



## THE PARADIGM SHIFT FROM SUSTAINABLE TO REGENERATIVE TOURISM: A CASE STUDY OF HERITAGE WOODEN CHURCH PRESERVATION IN ROMANIA

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### Abstract

The study responds to the paradigm shift that is taking place within the concept of sustainable tourism development. The so-called “regenerative shift” moves the goals of its development from minimizing impacts on sociocultural-ecological systems (SES) towards the ability of tourism to contribute to the improvement and restoration of SES. Many authors consider it a significant paradigm shift, which they also refer to as a separate line of development outside sustainable tourism. Although there are already relatively solid theoretical frameworks for



the concept of regenerative tourism, it has not been sufficiently developed in the area of cultural heritage restoration. This study responds to this gap by applying a regenerative framework to a specific case of a historical building – the wooden church of Sfântul Gheorghe in Prodănești, Romania. The aim of the research is to empirically assess the extent to which the microclimatic and environmental conditions of the building are compatible with the principles of regenerative cultural heritage management and how they affect its physical integrity and usability in the context of local tourism and community needs. Methodologically, the study is based on long-term monitoring of the internal microclimate, which took place between August 2024 and January 2025. The subject of monitoring was the measurement of temperature, relative humidity, particulate matter PM2.5 and PM10, volatile organic compounds, light intensity, acoustic intensity, negative and positive ions. Within the research, biological degradation factors (lichens, microorganisms) were examined, and the research was supplemented by a non-invasive investigation using infrared thermography to capture the momentary condition of the surface temperature and interior painting in the wooden church, which is in a state of significant decay. The results show a significant exceedance of the recommended temperature and relative humidity values, a high dependence of the interior environment on external climatic conditions, and the presence of biological degradation processes that negatively affect the authentic building materials and preserved fragments of interior decoration. It transpires that the physical degradation of the building is not an isolated technical problem, but a manifestation of the broader dynamics of the SES within cultural heritage management. Recommendations include the introduction of continuous microclimatic monitoring, the application of non-invasive conservation measures. The proposals include adaptive management, which combines data-driven decision-making with community participation, and enables flexible responses to the SES dynamics of cultural heritage systems.

#### **Key words**

Regenerative turn, regenerative tourism, sustainable tourism, degrowth, heritage, microclimate, preservation.

## **INTRODUCTION**

Recently, in connection with research into minimizing the potential impacts of tourism development on *sociocultural-ecological systems* (SES), issues related to its ability to contribute to their improvement and restoration have been increasingly addressed. This shift in the discourse on tourism sustainability is now considered by many authors as a significant paradigm shift and is referred to as the “regenerative turn” (e.g., Bellato et al., 2023; Dredge, 2022; Khater et al., 2025). Thanks to the growing number of studies focusing on this issue, the concept of regenerative tourism basis has been established. Numerous applications in the field of cultural heritage have thus led to the formation of the foundations of regenerative tourism frameworks, mainly at the normative-conceptual level. Current literature points to the need to move from abstract principles to empirically comprehensible tools that would make it possible to assess whether and how tourism actually contributes to the regeneration of SES of heritage (Bellato et al., 2023; Dredge, 2022; Khater et al., 2025). The key problem remains the operationalization of



the concept of “regeneration” at the level of specific locations, processes, and measurable indicators. In the context of cultural heritage, the regenerative approach is not limited to protecting the physical integrity of monuments, but also includes restoring their functionality, significance, and relationships with the local community, institutional structures, and environmental conditions (Bellato et al., 2023; Dredge, 2022). In this case, cultural heritage is understood as a living SES, whose vitality depends on interactions between the physical condition of the object (in the case of buildings, including the complex of interior attributes), modes of use, forms of management, and broader environmental processes (Rani et al., 2025). It is these relationships that represent the critical interface between the theoretical foundations of regenerative tourism and its practical implementation.

This study responds to the existing gap between the existing conceptual framework of regenerative transition and empirical research by applying the principles of regenerative cultural heritage management to a specific case of a historic object – the wooden church of Sfântul Gheorghe in the village of Prodănești (Sălaj County, Romania). The case study serves as an empirical research context for assessing the extent to which physical, environmental, and microclimatic conditions are consistent with the requirements of regenerative cultural heritage management and its integration into local tourism practices and the sociocultural needs of the local community. The focus on internal microclimatic parameters (temperature, relative humidity, air quality, and biological factors of degradation of building materials and other interior elements) allows the physical condition of the monument to be interpreted not as an isolated technical problem, but as part of a broader regenerative system of relationships between the environment, visitors, and methods of building management. This approach corresponds to the epistemological shift in regenerative tourism from static indicators to a process-oriented assessment of the vitality of the system. The aim of the study at the empirical level is therefore not only to document the microclimatic conditions of the wooden church, but also to interpret the results obtained in the perspective of a regenerative framework for cultural heritage management. The case study contributes to the discussion on how the principles of a systemic approach, resilience, and ecological regeneration can be linked to specific conservation and management measures at the local level. At the same time, it emphasizes the need for integrated and non-invasive conservation approaches that ensure not only the preservation of the physical integrity of the monument, but also the long-term compatibility of its protection with the conditions of the local environment.



## THEORETICAL FRAMEWORK

### The regenerative shift in tourism: context and premises

The discussion on the relationship between tourism and cultural heritage has long been conceptually anchored primarily in normative “sustainability” – i.e., minimizing the negative impacts of visitor numbers on the tangible and intangible cultural heritage values of sites. In recent years, however, there has been intense discussion in tourism about the so-called regenerative shift, which moves management goals from the principle of “do no harm” to the ambition of “net positive impact.” In other words, the development of tourism should not only focus on reducing its negative impacts on the natural and sociocultural environment, but expectations are shifting towards its active contribution to improving the condition of the entire system of which it is a part (Bellato, Pollock, 2023; Dredge, 2022).

The regenerative approach is particularly relevant to cultural heritage management. In this case, natural and cultural heritage is not understood as an isolated element (attribute, artifact) of the environment, but as a living SES, whose “health” (viability) is the result of interactions between the physical location, community, land management structures, and local authorities (such as various levels of governance, institutional management structures, etc.), tourism-related flows of resources and benefits, and environmental limits (Bellato, Pollock, 2023; Boros, Korcsmáros, 2024; Sharma et al., 2025). In the heritage context, this shift is beginning to be explicitly linked to the themes of community renewal, participation, and empowerment, as indicated by recent studies on “reviving heritage through regenerative tourism” or “heritage revitalization” (Khater et al., 2025).

Research into regenerative tourism is undergoing rapid conceptual consolidation. Bellato, Frantzeskaki, and Nygaard (2023) summarized the conceptual frameworks and specifics of regenerative tourism, pointing out its key difference from sustainable tourism, namely that it aims to improve the vitality of living systems (Bellato et al., 2023). Dredge (2022) adds another distinguishing attribute in this context, namely a shift towards a change in mindset, systemic transformation, and “boundary spanning” practices, i.e., practices that bridge boundaries between sectors, actors, disciplines, and levels of governance decision-making. In other words, regenerative tourism connects these epistemic worlds to create a common understanding of the problem and its solutions. To do this, it needs actors and institutions that can act as “bridges” between the tourism sector, heritage protection, communities, and politics (Dredge, 2022).

