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ANALYSIS OF THE IMPACT OF MOISTURE AND BIODETERIORATION ON THE ASSESSMENT OF THE TECHNICAL CONDITION OF HISTORICAL BUILDINGS

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Abstract

This paper deals with issues related to the diagnosis of dampness and mycological tests in historic buildings. The selection of appropriate diagnostic procedures in the case of historic buildings undergoing modernisation, revitalisation or renovation is an important element of properly conducted works aimed at the preservation of cultural heritage. The article presents the issues of biodeterioration, and the scope of procedures for carrying out expert assessments of historic buildings, with emphasis on the issue of mycological testing. In conclusion, the article states that due to dynamic degradation processes caused by biological corrosion, mycological examinations of buildings containing wooden structures should be obligatory in the building law. It was pointed out that economics repeatedly determines the depth of research and thus the reliability of the analysis results obtained.

Keywords: moisture testing, mycological testing, expertise, historic buildings

1. INTRODUCTION

Over the centuries, wood has been the most popular building material, while ceramic and stone walls form the basis of historic buildings. By carrying out detailed moisture and mycological surveys, it is possible to comprehensively eliminate the state of danger to structures that have been in use for many centuries. Contrary to appearances, the problem is very wide and important, and its importance is emphasised by the social and executive unawareness of the existence of such hazards in objects, especially wooden or wooden-brick (of checkered structure) looking massive and safe[5,14].

The technical and construction regulations, which include the technical conditions to be met by buildings and their location, as well as the principles of technical knowledge, define the obligation to maintain a building in an appropriate condition [17]. In the case of a historic building, it is the provincial conservator who each time defines the conditions and guidelines for possible actions in the historic

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building. In the conservation guidelines, an important item is to carry out a moisture diagnosis of the object and a mycological examination every time. The situation is different if the building is only located in a historic area and is not listed in the monument register. In this case, the contractor satisfies the diagnosis guidelines for renovated or modernised buildings to varying degrees. The National Heritage Institute conducts cyclical activities to determine the number of objects at risk (working in a bad or emergency state). According to a report [24] carried out between 2009 and 2015, the majority of the objects registered in the register of historical monuments are masonry objects, in total as many as 86.5% of the immovable objects listed in the register of. The next large group are all timber objects accounting for 11.3% of the register. Other objects made of materials such as concrete, various metals, turf, rammed clay or soil and objects for which no structural data could be established account for only 2.2% of the inscribed objects.In order to protect cultural heritage in the form of immovable heritage, it is important to check their technical condition.As the NID report shows, 72.1% of the objects require repair work to varying degrees in the coming years. In the case of 23.3 per cent of the objects, moderate structural damage requiring repair work was found, while in the case of 6.08 per cent, significant structural damage requiring rapid and comprehensive construction intervention was found. These 6.08% of the most severely damaged buildings of the inventoried stock represent almost 3984 structures in the total inventory [24].Historic buildings deteriorate completely due to accelerated wear and tear. If inappropriate construction work is carried out, the buildings may be subject to disaster [3]. Data collected on the website of the Central Office of Building Supervision shows that 8169 building disasters occurred in Poland between 1995 and 2019 (Fig1).An analysis of the causes of construction disasters compiled on the basis of 244 unintentional, violent destruction of building structures that occurred in Poland in 2019 showed that in 77.5 per cent, the main cause of disasters was due to random events and 15.5 per cent was due to errors during the maintenance of the building and 9 per cent was due to errors during the execution of construction works in an existing building. In the majority of incidents, several factors contributed to the disaster simultaneously, for example, in addition to allowing excessive deterioration of technical performance, there was also a lack of preventive action by not carrying out periodic inspections or not implementing the recommendations resulting from these inspections

