METHODS FOR THE ANALYSIS OF MATERIALS USED IN THE REHABILITATION OF HISTORICAL CONSTRUCTIONS

Brăduț Alexandru IONESCU[1], Andreea HEGYI[2], Carmen DICO[3]
[1] Eng., NIRD URBAN-INCERC Sucursala Cluj-Napoca, bradut.ionescu@incerc-cluj.ro
[2] PhD, NIRD URBAN-INCERC Sucursala Cluj-Napoca, andreea.hegyi@incerc-cluj.ro
[3] Eng., NIRD URBAN-INCERC Sucursala Cluj-Napoca, carmen.dico@incerc-cluj.ro

ABSTRACT

In the case of repairs and restoration of historical buildings, the difficulty lies in preserving their value. It is important that the used materials to be as similar as the original ones, both in terms of composition and of application mode. The purpose of this paper is to present a synthesis of current analysis of techniques and methods for the used building materials in the historical buildings rehabilitation. Therefore, a bibliographic study has been carried out regarding the causes and types of degradation, the evolution in time of construction and building materials and the current analysis methods on their characteristics and the compatibility with the original substrate, too. The results of the theoretical analysis have shown that the degradation of historical constructions can occur as a result of natural causes (chemical, physical, biological and mechanical) or traumatic (fires, earthquakes and wars), resulting in strength and stability reduction of the structure, the loss of historical value due to deterioration of the architectural details etc.

Keywords: construction materials; analysis methods; rehabilitation; historical buildings

REZUMAT

În cazul reparațiilor și restaurării construcțiilor istorice dificultatea constă în păstrarea valorii acestora. Este important ca materialele utilizate să fie cât mai asemănătoare cu cele originale, atât din punct de vedere a compoziției cât și a modului de punere în operă. Scopul acestei lucrări a fost să prezinte o sinteză a tehnicilor și metodelor de analiză actuale destinate materialelor de construcție utilizate la reabilitatea construcțiilor istorice. Prin urmare, s-a realizat un studiu bibliografic privind cauzele și tipurile degradărilor, evoluția în timp a construcțiilor și a materialelor de construcție și metodele actuale de analiză privind caracteristicile și compatibilitatea lor cu substratul original. Rezultatele analizei teoretice au arătat că degradarea construcțiilor istorice poate să survină ca urmare a unor cauze naturale (chimice, fizice, biologice și mecanice) sau traumatice (incendii, cutremure și războaie) având drept consecință reducerea rezistenței și stabilității structurii, pierderea valorii istorice ca urmare a deteriorării detaliilor arhitecturale etc.

Cuvinte cheie: materiale de construcție; metode de analiză; reabilitare; construcții istorice

1. INTRODUCTION

Throughout history, the constructions have been continually evolving. If, at first, were used less sintered materials, closer to the natural one, nowadays are produced and used complex composites that bring the advantage of several properties and benefits cumulating. In the case of historical buildings repairs and restoration, the difficulty lies in preserving their value. For this purpose, it is important that the used materials are similar with the original ones, both in terms of composition and mode of application. Only in this way, the architectural details keep their value, approaching authenticity.

The theoretical analysis results have shown that the degradation of historical constructions can occur as a result of natural causes (chemical, physical, biological and mechanical) or traumatic ones (fires, earthquakes and wars), resulting in a reduction of the structure strength and stability, the loss of historical value due to the deterioration of architectural details etc., as shown in Fig. 1.

The historical buildings are an important component of our cultural heritage. As other authors have indicated (Lee, 1996; Wang,

2008; Chua et al., 2001; Ipecoglu, 2006; Kim et al., 2004a; Kim et al., 2004b), at global level, the historical buildings are part of the national cultural identity and the basis of cultural, social, economic and urban development. As a result, for the achievement of a conservation, renovation and restauration activity as correct as possible, government-funded funds are allocated (Pickard, 2002; Feilden, 2003; Wang, 2008; Chua et al., 2001; Ipecoglu, 2006; Kim et al., 2004a; Kim et al., 2004b).

