilli, were also identified.

On the second painting on wood (Fig. 3) *Aspergillus* sp., *Penicillium* sp., *Alternaria* sp., *Cladosporium* sp., *Streptomyces* sp. And *Penicillium* sp. were isolated. Fungi can penetrate through cracks at the back of the paintings, resulting in their detachment over time. Fungi can seriously contribute to cellulosic damage in the composition, as well as to lignin degradation, even if it is difficult to observe the above in indoor environments (Sterflinger, 2010; De Souza and Gaylarde, 2002). The above-mentioned organisms, when serving as human-opportunistic pathogens, can generate such infections as keratitis, cutaneous infections and pneumonia, among others. Superficial and invasive infections and allergies are common clinical manifestations of the *Penicillium* species (Chitasombat and Supparatpinyo, 2013). While *Aspergillus* can generate lung pathology, if it is localised at lung level, it can generate invasive or chronic pulmonary and aspergillosis infectious disease (Person et al., 2010). The *Alternaria* family fungal species, especially for immunocompromised patients, can cause skin and subcutaneous infections, eye mycosis, onychomycosis or rhinosinusitis associated with respiratory allergic diseases (Bush and Prochnau, 2004).

4. Conclusions

The conservation status of heritage objects preserved in wooden churches and the prospects for their improved conservation, are very important, as well as is the possible influence of the indoor microclimate on the health of visitors, priests and parishioners, and during the preservation and conservation stage of heritage building investigations and assessment. The fungal types isolated can colonise different surfaces of the paintings concerned. Recommendations are made that the indoor microclimate should be continuously monitored, together with the maintaining of good hygiene, suitable cleaning conditions, proper ventilation (including the regular changing of air-conditioning filters), and natural ventilation, by way of often opening doors and windows. All of the above can successfully contribute to the slowing down of the degradation of objects inside heritage buildings over time. The presence and development of the fungi on the superficial surface of paintings should be brought to the attention of all those affected thereby, and who can have their health negatively impacted on by the inhaling of the spores. The presence of indoor microbes and microorganisms on interior valuable objects can constitute a high risk, both for their preservation and for the users of the buildings concerned.

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