The main pillars of regenerative tourism are considered to be: (a) systems thinking, (b) resilience theory, (c) ecological regeneration, (d) place-based development, and (e) tourism degrowth/post-growth.



*(a) Place as a dynamic system - systems thinking*

Regenerative tourism taps into the practice of systems thinking, which highlights non-linear connections, feedback loops, time lags, and the spontaneous behaviour of intricate systems (Meadows, 2015). Rather than focusing on the individual “impacts” of a problem, it shifts our attention to the system as a whole (for example, how visitors move through a place, the local economy, the way decisions are made, and ecological limits). It also looks at places where intervention has a particularly big effect (Meadows, 2015; Kostilníková et al., 2022). This approach builds on the traditional “*systems view of life*,” where “*life*” is interpreted as a network of relationships between elements of the system. This framework is important for regenerative approaches in that it shifts planning from the optimization of isolated variables to the promotion of relational quality (Capra, 1996). In tourism, this means that success is not defined solely by the volume of visitors or the amount of revenue (not outputs), but also by the *quality of the relationships* between visitors, hosts, institutions, and the place, i.e., the ability of the system to maintain and develop functional, cooperative, and long-term stable relationships, or to function and renew itself in the long term.

*(b) Resilience theory: adaptation, transformation, recovery capacity*

The second pillar is resilience theory, which is based on Holling’s (1973) traditional differentiation between stability and resilience. In his view, resilience is not just a return to the original state, but also the ability of a system to absorb shocks and maintain key functions (Holling, 1973). Later developments of the concept in the perspective of SES emphasize adaptation, learning, and transformability, i.e., the ability of a system to change its configurations while maintaining its viability (Folke, 2006; Walker, Salt, 2006; Szilágyi et al., 2025). Resilience is key to heritage management in tourism because the “pressure” on a location (tourist destination) is not only environmental but also social (between visitors and the community), institutional (capacity limits of land management), and economic (dependence on a single source of income; Kostilníková et al., 2022). In this regard, the regenerative framework shifts the emphasis from limiting visitor numbers to building the system’s ability to adapt and renew its capacities.

*(c) Ecological regeneration and regenerative design: from recovery to improved functionality*

The regenerative discourse is also based on traditions of ecological recovery and regeneration, where the goal is not only to “repair damage” but, above all, to restore the functionality and integrity of the system (Martin, 2017). In a broader sense, this shift reflects the thesis of a transition from “sustainability”



to “regeneration” – i.e., from maintaining the status quo to actively improving it (Reed, 2007). In tourism, this principle is transformed into the logic of “net positive,” i.e., revenues and activities associated with visitor numbers should generate the restoration of ecosystems, cultural practices, and infrastructure, while monitoring the balance of impacts and benefits across the dimensions of the system (Bellato, Pollock, 2023; Dredge, 2022).

(d) *Place-based development: locally embedded change and territorial governance*

Another pillar of the concept is place-based development, which emphasizes the need for development strategies to be based on local specifics, endogenous resources, and multi-level governance, rather than universal “best practices.” In this case, integrated interventions and institutional coordination, which are an important part of place-based development policy (Barca, 2009), are considered a key way of addressing complex territorial inequalities. In regional development theory, the place-based approach is normative in nature, as it raises the question of “what kind of development is being pursued and for whom,” explicitly addressing issues of values, social justice, and the distribution of costs and benefits (Pike et al., 2007). In regenerative tourism, place-based logic is present in the emphasis on locally defined values, socially legitimate goals, and the connection of tourism with local life strategies rather than with externally anchored demand maximization.

(e) *Degrowth / post-growth in tourism: criticism of growth as a target function*

The regeneration shift is part of a broader re-evaluation of the growth paradigm in tourism. For example, degrowth and post-growth literature in tourism explicitly questions the idea that growth in visitor numbers and consumption is compatible with ecological limits and social justice, and proposes a new research and development orientation towards well-being, justice, and resource limits (energy use, fossil fuels, renewables capacity; materials, land, water; carbon budget) and the assimilation capacity of ecosystems (waste, pollution; e.g. Higgins-Desbiolles et al., 2019; Fletcher et al., 2019). Current academic discourse also shows that the degrowth agenda is already considered a separate school of thought (Murray et al., 2025; Dredge, 2022). Degrowth tourism represents a more radical school of critical thinking of growth, based on normative criticism of growth and the reduction of material and energy throughput associated with tourism activities (Murray et al., 2025). Post-growth tourism represents a more moderate, reformist framework for criticizing the logic of growth, i.e., a “beyond growth” framework without the need for explicit reduction, but with an emphasis on quality, stability, well-being, local prosperity, and systemic transformation. Regenerative tourism stands between them, taking from degrowth its criticism of quantity and from post-growth



its focus on the qualitative transformation of systems. What both concepts (regenerative tourism and degrowth) have in common is their criticism of “quantity” (growth) as an indicator of success. In both cases, greater emphasis is placed on transforming systems and strengthening local capacities (Dredge, 2022; Bellato, Pollock, 2023).

### **Axiological, ontological, and epistemological divergence between sustainable and regenerative tourism**

Despite the above characteristics, regenerative tourism cannot be reduced to a simplified idea that it is just a set of certain management tools or techniques for optimizing visitor numbers. Regenerative tourism is rather perceived from a metatheoretical perspective as a concept that redefines the possible goals of tourism, as well as from an ontological perspective the nature of interconnected relationships within social (e.g., actors, community, institutions) and natural systems (Dredge, 2022; Bellato et al. 2023; Bellato, Pollock, 2023; Kostilníková et al., 2022) that constitute it. In addition, the integrative ontological unit of “place” is also considered, which connects the social (people, communities, institutions), natural (ecosystems, landscape) with meaning (identity, memory, values; Matlovcova, 2024). In this case, place encompasses location (where), identity (who), meaning (what it means), and relationships (how it lives; Matlovcova, 2024). Regenerative logic thus makes it possible to bridge the traditionally perceived binary between conservation and exploitation (use). In this case, it is replaced by the perspective of relational co-evolution, in which tourism acts as a potential catalyst for SES restoration. From an axiological point of view, regenerative tourism shifts the value horizon from minimizing negative externalities to a “net positive impact,” i.e., the active production of positive effects on SES. At the same time, however, the goal is not only to stabilize the existing state, but above all to improve the vitality of the SES as a whole (Reed, 2007; Bellato et al., 2023). The shift described thus represents a qualitative change from the sustainability paradigm, which was primarily focused on maintaining a balance between the economic, social, and environmental dimensions of the SES, not on its restoration (Higgins-Desbiolles et al., 2019; Fletcher et al., 2019; Sharma et al., 2025). The normative criterion for assessing success is therefore not only damage reduction, but also the ability of tourism to contribute to strengthening local capacities, restoring ecological and cultural functions, and ensuring the long-term resilience of the SES.