In heritage areas, multi-hazard studies were conducted (URBASRISK Project, 2012) to identify the cultural values of historical buildings and their classification on specific scales for further mapping and analysis. With the help of field information, of satellite, street and aerial images, a database for the storage of building attributes was established (Georgescu et al., 2015). The scientific literature (Wang, 2008; Chua et al., 2001; Ipecoglu, 2006; Kim et al., 2004a; Kim et al., 2004b), also, points out the fact that often, although a proper initial assessment has been carried out, hidden structural elements or hidden material layers may appear during the renovation / restoration work, which may cause changes in the order of renovation / restoration phases and, implicitly, of the costs and of the execution duration. Therefore, a thorough diagnosis is required, which is not limited to assessing only the surface apparent overall condition. Thus, for the historical buildings rehabilitation / restoration, at least the following steps have to be considered:

- The type: buildings (castle, cathedral, museum etc.), bridges (concrete, metal, wood), cobblestone roads, frescoes / paintings (statues and monasteries) etc.
- The degradation degree (superficial, partial, total)
- The general degradation causes (natural or traumatic) and the specific ones for the local degradation
- The used materials for their construction: rocks (andesite, granite, limestone, marble etc.), wood (beech, oak etc.), the binder materials (lime, cement, mortar, iron nails).
- The used materials analysis methods in the historical buildings rehabilitation
- The materials identification and selection for renovation / restoration, compatible with the original ones.
- Establishing how to put in practice to keep alive the specific of historical buildings, of any type, for future generations.

The first materials used for historical buildings construction were stone, wood and lime. For the construction of walls, the stone (rock) from the immediate vicinity of the building site was used. This was either finished (carved) or put into work as it was found in nature. The used binder between them was made of lime and sand. After the lime (calcium oxide) is laid between the stones, water was poured over. Following the chemical reaction, the quenched lime (calcium hydroxide) resulted - a white paste which, by its hardening, established the adhesion between the stones. Roofs were made using hardwoods. The roofing cover was made either of tiles (burned clay), shingles (wood) or chipped sandstone.

Prior to the industrial development, the main degradation causes were, predominantly natural (earthquakes, floods etc.) or traumatic (wars). With the factories development, the atmospheric pollution increase caused a number of degradation phenomena of building materials used to the historical monuments and buildings. The most affected by the acidic air pollution were marble, limestone, sandstone and mortars, which contain a significant amount of calcite (Popister et al., 2011; Van Grieken et al., 1998). The main properties of these materials are the oxidic composition and the porosity. These will be affected as a result of the chemical reactions that occur under the pollutants action. Henley (1967) (Sabbioni, 2003) demonstrated how the calcium carbonate can be almost entirely substituted by gypsum or even by hard black carbon deposits.

The calcareous materials can also be affected by biological "colonisations", by mechanical properties degradation, by the limestone exfoliation, black crust or surface dirt, or by salt efflorescence. These degradation phenomena were also be observed

at the Cluj-Napoca Art Museum (Popister et al., 2011; Van Grieken et al., 1998).

2. MATERIALS AND METHODS

The purpose of this paper was to present a synthesis of the current techniques and analysis methods applicable to building materials used in the historical buildings rehabilitation. Therefore, a bibliographic study has been carried out regarding the causes and types of degradation, the over time evolution of buildings and construction materials and the current analysis methods on their characteristics and their compatibility with the original substrate.

