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ANALYSIS OF THE DESTRUCTION AND STRATEGY FOR THE BRICKWORK AND STONE DECOR CONSOLIDATION IN THE BUKOVINA AND DALMATIA METROPOLITANS' RESIDENCE

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Abstract

The Bukovina and Dalmatia Metropolitans' Residence in Chernivtsi is one of the most prominent historicist architectural ensembles in Central and Eastern Europe. Since 2011, this architectural ensemble has been listed on UNESCO's World Heritage List. The complex is distinguished by its exceptional artistic value, complex spatial organization, and unique synthesis of decorative materials. The article aims to systematize and critically analyze the technological and material science solutions used in the restoration process of the Residence; to comprehensively analyze the imperatives of implementing restoration work during the restoration of the Residence's facades in the context of international standards for cultural heritage protection; and to assess their effectiveness from the standpoint of preserving the authenticity and long-term operation of the monument.
The research methodology combines historical and architectural analysis, materials science research, non-destructive diagnostic methods, and comparative analysis of European experience in the restoration of World Heritage sites. As a result, the feasibility of an integrated approach combining traditional and modern materials, local craft practices, and modern, scientifically based conservation technologies has been substantiated. The conclusions obtained can be applied to the development of restoration strategies for other complex historical ensembles, provided the materials are suitable.

***Keywords**: Conservation; Consolidation; Preservation strategy; Stone decoration; Brickwork; Modern technology; UNESCO site; Residence of the Metropolitans of Bukovina and Dalmatia*

Introduction

In the second half of the 19th century, several large-scale architectural projects were implemented in Bukovina, at that time a crown land of the Austrian Empire. Their emergence cannot be entirely attributed to the administration of the Habsburg monarchy. However, their emergence reflects the cultural imperial policy and the counter-desire of local and imperial elites to integrate the region into the pan-European cultural society.

Certainly, the most representative among the architectural objects that arose during that period is the Residence of the Metropolitans of Bukovina and Dalmatia in Chernivtsi. The architectural ensemble was built in 1864–1882 according to the design of the Austrian architect of Czech origin, Josef Hlavka. The complex combines administrative, residential, and sacral functions and is distinguished by a complex semantic program embedded in its planning structure and decorative design.

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Since its construction, the Residence has been subjected to numerous influences, from climatic factors to functional transformations and destructive and restorative interventions of the 20th century. The interventions carried out are not always consistent with the principles of scientific restoration. To preserve historical buildings, in addition to political and legal protection, it is worth considering the traditional architecture of the region, namely the peculiarity and diversity of architectural forms, the skill of construction work, and the quality of building materials used, to select the most effective restoration methods.

In connection with the inclusion of the object in the UNESCO World Heritage List, which took place in 2011, the issue of using technologies and materials that ensure not only the physical stabilization of the building fabric but also the preservation of its authenticity became relevant.

The purpose of the article is to systematize and critically analyze the technological and material science solutions used in the restoration of the facades and interiors of the Residence of the Metropolitans of Bukovina and Dalmatia, taking into account international charters and recommendations for the protection of cultural heritage.

Theoretical and normative principles of restoration of World Heritage sites. Modern restoration theory is based on a set of international documents, among which the Venice Charter and the Nara Document on Authenticity, as well as ICOMOS guidelines and recommendations, play a key role. The central principles of these documents are minimal intervention, preservation of authentic material substance, reversibility of restoration solutions, and compatibility of new materials with historical ones.

After the architectural ensemble of the Residence was included in the UNESCO World Heritage List, it acquired a new status – from a monument of national importance to world recognition. As the head of the UNESCO Site Management Centre, Professor Tamara Marusyk, notes: "...since then, the University is the only one in Ukraine and one of six in the world to perform a dual function: a traditional one – an educational and scientific institution and an honorary one – a monument of world importance." [1].

During 2006–2016, Yuriy Fedkovych Chernivtsi National University, with the help of budget funding, carried out comprehensive repair and restoration work on the roofs of all buildings of the Residence: the Metropolitan Palace, the Seminary Building, and the House for Visitors. In addition, a significant amount of scientific and design work was carried out to continue the processes of comprehensive restoration.

For World Heritage sites, the concept of outstanding universal value acquires additional importance, which involves the preservation of not only material but also spatial, visual, and semantic components of the ensemble. In the case of the architectural ensemble of the Residence of the Metropolitans of Bukovina and Dalmatia, this means the need to simultaneously take into account architectural, urban planning, landscape, and functional aspects.