Currently, there are two opposing views on regenerative tourism. One group of authors considers it to be a conceptually different normative and epistemological framework, while the other group considers it to be merely an extension or “advanced version” of sustainable tourism. In this case, it should be emphasized that both approaches jointly criticize uncontrolled growth and environmental



and social externalities, but their basic ontological assumptions, target functions, and operational logics differ significantly (Bellato et al., 2023; Dredge, 2022). While sustainable tourism is historically rooted in the paradigm of “*harm reduction*” – that is, in an effort to reconcile economic development with environmental and social limits – regenerative tourism shifts the focus to the paradigm of systemic renewal, in which tourism is understood as a potential tool for the renewal of SES (Reed, 2007; Bellato et al., 2023). This shift is not only terminological, but also represents a change in the understanding of the subject of regulation itself, i.e., while sustainability aims to manage impacts, regeneration focuses on managing relationships and transformation processes (Bellato et al., 2023). Sustainable tourism is therefore based on an implicit understanding of a destination as a set of resources that must be managed so that they are not depleted (Butler, 1999; UNWTO, 2004). Such an approach assumes a relatively stable system in which the main variables are the rate of use and the rate of damage.

Conversely, regenerative tourism is predicated on systemic ontology, wherein the concept of place is understood as a dynamic SES that is subject to nonlinear changes, feedback, and adaptive processes (Capra, 1996; Meadows, 2015; Bellato et al., 2023). Fundamental methodological implications are presented by this ontological difference. The focus of sustainability is on the maintenance of balance (the achievement of equilibrium). By contrast, regeneration is associated with the concepts of transformation, learning, and co-evolution between tourism and place (Folke, 2006; Walker and Salt, 2006; Dredge, 2022). It’s not just about managing things anymore, it’s about working together to make things better.

From a normative perspective, sustainable tourism is defined in the first instance as an endeavour to minimise the environmental and social damage caused by tourism (UNWTO, 2004; Butler, 1999). Success here means reducing pressure on resources and making sure they’re available for future generations. However, regenerative tourism does not stop at criticizing or minimizing negative phenomena, but explicitly sets goals, values, and directions for change that are desirable to achieve. In other words, the goal is not to achieve a state that is “less bad,” but rather a “net positive impact,” i.e., “better than before” (Reed, 2007; Bellato et al., 2023). In practice, this normative shift means that the state of tourism development is assessed according to the extent to which it contributes to the restoration of cultural and ecological functions, increased community resilience, or the strengthening of local capacities and the restoration of the condition, function, and significance of cultural heritage (Dredge, 2022; Matlovcova et al., 2022; Matlovcova, 2024; Szilágyi et al., 2025; Khater et al., 2025). The value of regeneration in regenerative tourism thus goes beyond environmental sustainability into the sphere of social and cultural transformation.

The above considerations suggest that the epistemological divergence between sustainable and regenerative tourism lies in different understandings of



the goals of tourism development. At the methodological level, in the context of measuring change, static indicators of the state of the environment are replaced by process- and relationship-oriented metrics of system dynamics. Unlike sustainable tourism, which is based mainly on indicators measuring environmental impact, social impact, and sustainable economic benefits (UNWTO, 2004; McCool, Lime, 2001). These indicators allow for monitoring a predominantly linear perspective of development (e.g., number of visitors, energy consumption, resident satisfaction). However, regenerative tourism is oriented towards processes, relationships, and long-term trajectories of change, which are mostly non-linear, and therefore requires a different type of approach (Bellato, Pollock, 2023; Dredge, 2022). From an epistemological point of view, it therefore requires a change in approach:

- from measuring the existing state to examining the dynamics of development,
- from identifying (static) thresholds of development to monitoring feedback,
- from isolated indicators to their systemic configurations (Folke, 2006; Meadows, 2015).

The epistemological shift outlined above is often accompanied by a growing use of transdisciplinary and participatory methodological approaches, which are better able to capture the nonlinear dynamics of relationships, changes in institutional practices, and the meanings of “place” in changing contexts (Bellato et al., 2023; Matlovcova, 2024; Matlovcova, Kormanikova, 2014; Klimovský et al., 2016; Dredge, 2022).

Another difference between sustainable tourism and regenerative tourism is the different understanding of governance. This political-institutional divergence between them manifests itself in the replacement of regulatory mechanisms with transformative ones, as well as in the promotion of participatory institutional arrangements (Khater et al., 2025). In other words, within the framework of governance, sustainable tourism promotes regulation and control, i.e., visitor limits, environmental standards, certifications, and regulatory instruments (UNESCO, 2012). Regenerative tourism, on the other hand, prefers the transformation of institutional relationships, primarily through participation, co-management, and locally based governance (Dredge, 2022; Khater et al., 2025). In the field of management, sustainable tourism is usually based on an expert, technocratic model of decision-making, while its regenerative alternative emphasizes social learning, collective responsibility for heritage, and community legitimacy, which does not stem primarily from expert authority, the market, or the state, but from the recognition and consent of the local community as the primary bearer of the relationship to the place (Bellato et al., 2023). The governance (who decides, how they decide, based on what values, and with what legitimacy) of cultural heritage in tourism is thus a process of constant negotiation between actors in the destination about the values of protection, development, and social justice (Khater et al., 2025).



## Regenerative framework for cultural heritage management in tourism

In the context of the above considerations, the regenerative Heritage Tourism System can be defined as a SES consisting of four interconnected subsystems:

1. *cultural-material subsystem*, which includes the material values of heritage, their maintenance, restoration, and issues of physical integrity and material authenticity of heritage sites;
2. *social subsystem*, represented by community participation, social cohesion, and the legitimacy of decision-making processes in the field of heritage management;
3. *economic-institutional subsystem*, which includes various forms of governance<sup>1</sup>, redistribution, or benefit-sharing mechanisms resulting from tourism, as well as the capacity of institutions responsible for heritage management;
4. *environmental subsystem*, reflecting the ecological limits of tourism development, the possibilities for landscape regeneration, and the adaptive capacity of SES (Holling, 1973; Folke, 2006; Barca, 2009; Meadows, 2015; Dredge, 2022; Bellato et al., 2023; Boros, Korcsmáros, 2024; Rani et al., 2025; Sharma et al., 2025).

More recent state-of-the-art reviews point to conceptual plurality and the risk of “buzzwordization” of the term regenerative tourism. Regenerative discourse can thus be misused if it is not clarified what exactly “net positive” means and how it will be measured. (Bellato, Pollock, 2023).

Based on studies published to date, it can be argued that the difference between sustainable and regenerative tourism lies in the nature of the measures taken, which represents a paradigm shift in the understanding of tourism as a social phenomenon (Dredge, 2022; Bellato, Pollock, 2023). Regenerative tourism thus replaces:

- the logic of development limits → the logic of transformation,
- resource protection → system renewal,
- quantitative indicators → qualitative dimensions of vitality
- and technocratic regulation → participatory governance (Bellato et al., 2023; Khater et al., 2025).