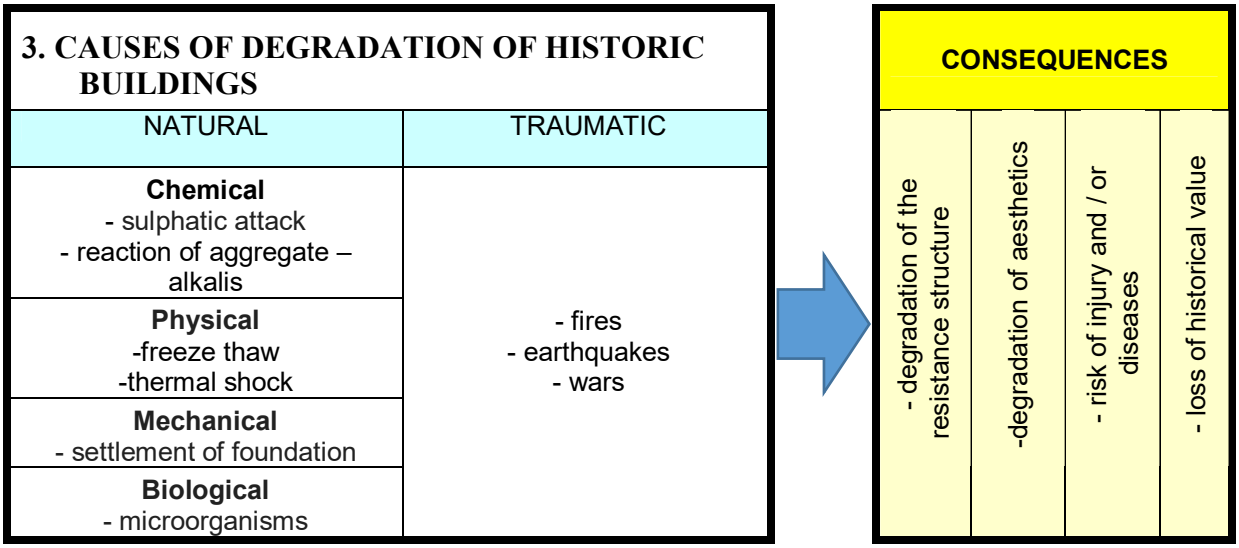

Fig. 1 The causes of the historical buildings degradation and their consequences

4. RESULTS AND DISCUSSIONS

At present, the usual building materials have in their composition a series of additives (acrylic, polyvinyl, elastomers etc.), because of which the compatibility with the initially used materials, in the historical constructions, is reduced. Therefore, it is necessary to analyze in detail the original material, so that it can conceive and use, for restoration, a material with characteristics as close as possible to the original ones.

The current analysis methods can be classified into:

- Physico-mechanical – for granulometry analysis, density, sand equivalent, humidity, mechanical strengths, thermal insulation and sound insulation properties, freeze-thaw resistance, waterproofing etc.
- Physico-chemical – for qualitative and quantitative of chemical composition determination (oxides type and properties, sulfates content, carbonates, chlorides, metals).
- Mineralogical – for the qualitative and quantitative component minerals determination.
- Advanced analysis methods, computer-assisted.

4.1. Physico-mechanical analysis methods

These analysis methods are based on known principles since antiquity - people being aware of the difference between a hard and a soft material, a compact rock and a porous one, a dry sand and a moist one etc. At present, most of these analysis methods are standardized, including mass, density, moisture, porosity, compressive strength, flexural strength, split resistance, wear resistance, frost resistance, thawing, the adherence on support etc. For all these, specific equipment has been developed, now with improved precision. Though empirically assessed thousands of years ago, the thermal conductivity and acoustic performance properties of materials are parameters for which advanced analysis techniques have been the most difficult to perfect, but these days,

even those do not imply major difficulties any longer.

The scientific literature indicates concrete cases when remediation methods have been applied after determining one or more of the above-mentioned parameters, where they have been identified as a cause of degradation. Thus, ventilation at the base of the old buildings wall, through natural ventilation or with a mechanical ventilation device, to treat the increased moisture in the old buildings walls was done by the Physics Laboratory of the Faculty of Engineering at the University of Porto. With the help of these experiments, it has been shown that due to this wall treatment technology by ventilation at the base, dampness was reduced. (Torres and Freitas, 2005, Freitas et al., 1996).

Another concrete case is the experimental analysis on rocks from Prední Kopanina quarry, near Prague (Czech Republic). Rocks have undergone to freeze-thaw cycles and salt crystallization tests, as well as accelerated weathering in the climate chamber using SO_2. By non-destructive and destructive techniques, the stone properties have been evaluated, including ultrasonic velocity measurement, capillarity water absorption determination, mechanical testing, detailed porosimetric analysis and microscopic study. (Prikril et al., 2003).

4.2. Methods of physico-chemical analysis

One of the simplest physico-chemical analyses is the pH determination.

For more sophisticated characterization, the modern analysis methods provide the UV-VIS spectrophotometry, atomic absorption spectrophotometry, flamephotometry.

The UV-VIS spectrophotometry principle consists in the qualitative and quantitative analysis of absorption spectra in the UV-VIS range of inorganic or organic substances, in liquid state.

The Atomic Absorption Spectrophotometry (AAS) is part of the UV-VIS optical methods and is based on the measurement of the radiant power absorbed by a free atoms population. Since at normal temperature only metallic mercury can provide vapours of free atoms, the samples should be atomized by heating. The evaporation and atomization mean, which were imposed in the AAS procedure, are: the flame and electrothermal evaporation (between the electrothermal evaporators, the graphite furnace is noted, the technique being symbolized as GF-AAS).

The Flamephotometry is based on the recording of the emission spectra of the flame-excited elements using a photoelectric cell that converts the emission energy into electric current in direct proportion with the element's concentration, current which is measured with suitable equipment (analogue or digital).

All these analysis methods, together with chemical analyses made by classical methods, based on chemical reactions, indicator turns etc., contribute to achieve a complete picture of material chemical composition and become tools for helping to characterize the material, the petrographical and mineralogical nature, of its compatibility with other materials and, not the last, its sustainability and behaviour in operation.