After the start of the full-scale aggression of the Russian Federation against Ukraine, protection works were carried out in case of damage from shelling. At the initiative of the Fundacja Dziedzictwa Kulturowego and Narodowy Instytut Dziedzictwa, municipal directors–restorers from the historical cities of Poland: Poznań, Warsaw, Kraków, Rzeszów, Lublin, Racibórz, Szczecin, Żory, Toruń, and Łódź, in particular restorer Michal Krasucki, materials were sent to Chernivtsi to protect and preserve valuable elements of cultural heritage sites of world, national, and local importance of the city of Chernivtsi in war conditions. These works were made possible thanks to the cooperation of Liliia Onyshchenko, the head of the Department of Historical Environment Protection of the Lviv City Council; Iryna Korotun, the head of the Department of Architecture, Urbanism, and Preservation of UNESCO Sites of the Yuriy Fedkovych Chernivtsi National University; and Victoria Didenko, the head of the Department of Cultural Heritage Protection of the Chernivtsi City Council in the person of Victoria Didenko.

The distribution of materials and work on their installation were carried out by owners and users, volunteers, students, and members of the Local Organization of the National Union of Architects of Ukraine in the Chernivtsi region, with the involvement of municipal enterprises.

Materials and Methods

The purpose of the study determined the choice of such general scientific methods as the method of historical analysis and the method of comparative analysis, as well as the empirical method as field research. The application of the method of historical analysis made it possible to clarify the history of the construction of the unique complex of the Residence of the Metropolitans of Dalmatia and Bukovina, its re-profiling to accommodate Yuriy Fedkovych Chernivtsi National University, and its preservation as an outstanding architectural monument included in the UNESCO World Heritage List. The application of the method of comparative analysis made it possible to compare various methods used to eliminate damage, excessive moisture, and salinization of brickwork; damage to limestone stone parts; and biodegradation of architectural elements of architectural monuments. Field research of the condition of the Residence buildings, carried out with the involvement of university students, made it possible not only to improve the process of practical training of future architects in restoration issues but also to identify problems of preserving the Residence buildings, as well as to take practical measures to partially solve them.

The research objectives determined the list of sources studied on the following issues:

– theoretical foundations of historical heritage preservation [1], [2];

– historical architecture of Chernivtsi during the Austro-Hungarian Empire [3], [4], [5];

– data on mineral resources of the Chernivtsi region, which were used as a raw material base for the construction industry during the Austro-Hungarian Empire [6];

– technologies for the restoration of brick and stone elements of architectural monuments [7-22];

– modern Ukrainian methodological developments in the field of conservation and restoration of architectural monuments [23], [24];

– changing the original function of an architectural monument as a guarantee of its preservation with the possible addition of new objects to the historical environment [25-31];

– the role of practical skills in the protection of cultural heritage in the development of architectural education [32].

Results and discussion

Historical and architectural characteristics of the complex. The architectural ensemble of the Residence consists of three main buildings: the Metropolitan Palace, the Seminary Building with the Church of the Three Saints (since 1875 – the Theological Faculty of Chernivtsi University). The spatial composition of the architectural ensemble is solved in the form of a closed space with courtyards that have different functional and symbolic significance.

The material structure of the facades of the complex is distinguished by the use of three main building materials: brick, stone (limestone), and glazed multi-colored tiles. The bright terracotta color of the facing brick and the red color of the decorative elements, in combination with the monumentality of the buildings, create a unique image of the architectural ensemble.

For the decoration of the facade walls, red facing brick of the stud masonry with a seam "under the forehead" was used. This method of filling the joints is considered the most affordable; it is often used when forming neat seams of brickwork. The preserved authentic surface of the seams is embroidered with a black line.