In this sense, regenerative tourism can be seen as a synthesis of systems thinking, resilience, place-based development, and post-growth criticism in tourism, which allows us to transcend the dilemmas between heritage protection

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<sup>1</sup> Governance of cultural heritage (or tourism) can take hierarchical, market-based, network-based, participatory, and place-based forms depending on the source of legitimacy, decision-making methods, and normative orientation (Rhodes, 1996; Hall, 2011; Healey, 2007; Ansell & Gash, 2008; Graham et al., 2000).



and exploitation and thus formulate a new horizon for the development of tourism as a tool for social and cultural renewal (Higgins-Desbiolles, 2019; Fletcher et al., 2019; Bellato et al., 2023).

### **Case study Wooden Church „Sfântul Gheorghe” (Prodănești Village, Sălaj County, Romania)**

Despite relatively broad theoretical discourse on regenerative tourism, there are still few empirically oriented studies in the field of cultural heritage management. Most existing works focus on conceptual models, principles, and governance frameworks, while less attention is paid to examining the specific physical and environmental conditions that form the basis of the material vitality of heritage. However, the regenerative approach assumes that the restoration of the sociocultural functions of tangible cultural heritage is inextricably linked to its physical condition and the environmental context in which the object is situated. It therefore requires detailed knowledge of the processes of degradation, adaptation, and regeneration at the level of specific sites.

In this context, the case study of the wooden church of Sfântul Gheorghe in the village of Prodănești (Sălaj County, Romania) is understood as an empirical contribution to the application of the theoretical principles of the regenerative framework of cultural heritage management. The building represents a cultural-ecological system in which microclimatic processes, biological factors, building materials, and forms of use associated with liturgical and tourist activities intersect. The analysis of the microclimate of the interior of the object and its impact on the building structure, as well as other elements of the interior, allows us to interpret the physical condition of the monument as a manifestation of the overall vitality and adaptability of the SES.

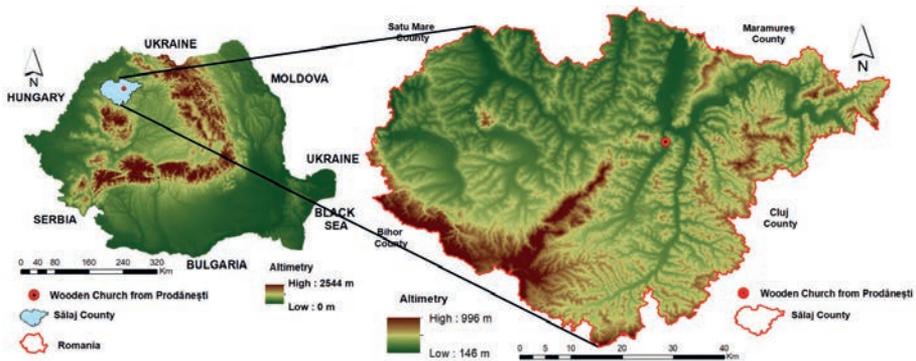
The case study is not only a technical assessment of the condition of a cultural heritage site, but also a contribution to the discussion on the possibilities of linking specific conservation measures to the management of regenerative tourism – systemic thinking, adaptive management, and a focus on long-term restoration (Ciangă, 2007; Wendt et al., 2018; Elian, Stoean, 2013; PFB, 2017). The example of the wooden church in Prodănești thus serves as an illustration of the possibilities, but also the limits, of applying a regenerative framework in the conditions of small rural cultural heritage sites.

### **Research object**

The object of the research is the wooden church “Sfântul Gheorghe”, which is located in Prodănești village in Sălaj County in northwestern Romania. Dating back to 1730, the church is a notable historical monument and an important part of the local cultural heritage (MCR, 2015). The edifice stands out through its reduced



dimensions, 8.55 m long and 3.55 m wide, being one of the smallest wooden churches in Sălaj County. Construction-wise, it has a rectangular plane, with square, unhooked apse. The wooden church walls are made of thick beams and have small, cut windows, and the tower is directly proportional with the edifice's dimensions, being of medium height (Măruțoiu et al., 2017). The coverage is made in the narthex by a straight ceiling and, in the nave and altar, it has a semicircular vault which ends in the eastern side with a tympanum prolonged with the wall (Godea et al., 1978). Due to the small size of the wooden church, the iconostasis presents only two entrances, compared to the usual three, and, due to the small surface of the altar, the altar stone is placed in the nave. Inside the church, there are only traces of painting (Măruțoiu et al., 2017).



**Fig. 1** The location of the wooden church in Prodănești at the level of Romania and Sălaj County

*Source: visualized by the authors*



**Fig. 2** The wooden church is a historical monument in the locality of Prodănești, exterior (left) and interior (right)

*Source: Authors' archive*



In the field of indoor microclimate, numerous studies were carried out, investigating the effects of parameters characterizing it upon cultural heritage (Alterio et al., 2010; Fabbri et al., 2019; Mihincău et al., 2019b; Ilieș et al., 2022; 2020; Rosina et al., 2023; Tringa et al., 2024).

Wooden churches have been an interest point for researchers, both internationally and nationally. Nawalany et al. (2020; 2021; 2025) conducted many studies on wooden churches in Poland, investigating temperature and humidity conditions inside them. The studies concluded that temperature and relative humidity exceeded optimum values over long periods of time and, during Mass, the number of present people influenced temperature and relative humidity levels. It was also concluded that when wooden churches were heated inside, temperature and relative humidity values were more optimum.

Temperature fluctuations can be a risk for the paintings within wooden churches and, in this context, Califano et al. (2024) made a study on this topic and provided useful preservation advice, based on possible scenarios.

Andres et al. (2024) investigated the microorganisms and the role of humidity inside a wooden church from Poland, showing the high humidity values within walls, as well as the need for conservation measures which must be considered to protect the wooden church.

Nationally, the indoor microclimate features were studied in many wooden churches. Numerous studies were made at the wooden church in Oradea, where Mihincău et al. (2019a) investigated the indoor microclimate inside the Wooden Church from the University of Oradea Campus and the way in which it could be influenced by religious activities. From the data obtained, it was concluded that the interior microclimate was not optimum and that it could represent a risk factor for the construction itself and for human health. Ilieș et al. (2021; 2022) investigated the microbiological, health and comfort aspects of air quality within this wooden church.

Regarding the research of wooden churches in Sălaj County, studies were made at the Wooden Church from Răstolțu Deșert, investigating the indoor microclimate and its influence on the edifice. The second part of the research focused on visitors' perception on air quality and its effects on human health. The research concluded that the indoor microclimate parameters systematically exceeded optimum values and represented a potential risk factor for the edifice (Noje et al., 2025).

Other studies regarding indoor microclimate were also accomplished and indoor well-being factors and environmental infrastructure represented a preoccupation in researches carried out in Romania (Marcu et al., 2021; Ilieș et al., 2021; 2022).



## DATA AND METHODS

The research methodology consisted in the indoor microclimate parameters' analysis and the way in which it influences the edifice and visitors' human health.

### Determination of microclimate features

The study was carried out over a period of six months, from the 1<sup>st</sup> of August, 2024, till the 31<sup>st</sup> of January, 2025, with the aim to research the indoor microclimate features over several seasons, and the way in which outdoor climate changes influence the indoor microclimate of the wooden church. For gathering data, sensors were used and their specifications are presented in table 1.