In the absence of these methods of analysis it would not be possible, for example, the restoration of buildings in China, for which the specific element is a cementitious rapid setting mortar, very compact (low porosity) and with a high alkaline pH, based on aerial lime and animal blood.

The hardening mechanism of the mortar is based on the reaction between the calcium hydroxide and the specific protein in the blood and by modifying the three-dimensional structure of the protein by adding Ca^{2+} ions (Fang et al., 2015; Lanzon and Garcia-Ruiz, 2009; Moropoulou et al., 2005; Silva et al., 2013).

4.3. Petrographical and mineralogical nature analysis

Due to the large diversity of rock types due to the mineralogical structure, the petrographical and mineralogical analysis is particularly important. Thus, it is possible to identify the origin of the rock, to characterize the rock in qualitative and quantitative terms of the mineralogical structure and to obtain an image of the physico-chemical and mechanical

characteristics as well as its durability and its behaviour over time. In principle, the petrographical and mineralogical analysis is done by microscopically identifying of the mineral components which are observed in the thin blades of rock. This analysis will be certificated and qualitative completed on the basis of the results obtained from the complete chemical analysis and RX diffraction.

Dreesen and Dusar (Dreesen and Dusar, 2004) presented the importance of these analyses for the rocks in the Limburg area, Belgium. The authors have shown that in the Flandra area and beyond, most historical buildings were built with a specific local stone, the so-called "white Flanders rock". At present, the natural deposits containing this rock are reduced, and because of this, but also because of the difficulty of processing this rock and the inconsistency of its quality, it is important to identify compatible materials that can be imported from other areas so that the restoration of historical buildings is achieved by preserving their value (Guillitte and Dreesen, 1994).

On the other hand, the spectacular character of the Islamic medieval buildings in Spain is possible due to the use of two types of gypsum, as stated, one powerfully contaminated with ash resulted from the incineration process (the so-called " black gypsum") and another one based on pure $CaSO_4$ hemihydrate (the so-called "white gypsum") (Navarro, 2004).

4.4. Computational, non-destructive analysis methods

The scanning method using laser fluorescence spectra is a non-destructive technique that was first used at the Cathedral in Lund, Sweden, XII century. Thus, it has been identified the algae, lichens, the peeling surfaces, the salt crusts and the pollution deposits on the facade of the cathedral. Through this method it can make an assessment of the historical monuments surface degradation and taking quickly of rehabilitation measures (Weibring et al., 2001, O'Neill et al., 1980, Raimondi et al., 1998).

Non-destructive scanning method with acoustic emissions allows the determination and time monitoring of structural degradation, cracks, and other plastic deformations in masonry ("Casa Capello" - historical building near Turin - Italy, 14th century) (Carpinteri and Lacidogna, 2006; Ohtsu, 1996).

Studies on the Senate Office Building in Saint-Petersburg, Russia have shown that, with the help of radar monitoring, a very precise image about the position of the pipes and the routes of the wires can be obtained and therefore, future repairing and restoration works will not cause more damage by affecting them (Razevig et al., 2008).

5. CONCLUSIONS

As a result of the above, it can say that a detailed knowledge of the analysis methods is particularly important in the case of the historical buildings restoration. In the absence of a thorough analysis of the original material, it cannot be identified the causes of degradation and the optimal restoration technology with a material with the highest compatibility with the original one. The use of poorly documented restoration techniques or of a material that differs greatly from the original one can cause the accentuation of degradation and the loss of historical and architectural value.

REFERENCES

Carpinteri, A., Lacidogna, G., *Damage monitoring of an fistorical masonry building by the acoustic emission technique*, Materials and Structures, 39: 161-167, 2006.

Chua, D. K. H., Li, D. Z., Chan W. T., *Case-based reasoning approach in bid decision making*, Journal of Construction Engineering and Management, 127(1):35–45, 2001.

Dreesen, R., Dusar, M., *Historical building stones in the province of Limburg (NE Belgium): role of petrography in provenance and durability assessment*, Materials caracterization 53:273-287, 2004.

Fang, S., Zhang, K., Zhang, H., Zhang, B., *A study of traditional blood lime mortar for restoration of ancient buildings*, Cement and Concrete Research, 76:232-241, 2015.

Feilden, B. M., *Conservation of historic buildings*, UK: Butterworth Heinemann Oxford, 2003.

Freitas, V. P., Abrantes, V., Crausse, P., *Moisture migration in building walls,* Building and Environment—The International Journal of Building Science and it's Applications 31(2):99–108, 1996.

