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TECHNICAL CONDITION ASSESSMENT OF HISTORICAL BUILDINGS – FLOWCHART DEVELOPMENT

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Abstract

The article presents a methodology of technical condition assessment of masonry and timber structures of historical buildings, demonstrated on the example of palace complex at Gorzanów. Based on a comprehensive diagnostic study prepared by the authors, both on location and in the laboratory, a flowchart was developed to illustrate technical condition assessment procedures for historical buildings as well as for determining existing damage. The flowchart presented here may be found helpful by those providing expert opinions while designing their research and determining damage causes and investors who undertake such a difficult task as an adaptation of historical buildings to modern functional requirements.

Keywords: building and construction diagnostics, technical condition assessment

INTRODUCTION

Historic castles and palaces are an indispensable part of the landscape of south-eastern part of Poland. In the Valley of Palaces and Gardens of Jeleniogóra, there are nearly 30 historic buildings of this kind per 102 square kilometers. Within the whole Lower Silesia province, there are 10 times more palaces – not including castles, ruins and manor houses (Urbanek 2003). In the past, palaces were the central places of cultural and economic development of the region, which was based primarily on agriculture. Therefore, the most common palace complex consisted of a residential part and extensive outbuildings, which architecture does not differ substantially from the core part. Currently, due to the destructive processes, whose progress and course are varied and depend of a number of factors, buildings require a comprehensive assessment of the technical condition. Thus far, research on historical buildings was limited to subjective visual assessments of visible surface changes. The development of physics and chemistry has allowed for the development of various analytical methods which provide information on composition, structure and the spatial distribution of materials used in construction, therefore, making the most accurate assessments of the technical condition. Tests performed should also allow damage causes and the scope of potential renovation works to be determined clearly, as well as any reinforcement to be designed into the project. Therefore, the evaluation of the technical condition requires development of a methodology based on the potential of modern diagnostic tools. Article presents the methodology of the technical condition assessment of historic buildings on the example of palace complex in Gorzanów. Based on experience, a flowchart of technical assessment procedures for historical objects and determining damage causes was developed.

MATERIAL AND METHODS

Examination of a historical building begins with a construction and conservation inventory, including measurements and drawings, which is not only practical, but also scientific and documenting in character, due to the fact it records the status quo before work is carried out which is bound to introduce changes. Knowledge of a historical building is based on comprehensive research, whose individual scope depends on the characteristics of a given building. There are three types of research on historical buildings distinguished depending on the methods used and various resources applied. These are: historical and conservatory case study of a historical architectural object, measurement and drawing inventory, mycology tests and construction expert evaluation (Bucur-Horváth 2008).

Architectural examination, including preliminary archival research and examination of architectural layers and changes in architectural features and the structure of the building should be conducted for older objects whose history covers at least two architectural periods and whose value assessment may be determined by the scope occurrence and state of preservation of historical substance which represents various periods (Mączyński 2010, Yang 2016).

Measurement and drawing inventories should include situational drawings with linear measurements, plans, sections, elevations and documentation. Recorded damage caused to the building, such as cracks, damp spots, biological corrosion, plaster flaking and mechanical damage, are marked on the inventory drawings. Measurement and drawing inventories, along with photographic documentation of the status quo and accumulated damage, form the basis for planning the mycology tests, construction examinations and for determining the scope of necessary research.

Mycology tests are aimed at measuring the destructive impact of fungi and mould. They are performed by specialised bodies, but general mycology tests may be carried out based on macroscopic observations. Such tests should not only determine the state and cause of fungi infestations, but also provide some tips concerning further countermeasures on areas infested with fungi and mould (Borusiewicz 1985).