**Tab. 1** Specification of the measuring equipment used

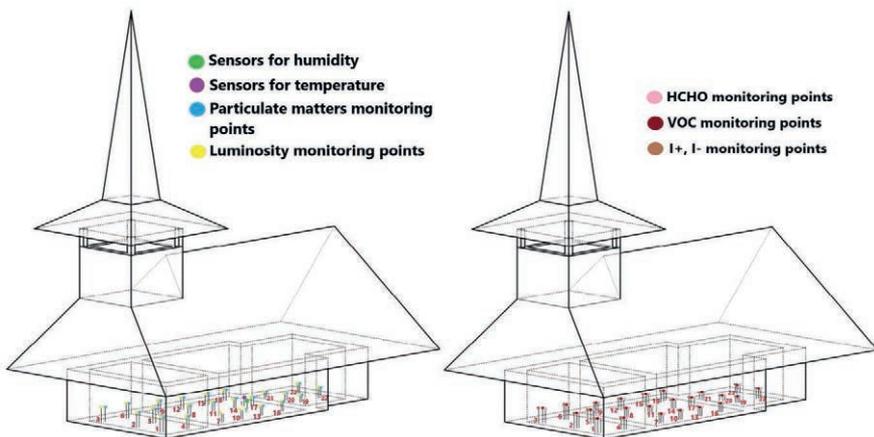
| Equipment model   | Determined indicators                                 | Producer  | Precision   |
|---|---|---|---|
| Climate data logger BL30  | Temperature, RH                                       | Trotec, Germany                                     | $\pm 1$ °C (Temperature), $\pm 3\%$ (RH)  |
| CEM DT-96 mini particle counter PM <sub>2.5</sub> , PM <sub>10</sub>                  | Temperature, RH, PM <sub>2.5</sub> , PM <sub>10</sub> | Shenzhen Everbest Machinery Industry Co, China      | $\pm 1$ °C (temperature), $\pm 5\%$ (RH), to $\pm 5\%$ (PM <sub>2.5</sub> , PM <sub>10</sub> )  |
| CEM DT-93 Detector of formaldehyde (HCHO) and total volatile organic compounds (TVOC) | HCHO, TVOC  | Shenzhen Everbest Machinery Industry Co, China      | $\pm 2\%$ (VOC), $\pm 2\%$ (HCHO)   |
| Split type luxmeter GM1030  | Temperature, Natural light LUX                        | Shenzhen Jumaoyuan Science and Technology Co, China | $\pm 1$ °C (temperature)<br>Stage X1 - $\pm 3\%$ rg +5digits<br>Stage X10 - $\pm 3\%$ rg +10digits<br>Stage X100 - $\pm 4\%$ rg +10digits<br>Gear X1000 - $\pm 4\%$ rg+10digits |
| HOKUTO Model NKMH-103   | Positive ions, negative ions                          | Hokuto Electronics, Inc., Japan                     | 100-19.990.000 (piece/cc)<br>100-199.900 (piece/cc)<br>1.000-1.999.000 (piece/cc)<br>10.000-19.990.000 (piece/cc)   |
| Sonometer SL400   | Sound level   | Trotec, Germany                                     | IEC 61672-1 class 2, ANSI S1.4 type 2   |
| TD120 Trotec  | Distance, surface, volume                             | Trotec, Germany                                     | +/-1,5 mm   |
| Infrared thermal imaging camera Flir E5   | Thermographic images                                  | FLIR Teledyne, United States of America             | $\pm 2$ °C  |

Source: Trotec (2025); Shenzhen Everbest Machinery Industry Co. (2025); Hokuto Electronics (2025); FLIR Teledyne (2025).



To determine the wooden church microclimate, several parameters were monitored using multiple procedures. Temperature and relative humidity were automatically monitored every 60 minutes with the help of a data logger climate sensor Trotec BL30 (Trotec, 2025). The sensor was placed in the nave to better cover the church interior, at a height of 1.5 m.

The Particulate Matter (PM<sub>2.5</sub>, PM<sub>10</sub>), the amount of VOC, HCHO, NL, I<sup>-</sup> and I<sup>+</sup> were manually monitored. The measurement intervals were 7:30 a.m., 1 p.m. and 7:30 p.m. For optimum coverage of the wooden church, 23 gathering points were selected: 6 points in the narthex, 12 in the nave and 5 in the altar, and their positioning can be seen in Fig. 3. Acoustic intensity was recorded over 3-hour intervals. To analyze the effect of temperature and humidity on the wooden church surfaces, thermographic images were taken with an infrared thermal imaging camera Flir E5 (FLIR Teledyne, 2025), and to analyze and interpret the thermographic images, Flir Tools + 6.4 software was used.



**Fig. 3** Spatial distribution of sensors and data collection points inside the wooden church  
*Source: Authors' own visualization*

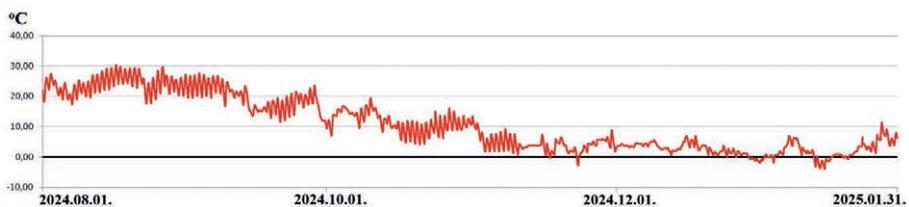
## RESULTS

### Indoor microclimate data analysis and interpretation and their influence on the edifice and human health

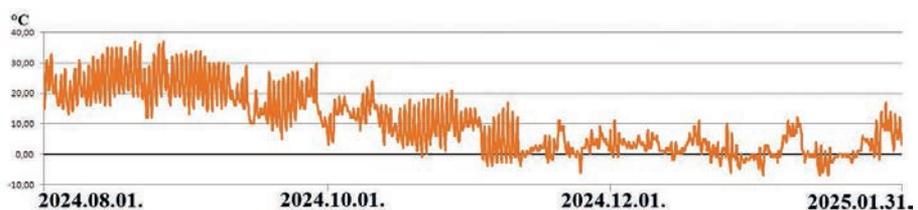
For proper preservation and conservation of the Wooden Church from Prodănești, but also for human health, the temperature value must be maintained within optimum limits proposed by standards in effect. A first standard is ASHRAE (2011), which stipulates an average temperature of 20 °C ( $\pm 1-2$  °C), and for human health, the ASHRAE standard stipulates values between 20–24 °C in the cold season and 23–26 °C in the warm season (ASHRAE, 2020).