Brick as a building material began to be widely used in Chernivtsi after 1778, when the Austrian administration published the first construction instructions [4]. In particular, they noted the requirements of the new Austrian authorities to build stone houses. It should be noted that the foundations of the houses of wealthy townspeople were built of stone, and the walls and ceilings of the basement and first floor were made of imported brick. Until that time, clay was used mainly in artisanal production (local brick pits, temporary field ovens, manual brick molding), which was typical of traditional rural and urban construction. Clay and loam deposits began to be explored and developed on an industrial scale in preparation for the start of construction of the architectural ensemble of the Residence of the Metropolitans of Bukovina and Dalmatia. Since the middle of the 19th century, they have been used for the production of bricks, tiles, and ceramic products. The deposits belong to the deposits of the Neogene and Quaternary ages. The specified types of minerals are characterized by significant capacity; however, only their upper layers (1.5–10.0 m) are being developed. In the plain territory of northern Bukovina (Chernivtsi region), 78 deposits of brick and tile raw materials have been explored (industrial reserves in categories A+B+C1 – 64.4 million m^3), which are characterized by significant layer capacity. More than 10 deposits of clay and loam have been explored in the mountains and foothills of the region. The largest deposits in terms of reserves are Storozhynetske (5788 m^3), Chornohuzivske (641.76 m^3), Ispaske (over 636 m^3), Berehometske (over 313 tm^3), Vashkivske, and Myhivske (almost 300 m^3). The average thickness of clay and loam layers ranges from 0.6–2 m (Ploskivske deposit) to 7–8 m (Berehometske deposit) [6].

Thus, the construction of the Residence of the Metropolitans of Bukovina and Dalmatia in Chernivtsi, begun in 1864, became a determining factor in the industrialization of brick production. As part of the preparatory work, two brick factories and a factory for the production of ceramic (glazed) tiles were specially built to meet the needs of the large-scale construction of the complex. Raw materials for brick production were extracted from local clay deposits, in particular from areas near Chernivtsi, including the famous quarries on the territory of Vynna Hora, which supplied red molding clay for facing and ordinary bricks [3].

The quality of the bricks was controlled according to strict standards: measurements of linear dimensions, weighing, and acoustic tests (tapping) were carried out to detect internal cracks and cavities. This indicates a transition from artisanal to semi-industrial and industrial types of production, focused on high-quality architectural and decorative bricks, characteristic of the Austro-Hungarian school of construction.

In the second half of the 19th and early 20th centuries, local brick factories specialized in the production of ordinary and facing bricks, as well as ceramic tiles, operated in Chernivtsi and surrounding settlements (in particular, in the areas of Kitsman, Zastavna, and Storozhynets). Although specific trademarks of Bukovina factories have been preserved fragmentarily, archaeological and architectural-historical research indicates the use of stamped bricks with local factory marks, typical of the Austro-Hungarian period.

Thus, from the middle of the 19th century, the clay-raw material base of Bukovina was integrated into the regional system of industrial production of building ceramics. This contributed to the formation of a characteristic architectural image of Chernivtsi and other cities of the region, where facing bricks and glazed tiles became key materials of historical buildings and important objects of modern restoration research in the field of heritage science.

In addition, the facades of the architectural complex are decorated with various terracotta linear and polygonal inserts. Terracotta was used as a linear ornament on horizontal stripes. The pattern of decorative inserts is diverse: chevrons, "rusks," rose hips, crucifers, and rosettes. The authors identified more than 7 dozen varieties of decorative forms of terracotta inserts in bright red shades.

It is worth noting that there were certain requirements for the quality of raw materials: in particular, clay without foreign impurities, sufficiently plastic during its formation and firing, and uniform in color were suitable. The development of quarries for the extraction of clay led to the creation of powerful brick factories. Other objects in Chernivtsi were built and decorated with this brick.

For the basic parts of the facades—carved mouchette decor, brackets, decorative inserts, and figured cornices—natural local stone was used—"white" limestone, of beautiful shades, from yellow to gray-white. White limestone belongs to sedimentary calcite-containing rocks based on the mineral calcite ($CaCO_3$).

Limestone is a traditional local building material. It is widely used in the historical architecture of Bukovina and Moldova due to its constructive and aesthetic properties. Its main advantages include local origin and historically determined availability [3], [4]. The physical and technical characteristics of limestone, in particular, easy processing, which is confirmed by material science studies of natural stone, allow it to be used for the execution of complex architectural and decorative elements of facades [8], [18]. The material is characterized by good vapor permeability and compatibility with lime mortars, which ensures stable moisture exchange in masonry and reduces the risk of cracking [8], [23].

Local stone deposits located in the north and south of Bukovina (Ukraine/Romania) were used as the material for the construction of the Residence of the Metropolitans of Bukovina and Dalmatia.