A construction expert evaluation determines the preservation state from a technical and durability point of view. It is based on testing the construction elements of the building and the ground substratum and determining their physical and mechanical properties. In the case of historical buildings, the scope of examination is set individually, but the tests cannot interfere with the historical substance significantly. A technical analysis of historical buildings should include first and foremost (Borusiewicz 1985):

- quality assessment (durability, density),
- dampness assessment,
- assessment of condition of individual construction elements (cracks, deformations – especially at joint areas),
- stability assessment of the whole construction (movements, stability),
- geological and technical assessment of the ground substratum,
- load-bearing capacity assessment of individual construction elements and joint areas,
- mycology assessment,
- durability assessment.

Construction expert evaluation is usually based on macroscopic assessment, geometrical measurements, dampness measurements, and destructive laboratory tests. The last is unacceptable for historical buildings in most cases due to its damaging character resulting from the need to collect core samples or large portions of construction elements. However, such tests are sometimes necessary for correct static and strength analysis. Laboratory tests also include the precise identification of fungi and mould types that occur in the given building, as well as the physical and mechanical properties of the ground and construction materials. A large numbers of destructive tests may be replaced with nondestructive testing methods, such as: sclerometric testing based on surface hardness measurement of a layer of material, acoustic testing based on speed measurement of longitudinal or transverse waves, radiology testing based on measurement of weakening of X and gamma radiation (beam) passing through material, semi-nondestructive testing of materials used in construction (e.g. pull-off or pull-out tests, machining resistance testing with the use of resistograph, etc.)(Negro 2009, Cardani 2015).

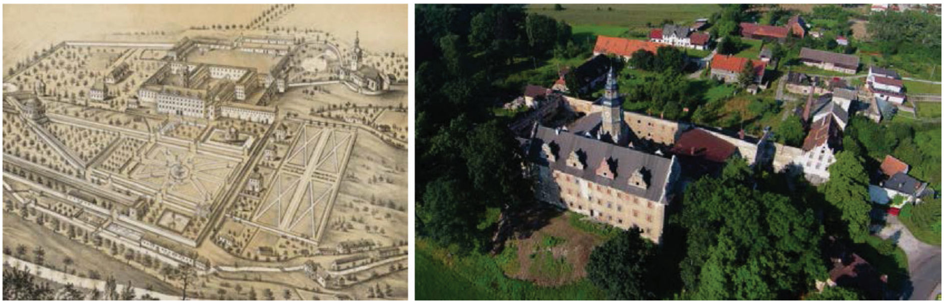
These methods are indirect and based on the empirical relations between measured physical properties and the searched characteristics of materials used in construction. The methods listed above require the preliminary calibration of measurement instruments and devices. It should be noted that nondestructive test methods cannot be applied without the verification of testing results by means of a destructive testing method (Negro 2009, Cardani 2015).

The most dangerous threats, which are at the same time most difficult to eliminate, are related to changes in the ground substratum of the building, concerning both the condition of the foundations and the ground itself. The accurate identification of these threats forms a basis for further works related to the renovation and restoration of the building (Pająk 2006, Berengo 2013). In the case of historical buildings, ground substratum testing is mainly aimed at determining the geological and technical parameters of the ground which will allow assessment of load-bearing capability and mutual impact of the ground and the building. Ground (substratum) field tests consist mainly of geotechnical drills, sound tests and opencast examination of foundations (Pyrak 2006).

RESULTS

Historical analysis of the object – preliminary archival research

Preliminary archival research allowed those elements of the palace which were considered important from a historical (conservation) point of view to be determined and approximately dated.



Source: Materials made available by Towarzystwo Miłośników Gorzanowa

Figure 1. Panoramic view of the palace complex in Gorzanów from 1738 (left) and 2014 (right)

In 1573, a renaissance palace complex was erected in Gorzanów funded by Johann Friedrich von Herberstein. In the years 1653 to 1657, the monumental palace was modernised and partly rebuild in the baroque style. The palace and park complex in question represent the *entre cour et jardin* type (fig. 1).