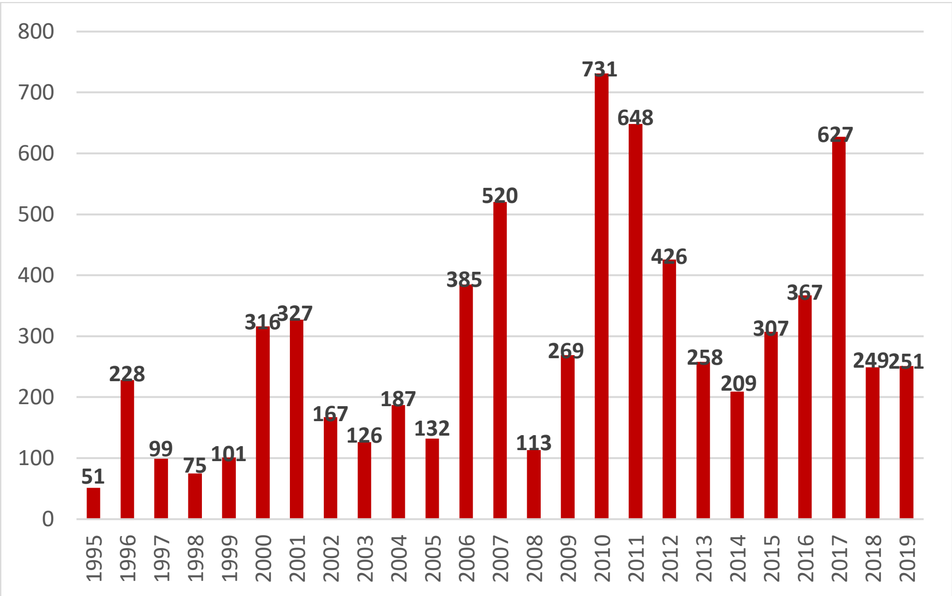

Fig.1. Number of building disasters between 1995 and 2019 [24]

The most common errors in the maintenance phase of the construction works, shown as the main causes of disasters in 2019 according to GINB analyses, were:

- poor technical condition of the building structure (84.8 %),
- failure to carry out inspections of the building structure (27.2 %),
- failure of the owner or manager to take the required recommendations resulting from mandatory minimum annual inspections of the building (9.1 %),
- building not being used for its intended purpose (6.1 %),
- failure of the owner or manager to take the required measures resulting from other technical studies (3.0%),
- failure of the owner or manager to carry out the required obligations resulting from the actions of the building supervisory authorities (3%), other circumstances (18.1%).

According to the disaster register, 58.0 per cent of the in-service disaster facilities had been in operation for more than 50 years. The service life of the disaster facilities is shown in the graph (Fig.2) . The facilities were ranked by age:

- less than 10 years (7%),
- between 11 and 50 years (35%),
- between 51 and 100 years (41%),
- over 100 years (17%).

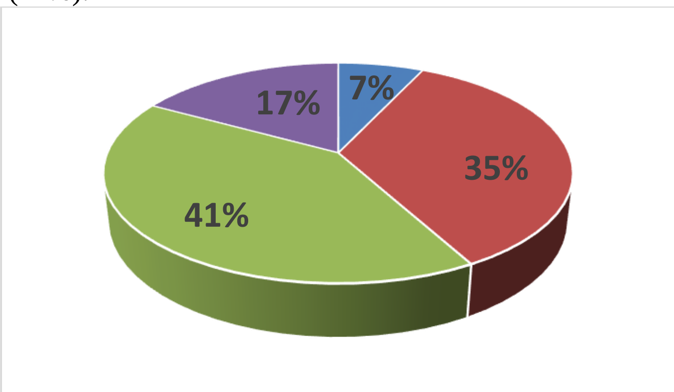

Fig.2. Service life of building structures that have failed[24]

2. CONSTRUCTION DIAGNOSTICS

As In order to correctly realise the renovation or modernisation of a historic building, it is necessary to first have a particularly good understanding of the historic structure [26]. Any planning of the conservation of wooden and masonry structures requires qualitative data based on direct observations of the process of material deterioration and wear or damage to the structure, historical research, etc., as well as quantitative data based on tests and mathematical models [1,2,9,15], and its purpose is to create a pre-drying baseline that can be referenced at a later date when assessing the effectiveness of the drying systems used. An additional goal is to check the conditions prevailing in the wall (some drying methods are limited by the level of moisture content to which they can be applied) and to create a moisture balance for the tested structure.