Due to the fact that the wooden church does not have a heating source and the construction allows communication with outdoor air, the temperature values inside the wooden church depend on the outdoor air, as seen in Fig. 5. The temperature value, over the monitored period of time, fluctuated almost for the entire period, as seen in Fig. 4. Over the monitored period of time, the highest temperature values were recorded in August and the maximum temperature value of 30.2°C was recorded on the 16th of August, 2024, at 6:39 pm. During the autumn months, the temperature values decreased and significant fluctuations could be noticed during short periods of time of only a few days. In December and January, the temperature values fluctuated between 0° C-10° C, however, short periods of time, of a few days, could be noticed when the indoor temperature decreased under the value of 0° C, respectively, to a minimum value of -4° C, recorded on the 16th of January, 2025, at 9:46 a.m. The average temperature value was of 10.72° C, with thermal amplitude of 34.2° C.

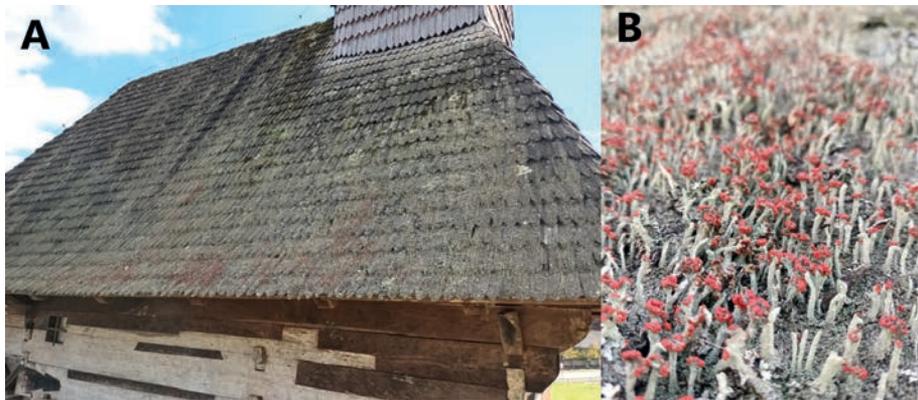


**Fig. 4** Indoor air fluctuations (°C) from August 01, 2024 to January 11, 2025



**Fig. 5** Fluctuations in outdoor air temperature (°C) from August 1, 2024, to January 11, 2025

As seen in Fig. 6.A., on the north-western roof side of the Wooden Church from Prodănești, *Cladonia transcendens* lichen species dominantly developed. Factors which enhanced their development were the old wood, with water retaining cracks and irregularities (Brischke, Alfredsen, 2020; Cozzolino et al., 2022), and the high relative humidity condition of the wooden church microclimate, with approximate average values of 70%.

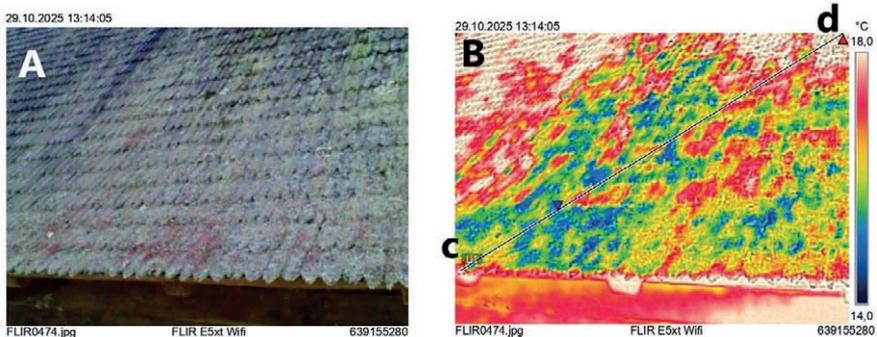


**Fig. 6** Roof of the Wooden Church from Prodănești (A), colonized by *Cladonia transcendens* lichen species (B)

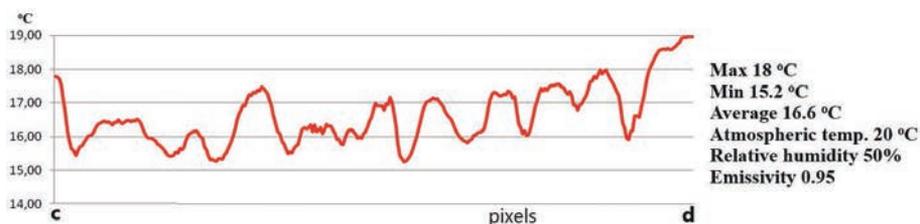
On the temperature profile from Fig. 8, it can be observed the way in which surface temperature is distributed, on the left-right diagonal of the wooden church roof, fluctuating from 15.2 °C to 18 °C, and also depending on the *Cladonia transcendens* lichen colonization.

In the thermographic image from Fig. 7.B., it is noticeable the way in which fungi influence humidity distribution on the roof surface (Kraniotis et al., 2016; Madruga et al., 2020; Barreira et al., 2020; Dafico et al., 2022). In the current case, retained humidity has, in time, a rotting effect on wood.

Due to the fact that the wooden church is a historic monument, preservation measures with non-invasive methods are recommended (St. Clair, Seaward, 2004). To prevent *Cladonia transcendens*, the relative humidity level must be monitored and controlled inside the wooden church, to maintain the wood dry and to achieve ventilation of the wooden church (Moron et al., 2016; Walsh-Korb, 2022; Cozzolino et al., 2022).

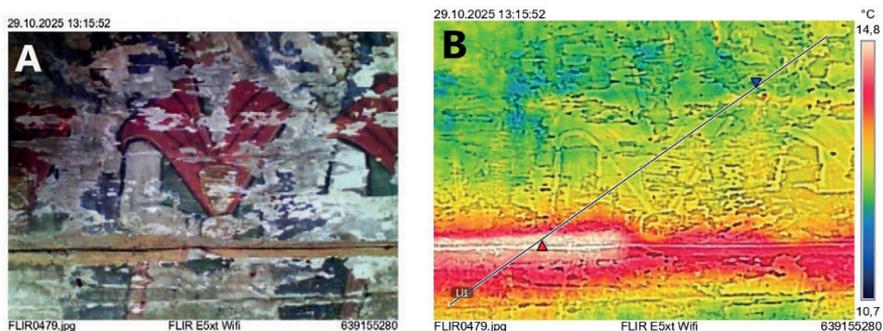


**Fig. 7** Roof of the Wooden Church from Prodănești (A) and its thermographic image (B)

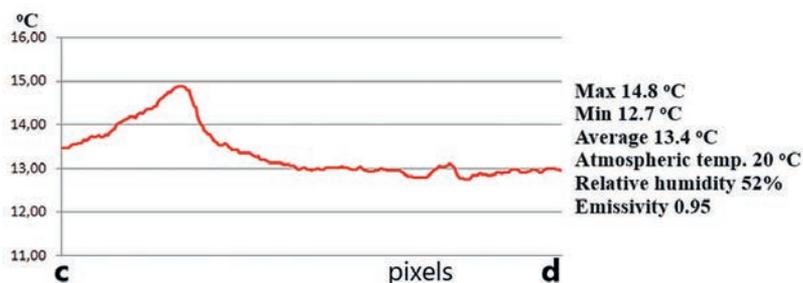


**Fig. 8** Temperature profile on the left-right diagonal of the roof area, from the thermographic image B from Fig. 7

Inside the Wooden Church from Prodănești, the painting is in an advanced state of decay and, as seen in the image in Fig. 9. A, the scenes in the painting are barely visible. To observe the way in which the painting is influenced by various factors, infrared thermography was used, being a non-invasive method, and a temperature profile was made for the photographed painting. As it can be seen in both images in Fig. 9, the painting was significantly deteriorated at the construction beam joints.