At the beginning of the 20th c., renovation and conservation works were executed and, among others, the palace water supply and sewage system was modernised. The décor of the palace's elevation was preserved and enriched. After World War II, the palace shared the fate of many other historical buildings. Outbuildings were utilized, while the main body of the palace was unused. Initially, the palace was supposed to become a part of a health resort planned in Gorzanów, but the scheme has never been executed and the building was regularly robbed and devastated. In the years 1957 to 1977, minor conservation works were carried out in the palace, but numerous attempts at securing the valuable interiors against acts of vandalism, and later on, against atmospheric factors, failed. One of such attempt at saving the building ended up in a construction catastrophe – the roof structure collapsed. The building's ownership changed in 2012. Numerous preservative bricklaying and roofing works are presently being executed in the palace.

Description of the building's current condition

The technical description of the building was executed based on preliminary archival research as well as architectural and construction layer and change observations.

The palace is located on an escarpment with basements under a part of the building on its eastern wing. Foundations and basement walls are made of irregular stone blocks. Outer walls and interior load-bearing walls on subsequent floors are constructed from fired clay brick mixed with stone masonry elements. The building's corners were made of regular stone blocks. Construction materials used for walls are largely inhomogeneous which results from numerous construction changes introduced over time and thus from differences in technologies of manufacturing wall masonry elements. Some parts of the wall were filled in (re-bricked) with contemporary material. In the southern wing of the palace there are also walls constructed from concrete hollow brick. Partition walls have been made using fired clay brick and wooden framing. Most of the ceilings are wooden beam, however some rooms on the ground floor and in basements have brick multi-curved ceilings. The palace's roof was originally covered with red shingle and later with black slate. At present, the roof over the eastern wing is a steep gable with a collar beam structure with dormers covered with slate in the northern part of the wing. In the southern part of the wing, the roof structure was damaged. All of the other wings have mono-pitched low slope roofs of post structure. The roof in the northern wing is covered with wavy steel roof panels, while the southern wing is covered with ceramic roof tiles. A part of the western wing is not covered with roof at all due to a construction collapse, while the preserved part of the roof is covered with tar paper. Measurement and drawing inventories of the building include photographic documentation of various damage with descriptions as well as architectural and construction inventories in the form of plans, elevations and sections with the scope of damages, construction systems and materials marked.

The following damages of the building were recorded:

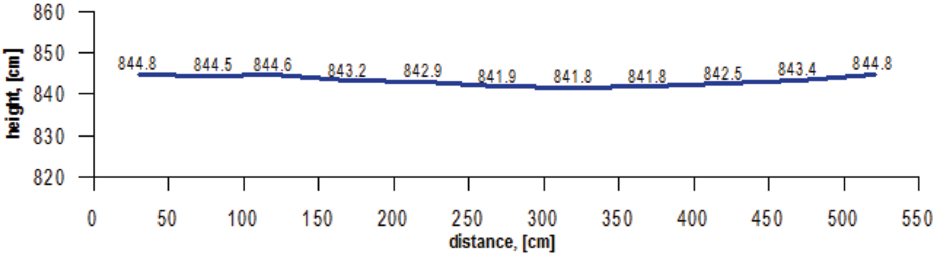
- damages to the roof – whole patches of roofing missing, leakage of existing roofing,
- damages and gaps in ceilings,
- vault damages,
- cracks in walls,
- dampness in walls, ceilings and floors,
- damages to floors and plasters.

Examinations on location

The examination of the building in question performed on location included walls and wooden constructions, as well as ground substratum. The tests performed were non-destructive. Within the scope of construction examination, measurements of bending of the construction, cracks and bonds were performed along with dampness measurements on selected elements and mycology assessment.