2.1. Terms of reference for the expertise of historic buildings

In order to determine the causes of damage and select correct repair measures that do not disturb, from a conservation point of view, elements and details, even a small historic building should be assessed in a comprehensive manner taking into account historical conditions. Therefore, the full scope of research should include [27,28]:

- a historical analysis of the building against the background of the history of the locality and neighbouring buildings consisting of :
- – archival analysis using archival documents and photographs;
- – an architectural study of the layering and any architectural and structural changes;
- description of the existing condition
- – architectural inventory (projection drawings, sections, details);
- – structural inventory (determination of technology, structural layout and construction materials and their strength parameters);
- – damage inventory (drawings and photographic documentation);
- In situ and laboratory investigations
- – of geotechnical conditions;
- – state of damage to building elements;
- – state of dampness and salinity of masonry;
- – Mycological.

The main diagnostic steps are summarised in Table 1.

Table 1. Diagnostics scheme [25]

Activity	**Description**
Documentation analysis	allows to recognize construction and technological solutions; depending on the age and history of the use of the building, the documentation may contain: technical design, as-built documents, provisions regarding mandatory inspections or expert opinions
Local vision	determining the subject, purpose and scope of the evaluation; specification of the type and function that the element fulfil in the facility; determination of the working conditions of the wall element; assessment of environmental aggressiveness
Visual assessment of the technical condition of the wall (bricks, mortar and plaster)	scope of assessment: wall thickness, type of brick, thickness of joints and their filling, occurrence of irregularities, damages and possible scratches, presence of salt efflorescence, moisture and possible frost effects, condition of horizontal and vertical insulation
Determination of test sites and methods (destructive and non-destructive) of physical and mechanical characteristics	scope of tests: humidity and absorbability, volumetric density, porosity and permeability, strength of brick and mortar and possibly masonry wall
Ultimate and serviceability limit state analysis	analysis is carried out after collecting materials concerning all factors affecting the condition of the structure; verification calculations are sometimes necessary
Technical condition assessment of the structure	the assessment should, first of all, contain information specifying the degree of risk of failure or structural damage; should determine the causes of damage and how to remove them and protect the structure for the period of further use
Conclusions regarding materials and elements of construction and further exploitation	

The problem of preservation of wooden elements takes into account not only the technical condition of the element, but also the cultural and aesthetic value of the building as a whole. According to the Aristotelian saying "the whole is more than the sum of its parts". The analysis to which wooden objects or individual structural elements should be subjected in strictly technical terms should primarily include:

- assessment of the quality (strength, density) of the wood,
- testing the moisture content of wood,
- examination of mycological changes
- approximate assessment of age and type of wood,
- evaluation of durability,
- evaluation of defects and damage to the wood (macroscopic method).

In the case of wooden constructions, the examination of mycological changes includes the analysis of the state of fungus infestation with household fungi, mould, bacteria and also the occurrence of insects - technical wood pests [10,16,22,29].

3. HAZARDS ASSOCIATED WITH MOISTURE

One of the greatest threats to masonry and timber structures is water, which is virtually everywhere, occurs in all states of aggregation and affects the structure both from the outside (environmental loads: rain, snow, fog) and from the inside (failures, condensation)[4].

Excessive moisture present in a structure causes damage to building materials and has a destructive effect on structures leading to catastrophes. Depending on the source of moisture in building materials, there may be:

- primary efflorescence,which results from the migration of chemical compounds from the ceramic material and fresh mortar;
- derivative efflorescence, resulting from the penetration of masonry by rainwater or condensation [1, 11].

Acids cause the metals in the binders (mainly calcium) to be bound in soluble chemical compounds, which are then dissolved in the building materials and washed away by groundwater, infiltration or rainwater. This weakens the structure of the building material or damages the binder. The most common acids include:

- nitric acid, which can be formed from nitric oxide or by bacterial decomposition of ammonia and organic nitrogen compounds (urine, protein, etc.),
- sulphuric acid is formed by the reaction of sulphur dioxide or trioxide with rainwater or by the bacterial oxidation of sulphides,
- hydrochloric acid is often formed by the combustion of PVC (thermal emission of HCl),
- carbonic acid is formed by the dissolution of carbon dioxide in water or its transformation in water [2].

The appearance of salts is often considered as a harmless damage to the façade. However, salt deposits are usually a symptom of salt movement within the masonry and the first signs of deeper problems that can significantly compromise the life of the building over time.