**Fig. 9** Wooden Church from Prodănești, Salaj County, narthex painting (A) and its thermographic image (B)



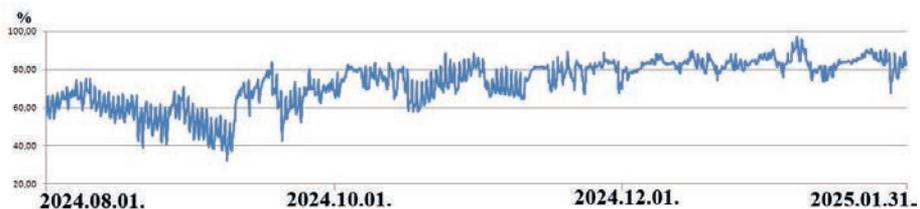
**Fig. 10** Temperature profile on the painting's left-right diagonal from the thermographic image in Fig. 9.B



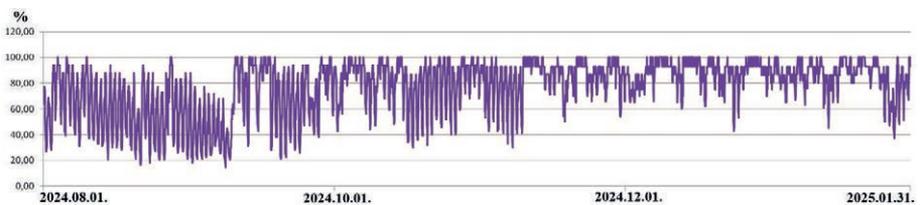
On the temperature profile in Fig. 10, it can be observed the temperature fluctuation on the painting surface. For the left-right diagonal, we notice values from 12.7°C to 14.8°C. Temperature distribution on the painting surface and humidity distribution on the painting surface are both influenced by outdoor air which, over time, can be a high-risk factor for the painting (Kraniotis et al., 2016; Madruga et al., 2020; Barreira et al., 2020; Dafico et al., 2022). At the horizontal beams' joints, the painting is deteriorated, as seen in Fig. 10A, while on the temperature profile, the highest value is in that spot because there is a gap through which it communicates with the outdoor.

Relative humidity must be contained between optimum limits regulated by the standards in effect to preserve and conserve the wooden church and, according to ASHRAE (2011), the relative humidity value must be maintained around the value of 50% ( $\pm 3\%$ ). ASHRAE (2020) stipulates for human health, thermal comfort and prevention of microorganism development or rash occurrence, relative humidity optimum values between 30–60%.

As observed in Fig. 11, relative humidity values were, most of the time, over the optimum intervals proposed by standards in effect and the relative humidity average value was of 73.03%, which depends greatly on the outdoor air values, as seen in Fig. 12. For September, it was noticed a period of a few days in which the relative humidity value had lower values, the minimum value of 32.40% being recorded on the 8th of September, 2024, at 6:39 p.m. During the autumn months, the values fluctuated around the 60–80% interval. During the summer months, the relative humidity value was higher and the maximum value was of 97.10%, recorded on the 8th of January, 2025, at 2:46 p.m.



**Fig. 11** Indoor humidity fluctuations (%) from August 01, 2024 to January 31, 2025



**Fig. 12** Fluctuations in outdoor humidity (%) from August 1, 2024 to January 31, 2025

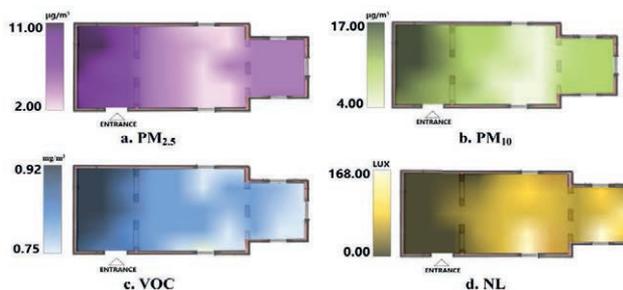


PM<sub>2.5</sub> concentration values fluctuated during the research period between minimum values of 0.00 µg/m<sup>3</sup> and maximum values of 15 µg/m<sup>3</sup>. As seen in Fig. 13.a., the PM<sub>2.5</sub> values are not even inside the wooden church, with higher values in the narthex, between 9.00-11.00 µg/m<sup>3</sup>, and lower values in the nave, between 2.00-10.00 µg/m<sup>3</sup>, and the altar, between 4.00-7.00 µg/m<sup>3</sup>. The PM<sub>2.5</sub> values were influenced by window positions, reduced dusting, the presence of textiles inside the church (towels, blankets, curtains, carpets, etc.).

PM<sub>10</sub> concentration, during the research period, showed values between a minimum of 0.00 µg/m<sup>3</sup> and a maximum of 25.00 µg/m<sup>3</sup>. The PM<sub>10</sub> average values' distribution was influenced by window positions, indoor textiles, reduced window cleaning and follows greatly the PM<sub>2.5</sub> values distribution, with higher values in the narthex, of 9.00-17.00 µg/m<sup>3</sup>, and lower values in the nave, 4.00-9.00 µg/m<sup>3</sup>, and altar, 8.00-9.00 µg/m<sup>3</sup>, as shown in Fig. 13.b.

VOC concentration values fluctuated, during the monitored period, between minimum values of 0.00 mg/m<sup>3</sup> and maximum values of 2.72 mg/m<sup>3</sup>, over short periods of time. As seen in Fig. 13.c., VOC concentration average values, during the research period, were between 0.75-0.92 mg/m<sup>3</sup>, with higher values in the narthex, of 0.80-0.92 mg/m<sup>3</sup>, and lower values in the nave, of 0.75-0.80 mg/m<sup>3</sup>, and altar, of 0.76-0.79 mg/m<sup>3</sup>. Inside the wooden church, VOC average values were according to standards in effect because the acceptance level is of 1.00 mg/m<sup>3</sup> (Directive 2000/39/EC → European Commission, 2000)

Light intensity inside the wooden church was, during the research, between 0 and 320 lux, influenced, as shown in Fig. 13.d., by window positions, around which the values were higher. The light intensity average values were between the minimum value of 0 lux and the maximum value of 168 lux, distributed as seen in Fig. 13.d., thus, in the narthex 10–155 lux, and in the altar 48–168 lux. Standards in effect stipulate values between 50–200 lux (BSI, 2011), and inside the wooden church, the average values are optimum; therefore, light intensity does not represent a risk factor for the indoor construction material and wooden objects.