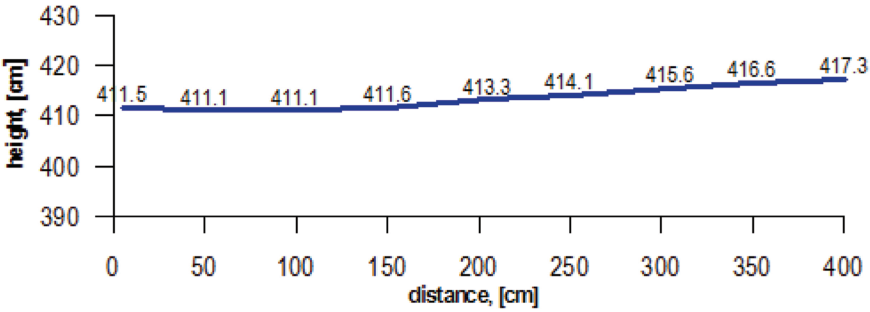
Measurements of bending in wooden ceiling beams were performed in rooms in which the whole ceilings were preserved or large portions of ceilings were intact. The bending measurements performed along with the macroscopic assessment allowed the character of beam work and degradation points to be determined. Based on these measurements, two specific types of movements were distinguished – bending in the middle of the beam's span resulting from its own weight and that of static load, which is natural for such a construction system, and lowering in supported areas (e.g. fixtures of ceiling beams) which may result from degradation of wooden elements and the significant tilt of walls from vertical position. Exemplary bending measurements are shown in fig. 2 and 3. Distance between a measurement point and a beam (ceiling) is marked on the Y-axis, while distance between subsequent measurement points is marked on the X-axis.

Cracks in walls and ceilings are the kind of damage common in historical buildings and also occur in the Gorzanów palace (fig. 4). It should be emphasized that the correct technical identification of the cracks real scope constitutes the basis for the diagnostic assessment that is the causes of cracks, their negative impact and repair possibilities (Masłowski 2000, Oliveira 2006). All cracks were marked on the plans and the elevations developed during the inventory. An analysis of position of wall cracks and monitoring their size allowed for the causes of construction damage to be determined and in some cases formed the basis for designing further examinations (e.g. geotechnical tests). These problems have been described in detail (Masłowski 2000, Rudziński 2010, Kim 2016).



Source: Own study

Figure 2. Bending example in the middle of a beam's span



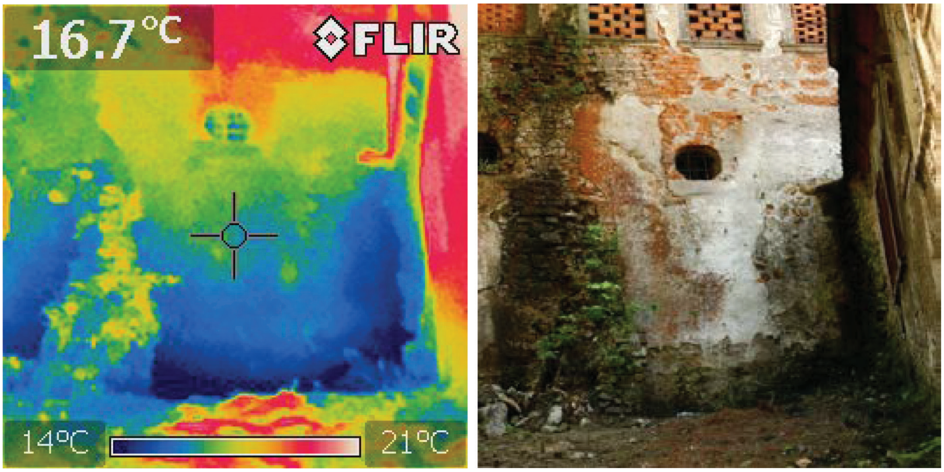
Source: Own study

Figure 3. Lowering example in supported area

Source: Own study

Figure 4. A view of exemplary cracks recorded during inventory

Wall bonds were also examined in order to determine their compressive strength (appropriate coefficients were adopted depending on the type of wall construction). The walls were examined for material used in construction, quality of mortar, occurrence of longitudinal mortar joints, as well as brick and stone bonds. During the examination, basic bonds occurring in the palace's wall were identified.