4. MICROBIOLOGICAL HAZARDS

Biodeterioration, or biological decomposition and corrosion, is the result of fungi, algae, bacteria, but also birds, insects and rodents. Microorganisms (algae, lichens, etc.) Are capable of carrying out a wide variety of metabolic processes that destructively affect. Mechanical properties, physical properties and change in chemical composition. Their development and rate of destructive impact depend, among other things, on the chemical composition of the substrate, moisture content and access to organic matter [20].Algae are self-sustaining and inhabit virtually all environments. Their detrimental effect on wood manifests itself in that the living organisms concentrated on the wood surface maintain increased moisture content of that surface, making it a favourable environment for the development of mycological lesions. These organisms secrete acids that destroy the substrate on which they occur. The appearance of algae is usually accompanied by the appearance of fungi and bacteria. Moulds, like algae, degrade the structure of building materials. Bacteria, the smallest cellular organisms, cause the decomposition of organic compounds with the character of wet rot, giving off an unpleasant odour. All these organisms can cause corrosion and decomposition of wood, limestone, dolomite, marble, granite and mortar containing lime compounds in particular. Fungi are particularly dangerous to historic buildings, as they have an extremely high capacity to adapt to environmental changes and reproduce rapidly [19]. Infection of structures by domestic fungi occurs mainly through spores, formed on the fruiting bodies of a fungus, located and developed in another part of the building, or carried downwind even from other buildings. Fungi belonging to the class of basidiomycetes, which cause decomposition of wood and other organic materials, and moulds belonging to the couplings, bagworms or imperfect fungi, usually develop in buildingsFungi need elevated humidity to grow, above 20% (the most optimal humidity is 27-40%) for most fungi the maximum humidity is 60% only mould fungi need elevated humidity, even up to 90%. Fungi can survive in extreme conditions e.g.: the cellar fungus will survive at -30^{0}C and +60^{0}C for 40 minutes. Fungi require air to grow, but they can survive for up to 15 - 20 days without oxygen and develop again once air is supplied. When the humidity increases, mycelium grows instead of fruiting bodies.

$$CaCO_3 + H_2CO_3 = Ca(HCO_3)_2 \tag{4.1}$$

Visible fungal fruiting bodies can be small in relation to the cords hidden in a masonry element, which can be up to 10 metres long [8].

Among the group of the most dangerous fungi degrading wooden elements are:

- Serpula lacrymans house fungus, the dry weight loss of the wood after 6 months is 50% and the strength decreases by 30%,
- cellar fungus Conophora puteana, dry weight loss of wood after 6 months is 45% and strength decreases by 75%,
- white-rot fungus Poria vaporaria, dry wood loss after 6 months is 40% and strength decreases by 60%.

The most damaging, most damaging insects are:

- the Common beetle
- Hylotrupes baj ulus and the house knocker
- Anobium punctatum;

they can damage the wood for several generations until the sapwood is completely destroyed.Animals, too, have a direct impact on the condition of the building (mice, rats, house martens, snails). They contribute to increased dampness and the secretion of harmful salts, and also pose microbiological risks to human health [20].

5. OBTAINING SAMPLES FOR TESTING

5.1 Testing the state of relative air humidity

The percentage of water vapour in the air to the maximum amount occurring under the given conditions, note that the maximum amount of water vapour in the air is dependent on the room temperature. Air humidity is measured each time a mycological survey of the building is carried out. The optimum air humidity level is between 40 - 60 %. Above 60 %, biological and chemical destruction of the building materials occurs [4].