Georgescu, E. S., Gociman, C. O., Craifaleanu, I. G., Florescu, T., Moscu, C., Georgescu, M. S., Dragomir, C. S., *Urban heritage value and seismic vulnerability mapping: challenges for engineering and arhitectural assessments case study of a protected area in Bucharest, Romania*, Construcţii, 1:30-39, 2015.

Guillitte, O., Dreesen, R., *Laboratory exposure chamber studies and petrographical analysis as bioreceptivity assessment tools of building materials,* Scientific Total Environment, 167:356– 374, 1994.

Ipekoglu, B., *An architectural evaluation method for conservation of traditional dwellings,* Building and Environment, 41(3):386–394, 2006.

Kim, G. H., An, S. H., Kang, K. I., *Comparison of construction cost estimating models based on regression analysis,neural networks, and case-based reasoning*, Building and Environment, 39(10):1235–1242, (2004a).

Kim, G. H., Yoon, J. E., An, S. H., Cho, H. H., Kang, K. I., *Neural network model incorporating a genetic algorithm in estimating construction costs*, Building and Environment, 39(11):1333–1340, (2004b).

Lanzon, M., Garcia-Ruiz, P. A., *Evaluation of capillary water absorption in rendering mortars made with powdered waterproofing additives*, Construction and Building Materials, 23:3287–3291, 2009.

Lee, S. L., *Urban conservation policy and the preservation of historical and cultural heritage: The case of Singapore*, Cities, 13(6): 399–409, 1996.

Moropoulou, A., Bakolas, A., Moundoulas, P., Aggelakopoulou, E., Anagnostopoulou, S., *Strength development and lime reaction in mortars for repairing historicmasonries*, Cement and Concrete Composite, 27:289–294, 2005.

Navarro, C. R., *Binders in historical buildings: Traditional lime in conservation*, Deposito legal, pp. 1698-5478, 2004.

Ohtsu, M., *The history and development of acoustic emission in concrete engineering*, Magazine of Concrete Research, 48(177):321–330, 1996.

O'Neill, R. A., Buja-Bijunas, L., Rayner, D. M., "*Field performance of a laser fluorosensor for the detection of oil spills*", Applied Optics, 19:863–870, 1980.

Pickard, R., *A comparative review of policy for the protection of the architectural heritage of Europe*, International Journal of Heritage Studies, 8(4):349–363, 2002.

Popister, I., Iordachescu, C., Duca, V., Pica, E. M., *Influența factorilor atmosferici poluanți asupra materialelor de construcție folosite la Muzeul de Artă Cluj – Napoca*, A XI-a Conferință Națională multidisciplinară – cu participarea internațională "Profesorul Dorin Pavel – fondatorul hidroenergeticii românești", pp. 219-226, 2011.

Přikryl, R., Lokajíček, T., Svobodová, J., Weishauptová, Z., *Experimental weathering of marlstone from Přední Kopanina (Czech Republic)—historical building stone of Prague*, Building and Environment, 38:1163-1171, 2003.

Raimondi V., Cecchi G., Pantani L., Chiari R., "*Fluorescence lidar monitoring of historical buildings*", Applied Optics 37:1089–1098, 1998.

Razevig, V. V., Ivashov, S. I., Sheyko, A. P., Vasilyev, I. A., Zhuravlev, A. V., *An example of holographic radar using at restoration works of historical building*, Progress in Electromagnetics Research Letters, 1:173-179, 2008.

Sabbioni, C., *Mechanism of air pollution damage to stone, Air Pollution Reviews - The effect of Air Pollution,* Built. Enviroment, 2:63-106, 2003.

Silva, C. M., Flores-Colen, I., Gaspar, S., *Numerical analysis of renders' adhesion using an interface model*, Construction and Building Materials, 38:292–305, 2013.

Torres M. I. M., Freitas V. P., *Treatment of rising damp in historical buildings: wall base ventilation*, Building and Environment, 42: 424-435, 2005.

Van Grieken, R., Delalieux, F., Gysels, K., *Cultural heritage and the environment*, Pure and Applied Chemistry, 70(12): 2327-2331, 1998.

Wang, H. J., Chiou, C. W., Juan, Y. K., *Decision support model based on case-based reasoning approach for estimating the restoration budget of historical buildings*, Expert System with Aplications, 35: 1601-1610, 2008.

Weibring, P., Johansson, T., Edner, H., Svanberg, S., Sundnér, B., Raimondi, V., Cecchi, G., Pantani, L., *Fluorescence lidar imaging of historical monuments*, Applied Optics, 40(33):6111-6120, 2001.