Source: Own study

Figure 5. Northern elevation of Gorzanów palace

Another important issue identified in the Gorzanów palace related to the considerable dampness in walls and ceilings. In practice, there are several methods which allow a dampness profile of a building, including indirect methods which consist in measuring another physical constant and calculating humidity values based on this constant to be determined. Humidity measurements of construction elements were executed with hygrometers whose operation is based on dielectric constant measurements. During examination, the humidity level in walls and ceilings was also determined. The largest dampness level in ceilings was observed in areas which are no longer protected against atmospheric conditions, while the walls were considerably damp at the foundation level. A visible decrease in the dampness level was also observed with increasing altitudes. Thermographic tests may also serve as an indirect method for determining dampness levels (identifying places of increased humidity). Tests executed at the Gorzanów palace complex identified leakage spots in roof drainage system as well as capillary absorption of groundwater (fig. 5). A change in humidity level along with a change in temperature was clearly visible in places where downpipes were damaged. The lowest temperature was noted in areas of rainwater impact. Low temperature areas spread from the damage point in a down pipe towards the ground and enlarged its span, which demonstrates water filtration within construction material. Absorbed water caused considerable erosion of the wall's surface which led to the development of vegetation in ground-adjacent part of construction. Apart from temperature changes resulting from direct impact of rainwater ingress, an increase in temperature along with an increase in altitude was also noted in the same area, which confirms that the dampness resulted also from capillary absorption.

Laboratory tests

In the case of the discussed building, due to a construction catastrophe which led to a roof collapse in the eastern wing, demolition of parts of ceilings and wall was necessary. This allowed for the collection of a sufficient amount of samples for laboratory testing. Physical and mechanical parameters of masonry and wooden constructions were determined via destructive tests. In the case of masonry constructions, density, humidity and compressive strength were determined for brick and stone elements in natural state and in solid mass state, as well as the compressive strength for the mortar. For wooden constructions, density, humidity, compressive strength along and cross fibres, flexural strength along fibres, and Young modulus along fibres were determined. Methods for testing the mechanical properties (strength) of construction elements are described in detail in Polish and European standards. Figure 6 shows, from left to right: bending test of standard wood sample, „*punch test*" compression and a brick sample destroyed in a compression test.

Source: Own study

Figure 6. Laboratory samples collected from examined construction elements under testing

Strength parameters obtained in these tests allowed material classes for individual elements to be determined. Due to the numerous historical layers, tests were performed in several groups according to original location of samples in the structure.

Compressive strength of a wall determined through laboratory strength tests of masonry elements and mortar fell within the range of 0.8 MPa to 8.2 MPa. Differences in strength values result from the various parameters of masonry elements. In all cases, strength in the natural state was lower than strength determined for the same elements in solid mass state.

Table 1. Characteristic compressive strength of a wall for brick and stone masonry

Element	Condition of wall sample	Normalised compressive strength [MPa]	Normalised compressive strength [MPa]	Value of *K coefficient*	Characteristic compressive strenght [MPa]
Brick wall	Air-dried	35.41	0.6	0.35	2.92
Brick wall	Natural	31.56	0.6	0.35	2.69
Stone wall	Air-dried	108.05	0.6	0.45	8.19
Stone wall	Natural	95.62	0.6	0.45	7.52

Source: Own study

Based on the results obtained, wood class was determined as C18 – C24 according to PN-B-03150:2000 standard. The parameter deciding the classification of examined material as a given wood class was the resilient modulus.

Table 2. Physical and mechanical parameters of wooden elements

Location	**Volume density ρ_{12} [kg/m^3]**	**Humidity [%]**	**Compressive strength $f_{c0,śr(12)}$ [MPa]**	**Compressive strength $f_{c90,śr(12)}$ [MPa]**	**Flexural strength $f_{m,śr(12)}$ [MPa]**	**Resilient modulus *E* [MPa]**
1	400.98	10.70	31.81	7.09	32.63	7.03
2	398.24	10.97	35.05	5.25	55.34	7.95
3	434.97	9.33	38.69	9.15	66.45	8.43
4	372.06	11.01	33.64	7.24	54.34	-

Source: Own study

Based on all test and examinations performed on location as well as laboratory tests, the physical and mechanical properties of individual elements could be determined: wood class for timber used in construction elements of the palace, approximate compressive strength of masonry walls, stability of the ground substratum and the humidity of materials. The data collected allowed for the statistic and strength calculations of selected elements and thus the limit states for load-bearing capacity and serviceability could be checked.