5.2 Moisture parameter test

The water content of solids is defined in two ways. The measure used is either the ratio of the mass of water to the mass of the dry material (absolute humidity, moisture content) or the ratio of the mass of water to the total mass of the substance under test (relative humidity). Both of these parameters are expressed as a percentage. At the same time, it is worth emphasizing that these parameters only correspond to the amount of water bound to the body in question physically, without taking into account chemically bound water [33]. The study of the moisture content of materials in construction is narrowed down to the study of mass or volume moisture. Mineral materials may contain chemically bound water, but this, being part of the material's structure, is not taken into account when testing moisture content. Mineral building materials also often contain harmful building salts, which can not only cause efflorescence and destruction of the material, but also change the sorption isotherms [12,13,30] masonry moisture testing is carried out using two basic groups of methods: invasive and non-invasive.Destructive methods include the traditional gravimetric method (drying and weighing), the carbide method (cm), karl fischer titrations [21]. In the construction industry, only a few methods are actually used for moisture testing. The dryer-weigher method is considered the most accurate and reliable, but it requires masonry samples. Indirect methods using moisture meters are recommended after correlating the readings. To do this, the moisture content of at least 6 samples must be determined using the traditional dryer-weight method and the meter reading, and then a correlation relationship must be determined using the 'least squares' method. It is also possible to select a correlation relationship between the mass moisture content and the indication of the meirometer by plotting hypothetical scaling curves provided by the instrument manufacturer [18,32]. Thus, there is no single, universal correlation between the meter indication and the mass moisture content of the masonry. In addition to the amount of water contained in the material, the results of meter tests are influenced by many factors, such as [4,9,30]:

- the structure, density and porosity structure of the material studied:
- type and amount of salts present in the masonry;
- the measurement temperature;
- human factor**.**

Testing the moisture content of wood is most often carried out using the electrometric method when conducting mycological tests. It uses the phenomenon of variation in electrical resistance, which changes with changes in wood moisture content. The PN-B-03150-2000 [22] standard defines the moisture content of coniferous wood used for structural elements depending on the conditions of their use, according to the rule that their moisture content may be 2% lower or equal to the usable moisture content, and so it is for:

- structures protected against moisture: 18%,
- structures located outdoors: 23%,

Moisture content criteria for masonry structures referring to the already outdated PN-82/B-02020 standard [23], in the absence of another valid standard classification, the permissible operating moisture content of a wall made of ceramic bricks and hollow ceramic blocks should not exceed 3% and that of cellular concrete is assumed as the maximum moisture content value of 12%. [1]. The classification in terms of mass moisture in walls is as follows[4,6,30]:

- dry walls (with permissible moisture content)≤3%,
- walls with increased humidity 3-5%,
- walls with medium humidity 5-8%,
- walls with high humidity 8-12%,
- wet walls>12%.

Particular attention should be paid to where and how samples are taken. Additional photographic documentation of the sampling locations and inventories of the measurements taken should be made.

5.3 Mycological tests

Fungi proper, the so-called macrofungi, can be detected with the unaided eye. Microfungi, or so-called micro fungi, on the other hand, already require laboratory diagnosis. Sampling for mycological tests is carried out using two methods. The degree of fungal growth on the surface of the material is determined using a non-destructive method - smearing with a 5×5 cm template (fig. 3) or using the pressure method. If the use of semi-destructive testing is permissible, i.e. When damage is produced that does not reduce the load-bearing capacity of the structure, the test material is taken from the component to be analysed. The criteria for assessing the degree of fungal activation the criteria for assessing the degree of activation of filamentous fungi on building partitions according to Piotrowska et al [19] are presented in table 2. The number of filamentous fungi in conditions considered normal should not exceed 10^3jtk/100 cm^2. A result above 10^4 and 10^6jtk/100 cm^2 indicates active or very active filamentous fungal growth. Macroscopic growth of filamentous fungi is visible on the surface of the partitions and the building materials become biodegraded [19,31**].**

Table. 2 Criteria for the assessment of fungi activity level in building surfaces [19]

Level of fungal presence	Number of colonies /100 cm^2
low	do 10
average	do 10^2
enhanced	do 10^3
high	10^4 -10^6
very high	>10^6

Fig. 3. View of moulds grown from swab samples author archive

6. CASE STUDY

The article presents excerpts from an expert opinion prepared for the pre-design phase of a historic building located in the sports and recreation complex in Gniezno. The aim of the study was to assess the infestation of elements by microorganisms, domestic fungi and insects - technical wood pests. In addition, to propose measures for the safe renovation of the building elements with the indication of the scope of impregnation and de- fungation works or the exclusion of renovation measures. The half-timbered building has a basement and a reinforced concrete staircase. Wood is the predominant material in the construction of the building. Constructed around 1900, the building is unoccupied and gradually deteriorating until 2010. Fig. 4 shows the condition of the masonry and structure of the first storey.