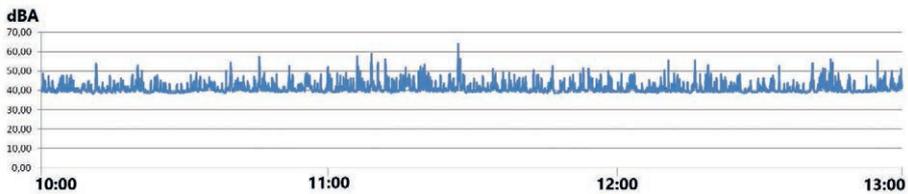


**Fig. 13** Indoor average values of PM<sub>2.5</sub>, PM<sub>10</sub>, VOC, NL for each monitoring point - (a) Particulate matter PM<sub>2.5</sub>, (b) Particulate matter PM<sub>10</sub>, (c) Volatile organic compounds VOC, (d) Natural light NL



The acoustic intensity value inside the wooden church has an important role because the more these values increase, the higher their effect on the human body will be. Levels up to 30 dB are comfortable for the human body, values between 30–60 dB are acceptable and values between 60–85 dB can cause stress and a slight hearing disorder, in case of prolonged exposure. Values over 85 dB represent a risk for human health (Stansfeld, Matheson, 2003; WHO, 2000).

Acoustic intensity monitoring since the 29<sup>th</sup> of October, 2025, between 10 a.m. and 1 p.m., provided data about the acoustic intensity values inside the wooden church, as seen on the graph in Fig. 14. The acoustic intensity values had an average value of 41.11 dBA and fluctuated between the minimum value of 38.60 dBA at 10:10:50 a.m., and the maximum value of 64.30 dBA, recorded at 11:27:12 a.m. Acoustic intensity values were influenced, firstly, by the wooden church's position near the county road DJ108A (approximately 35 m).

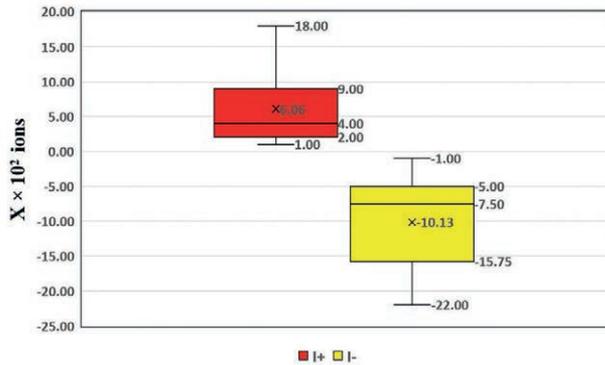


**Fig. 14** Acoustic intensity level on 29.10.2025, in the time interval 10:00 a.m. -13:00 p.m.

Ions have effects on human health (Perez et al., 2013; Xiao et al., 2023) and, as seen in Fig. 15, the positive ions concentration values, during the research, were between 100-1800 ions/ m<sup>3</sup>, with an average value of 606 ions/m<sup>3</sup>.

The negative ions' values fluctuated, during the research, between -100 and -2200 ions/m<sup>3</sup>, with an average value of -1013 ions/m<sup>3</sup>. The interval with most values of negative ions was between -500 and -1575 ions/m<sup>3</sup>, as seen in Fig. 8.

The specialty literature (e.g. Jayaratne et al., 2008; Perez et al., 2013; Jiang et al., 2018) stipulates values of positive ions smaller than 1000 ions/m<sup>3</sup>, while for negative ions, values of over -1000 ions/m<sup>3</sup>. Inside the wooden church, the average values of positive and negative ions were between the limits indicated by the specialty literature.



**Fig. 15** The concentration of I+ and I- during the period Aug. 01, 2024 -Jan. 31, 2025 inside the wooden church

## CONCLUSION AND RECOMMENDATIONS

As we have shown, cultural heritage objects should be perceived as complex SES, whose vitality is determined by the dynamics of relationships between the physical integrity of the object, the environmental conditions in which they are situated, and the ways in which they are used. The case study of the Sfântul Gheorghe church in the village of Prodănești allowed us to empirically grasp these relationships through microclimatic and biological indicators of degradation. The results thus serve not only for the technical assessment of the condition of the monument, but also as empirical verification of the extent to which the processes actually taking place in a specific cultural heritage object are in line with the objectives of regeneration-oriented tourism and cultural heritage management, emphasizing the restoration of systemic functions and the strengthening of adaptive capacity.

Data obtained from monitoring the indoor microclimate of the wooden church of Sfântul Gheorghe in the village of Prodănești indicate a significant exceedance of the recommended temperature and relative humidity values, as well as an increased presence of biological degradation factors (lichens, microorganisms) that have a negative impact on building materials and preserved interior elements. Specifically, indoor temperature values were not optimal during the research, fluctuating from the minimum of  $-4^{\circ}\text{C}$ , to the maximum of  $30.2^{\circ}\text{C}$ , being influenced mostly by the outdoor air. Relative humidity had an average value of 73.03%, representing a high percentage which enhanced microorganisms and lichens' development on the wooden church roof.  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  particulate matter and volatile organic compounds values fluctuated during the research, with periods of time when these values exceeded the optimum limits. Light intensity was, during the research period, within optimum values, but there were short periods of time when the values exceeded optimum limits. Acoustic intensity values



were acceptable for the human body, except when the Mass was delivered, with an average value of 41-45 dBA, being influenced by the position of the historic monument near the county road DJ108A. Positive and negative ions values were, most of the times, between the optimum limits stipulated in the specialty literature.

It is essential to monitor the wooden church's microclimate because the non-compliant temperature and relative humidity values have effects on the construction material, as well as on human health. Moreover, it also enhances microorganisms and lichen development, which can have a negative effect on the construction material. All these indoor microclimate parameters have negative effect on the indoor painting which is currently in an advanced state of decay (the painting is barely visible inside the wooden church). Non-invasive urgent measures should be taken for lichen removal from the roof and for the indoor painting preservation. The monument needs a heating source during the cold season, and a ventilation and air purifying system.

From a management perspective, the building requires adaptive management. This should be based on long-term microclimatic monitoring of temperature, relative humidity, air quality, and biological factors, which are essential for the early identification of degradation processes. In the case of the examined object, we therefore expect future research focused on indoor microorganisms that can affect human health and the artefacts, study of the lichens on the wooden church roof, which affect the construction material, and study of the indoor painting using infrared technology. Regular monitoring of these attributes supports data-based decision-making and thus contributes to increasing the effectiveness of the measures taken. In a broader context, our findings confirm that material degradation is not just an isolated technical problem, but also part of the broader dynamics of the SES of material cultural heritage (Holling, 1973; Folke, 2006; Meadows, 2015). In the context of regenerative SES management, strengthening links to local communities will also be required in the future (Klimovský et al., 2016; Brunn et al., 2018; Matlovcova et al., 2022). The legitimacy of decisions can be enhanced and the long-term sustainability of monument protection can be supported by the active participation of locals in the management of heritage and the harmonisation of the building's liturgical, tourist and conservation functions (participatory governance). The way in which the building is used by tourists should be dependent on its environmental and material capacity. To achieve the goal of improving the site's condition through regenerative tourism, the emphasis should shift from maximising visitor numbers to improving the quality of relationships within the SES, particularly between visitors and local communities, including stakeholders.



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