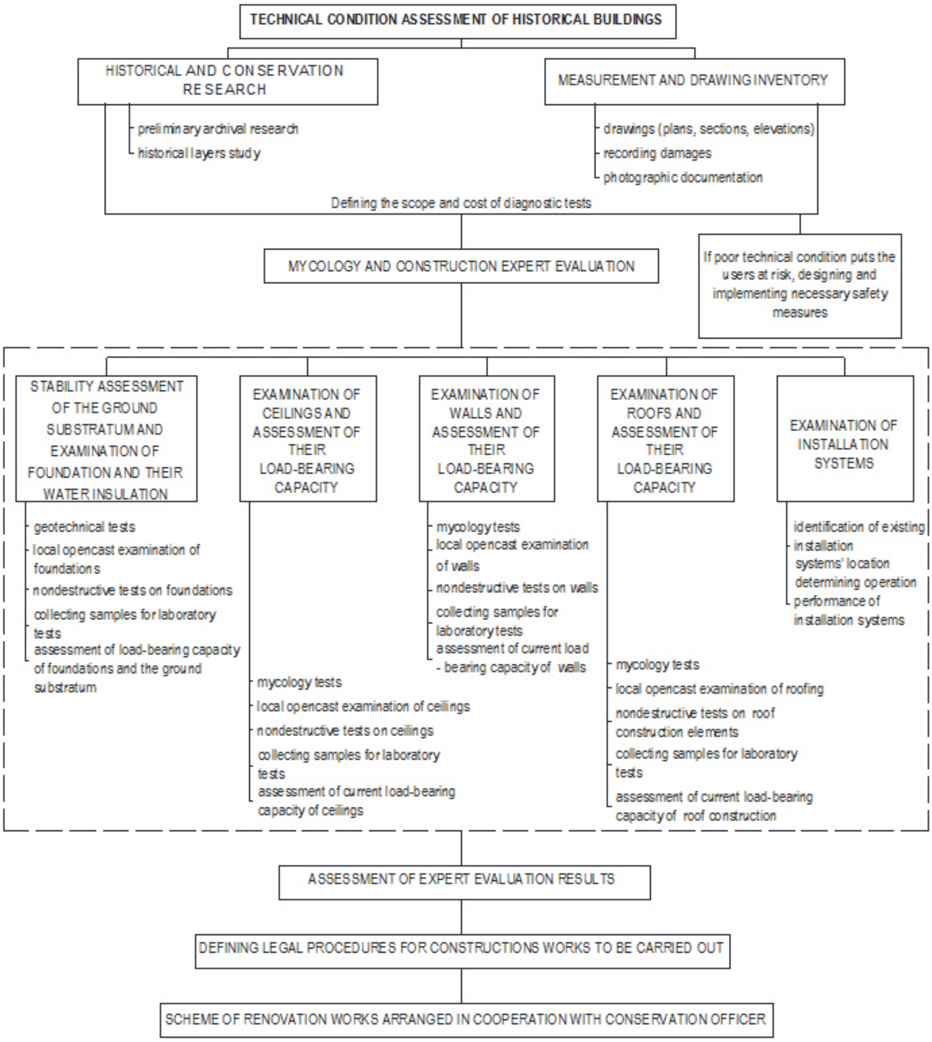
CONCLUSIONS

Based on tests and examination executed at the Gorzanów palace complex, observations of restoration works carried out there and literary resources, the following flowchart of technical assessment procedures for historical objects and determining damage causes was developed (fig. 7). In the future, the scheme presented here may help, among others, experts in conducting evaluation of technical condition.