Fig. 4. Elevation of the retrofitted building, condition of the masonry samples author archive

Dampness was observed over a long period of exposure, there are clear degraded elements on the roof truss elements in the roof slope section in the nave and on the lower floors of the building in the nave and along the slope line. Traces of fire are visible in the outer nave on the third storey (fig. 5).

Fig. 5. Structural elements damaged by fire, uncontaminated section of building structure author archive

Wood moisture measurements were carried out on selected elements both on the outside of the building and on the internal elements (Fig. 6).

Fig.6. Measurements of moisture content of construction elements selected for mycological tests author archive

The location of the measurement points is marked on the floor drawings of each storey. The moisture content of the selected elements (visually selected representative locations for the analysis) was as follows: 8-10,5%.

According to the given criteria, the tested elements in the most sensitive places showed a condition bordering on dry/humid. The internal temperature was not measured during the site visit, as this would have been unreasonable (the building had no windows); the environmental parameters on the day of the survey were determined:

– maximum temperature of 14°C;
– a maximum humidity reading of 66.2-69.8 %.

Table 3. Description of items sampled for testing

Nr	1	2	3	4	5	6	7
Symbol	ground beam facade wall	facade wall column	ground floor pole	sword ground floor	pole I floor	ceiling beam I floor	sword I floor
Nr	8	9	10	11	12		
Symbol	column I floor	ceiling beam outcrop II floor	ceiling beam II floor	floor III pole	ceiling beam outcrop III floor		

Fig.7. Containers with material collected for laboratory tests, documentation of representative sites author archive

On the day of the site visit, twelve samples were taken for microbiological testing under relative aseptic conditions from internal structural elements (floor beams, slabs, stringers, swords) and external structural elements (foundations and columns). The floor plans and Table 3 indicate the locations of the tests carried out (fig. 8).

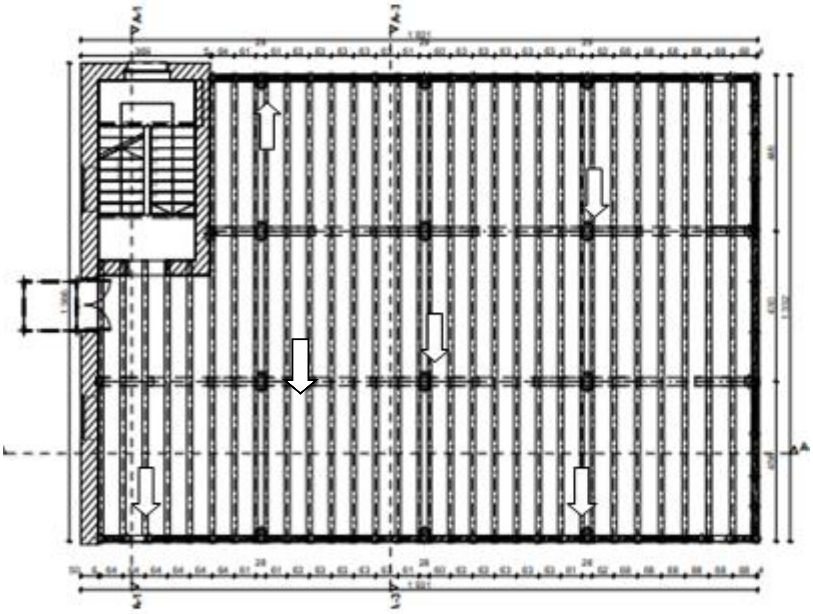

Fig.8. Example of mapping of selected areas of mycological analysis and moisture surveys carried out, ground floor plan

The presence of fungal structures in samples delivered to the laboratory was assessed by dividing them into 100 one-millimetre fragments, which were lined with 50 one-millimetre inocula each on PDA medium (glucose-potato agar). The growing colonies were counted and identified to species. With this type of testing method, it is assumed that the proportion of fungal or bacterial colonies in more than 25 % of the material fragments lined on the culture medium is indicative of strong microbial growth. Numerous pieces of wood supplied for testing showed signs of degradation. Symptoms of strong brown or white wood decay were observed on the majority of the wood samples taken for testing In addition, structures of 12 mould species were found in the wood samples (Table 4). Penicillium chrysogenum and Cladosporium cladosporioideswere predominant. Fungi of the genus Aspergillus were relatively numerous. Although Polish epidemiological studies have shown that the most common causes of inhalation allergy are fungi of the genera Alternaria and Cladosporium, followed by Penicillium and Aspergillus, the moulds found do not pose a threat to wood structures.

Table 4. Fungal species obtained from samples

Species	Sample number					
	1	2	3	4	5	6
	number of fungal colonies					
Absidia courulea	6				14	
Alternaria alternata	3	11				
Asprgillus ochraceus					18	
Cladosporium cladosporioides		16	12	16		3
Penicillium chrysogenum	68	23			35	
Penicillium variabilae				14		17
Penicillium oxalicum	4		1			
Gloeophyllum sepiarium	12		67		1	80
Serpula lacrymans		38			32	
Rhizopus niger	7	12	20	69		
	7	8	9	10	11	12
A. nidulans		4				8
A. ochraceus		3			12	1
Alternaria alternata	20		12			
Aspergillus ochraceus		11			1	1
Cladosporium cladosporioides		36	48	39	76	89
Penicillium chrysogenum	13		39	11		
Penicillium vermiculatum		23				1
Penicillium roseum					11	
Gloeophyllum sepiarium		23	1			
Serpula lacrymans	67			50		
total fungal colonies	100	100	100	100	100	100
% retreats	100	100	100	100	100	100

In samples 2,5,7,10 Serpula lacrymans was found and in samples 1,3,5,6,8,9 spores of the fungus Gloeophyllum sepiarium were present. In the literature, the authors of this work show that regardless of the level of colonisation achieved with the fungal species found, the wood is vulnerable to decay. The fungus Serpula lacrymans is included in the first group of construction fungi - the most damaging, causing strong and rapid wood decay. The dry weight loss of wood after 6 months can be 50% and the compressive strength decreases to 3% of that of healthy wood during this time. The level of risk of wood degradation depends mainly on its moisture content. In wood with a moisture content below 18%, the listed fungi will be in a state of anabiosis. At higher moisture contents, the lacewood structures present in the wood will form mycelium with a high capacity to destroy this material. The survey allows us to conclude that the building is in an unsatisfactory technical condition from the point of view of building mycology and currently requires repair work. It is recommended to dismantle the half-timbered structure and get rid of contaminated elements (foundations, damaged pillars), as it is not possible to maintain the moisture regime in the case of elements exposed to environmental loads. In addition, macroscopic examination of the roof truss revealed damage to the structure of the element and thus a marked decrease in the strength of the element, and thus the roof truss with numerous elements in a state of degradation should be reconstructed with new material. No destructive fungi were found in the ceiling and column samples taken from the third floor.

The wood from the ceiling and columns of the lower storeys may be safely used provided that a moisture regime is maintained during the renovation of the building, i.e. the wooden elements, especially those in which the most destructive fungi have been found, must be protected against additional moisture during the renovation and continuously monitored, and during use against the occurrence of additional condensation

7. CONCLUSIONS

The periodically high humidity of the wood and masonry provides favourable conditions for the development of building fungi and mould. As a result of fungi and insects, the building structure has been partially destroyed. The selection of appropriate diagnostic procedures for historic buildings undergoing modernisation, revitalisation or renovation is an important element of properly carried out heritage conservation work.The over-simplified procedure for damp and mycological testing is limited to verifying a minimum area, which is very often determined by designers or contractors on the basis of economic considerations. Another issue is the selection of an appropriate method of structural diagnosis. Based on many years of expert experience, the author concludes that by carrying out tests using a visual method or taking a few measurements, we cannot conclude on the extent and type of infestation of all building elements. Such a procedure can only serve as a preliminary stage of both moisture and mycological diagnosis. Too small a series of measurements, in the case of damp tests, and too few samples to carry out laboratory tests, can lead to wrong conclusions about the technical condition of the structure and further to an incorrect renovation concept for the object. Contractors very often, in order to simplify the technology of modernisation of a historic building, dismantle and dispose of the entire structure, which is many times only locally degraded [16]. As the study showed, the building qualified for demolition did not require this action with regard to all elements. The article indicates that mycological and moisture tests should be carried out to ascertain the actual hazards present in the diagnosed buildings on a minimum of a dozen or so elements. Determining the minimum number of examinations required should improve the quantitative condition of legally protected objects.

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