An analysis of the flowchart (fig. 7) justifies the conclusion that a technical condition assessment of a building is a complex, interdisciplinary task requiring the involvement of a whole group of experts. Therefore, those who attempt to save or modernize historical buildings, especially severely damaged ones, may follow the tips presented below, which will facilitate considerably in implementing the correct order of activities.

Technical condition assessment of historical buildings should begin with preliminary archival research and architectural and construction inventory. All damages should be catalogued. After completing the preliminary archival research and architectural and construction inventory, the scope and cost of necessary expert opinions is estimated. In the case of poor technical condition which may put the health or life of users or contractors at risk, necessary temporary security measures (anchor bolts, supports, pit props) should be designed and executed. The scope of necessary construction expert opinions should be defined for each individual building.

In the case of most buildings, it should be considered whether tests are necessary in order to assess the stability of the ground substratum. Geo technical tests should include penetrometric tests, which allow geotechnical layers to be identified, sounding, which allow the physical and mechanical parameters of these layers to be determined. In order to assess the technical condition of foundations and water insulation, local opencast examinations of foundations are recommended. The technical condition of foundations should be assessed through diagnostic destructive methods (collecting core samples, load-bearing tests on masonry construction) and nondestructive methods (sclerometric, ultrasound, semi-nondestructive tests, electromagnetic test in order to determine the thickness of concrete cover and the level of reinforcements used, reinforcement corrosion tests and concrete corrosion tests). Depending o n identified damages to foundations, a scheme of construction works should be designed in order to restore their load-bearing capacity and shift loads related to the building's new use from the building onto foundations (e.g. injection of foundations, executing concrete top plates, etc.). If the load-bearing capacity of the ground substratum is not sufficient, strengthening works should be designed and executed (e.g. by means of "*jet groutnig*" technology or other stilt systems).



Source: Own study

Figure 7. Flowchart of technical assessment procedures for historical objects

Assessment of the current technical condition of ceilings is recommended as the next stage. If justified, local opencast examinations should be performed in order to identify ceiling type and construction. If fungi or mould is observed, mycology tests and countermeasures should be undertaken. As with foundations, physical and mechanical parameters of materials used in ceilings may be determined by means of destructive and nondestructive diagnostic methods. If damage is identified, the most severely damaged elements should be repaired or replaced, but the necessity to preserve elements most valuable from an artistic and/ or historical point of view must be kept in mind. Based on inventory and technical condition assessment of ceilings, current load-bearing capacity of the ceilings should be determined and it must be checked whether they may bear other loads related to e.g. the building's new function.

As with ceilings, an assessment of current technical condition of load-bearing walls should be executed. During inventory, masonry bonds and historical layers should be identified. If damage is identified, parts of masonry construction should be repaired or replaced (rebuild). Again, as with ceilings, the current load-bearing capacity of load-bearing walls must be determined and it must also be established whether they may bear other loads related to e.g. the building's new function.

Technical condition assessment of roofing should be performed and, if leakage is observed, the roof must be secured. The technical condition of the roof construction must be assessed. If severe damage is identified, strengthening or replacement of whole construction elements should be considered. Windows and doors should also be secured in order to reduce the impact of atmospheric conditions on the building's interior.

The mycology and construction expert opinion includes the examination of installation systems present in the building, both for location and operation. Special attention should be paid to lightning protection systems and fire protection, as well as all water and sewage systems, because any leakage may cause rapid degradation of the building.

A comprehensive expert opinion often requires test results to be evaluated by interdisciplinary teams of experts representing various fields of study. A legal procedure for conducting construction works – renovation, status of construction damage, status of construction catastrophe – should be defined based on a technical condition assessment and in cooperation with a conservation officer. Therefore, a procedure must be set up in order to obtain appropriate permits.

It must be kept in mind that historical buildings are characterized by specific technologies, technical and architectural solutions and history of use. Therefore, each building requires an individual approach when it comes to technical condition assessment.

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