The explored limestone deposits within the Chernivtsi region are located among the deposits of the Paleozoic, Mesozoic, and Neogene ages. The main reserves are concentrated in the territory of the Transnistrian zone of Chernivtsi and Dnister districts. The deposits are characterized by a layer thickness of 2.5–5.0 m to 18–25 m. They contain 85–95.6% calcium carbonate and a small amount of impurities (which actually allows them to be used as raw materials for the production of cement, building lime, and rubble stone) [6]. In the territories of the city of Khotyn in the Transnistrian strip, deposits of limestone and gypsum-containing strata have been explored, where the limestones are characterized by increased fracturing and variable dolomitization.

Small limestone deposits with reserves not exceeding 400 thousand m^3 have been explored in the mountainous area near the village of Sarata, Putylskyi district; the village of Vyzhenka, Vyzhnytskyi district; the village of Stari Broskivtsi; and the urban-type settlement of Krasnoyilsk, Storozhynetskyi district. The thickness of the limestone layers in these deposits ranges from 1.5–3 m (Staro-Broskivske deposit) to 40–50 m (Saratske deposit). The explored reserves of the marbled limestone deposit in the village of Krasnoyilsk reach 414 thousand m^3. Currently, this deposit is used for the extraction of raw materials for the production of facing materials [6].

The stone for the construction of the architectural ensemble of the Residence of the Metropolitans of Bukovina and Dalmatia was supplied from the villages of Krasna (now Krasnoilsk, Romanian *Crasna Ilschi*), Vasyliv, Chunkiv, Doroshivtsi, Tauteni, and the city of Vyzhnytsia: the stone from Krasna was used in the construction of the metropolitan church. It was these deposits with limestone of a bright yellow hue and high porosity that were used in the construction of the columns of the transitional galleries between the wings of the Seminary Complex (later the Theological Faculty of Chernivtsi University), which are currently most affected by the processes of weathering and “wild patina” (Fig. 5). The use of limestone from southern Bukovina (Suceava County, Romania), in particular from Sucevita, for the decoration of corridors and stairs, is documented. In the areas of Suceava, Gura-Humorului, and Câmpulung-Moldovenesc, limestones with variable grain size and strength are common, which causes heterogeneous water absorption capacity and different durability in facade elements. These rocks were traditionally used as a local building material for masonry, the production of lime mortars, and decorative elements, as well as a raw material for lime, which shaped local construction and conservation practices focused on the use of autochthonous materials.

White limestone was used not only as a finishing material but primarily for the construction of foundations and socles of the buildings of the Metropolitan Palace, the Seminary Building with the Church of the Three Saints, and the Monastery Building on the fences. In addition, expressive, deep-relief decorative elements were made of it. In particular, window mouchettes, balconies with various consoles in the form of wolf bodies with heads, various fences, friezes, and cornices, as well as the white tower of the house church of St. John of Suceava of the Metropolitan Palace.

Interfloor ceilings are transversely vaulted, with flooring made of wooden beams. Roof structures are made of wood. The best wood from the villages of Vikova (now Verkhnii Vikov, Suceava County, Romania) and Bilki (now a tract near the village of Panka, Chernivtsi Region, Ukraine) was used to build the roof structures of the Residence.

The roof covering is made of multi-colored poured tiles of the “beaver tail” type. The pediments on the facade risalits are decorated with multicolored majolica inserts. Until 2009, due to the unsatisfactory condition of the roof, there were leaks in significant areas of the roof, the attic, and the ceiling of the upper floors were flooded. Work to replace the tiles on all three buildings, with a total area of 5 thousand m², was carried out during 2009–2019. The tiles for the restoration work were supplied by the Austrian construction company "Tondach," which was also a supplier during the construction of the architectural complex of the residence of the Metropolitans of Bukovina and Dalmatia [3].

The variety of historical materials – bricks of different firing and mineralogical composition; natural stone with different porosity and structure – lime and lime-cement mortars, as well as multi-layer plasters and painted coatings in the decoration of ceremonial premises, significantly complicates the restoration and conservation processes. Each of these materials is characterized by specific physical and mechanical properties, structure, capillary activity, and chemical sensitivity to moisture, salts, and temperature fluctuations. As a result, the use of universal or standardized restoration approaches should be limited, using scientific laboratory and empirical research, since it can lead to material incompatibility, local accumulation of moisture, violation of vapor permeability, and, as a result, activation of negative processes.

In this context, restoration measures require differentiated technological solutions based on the results of comprehensive material diagnostics, in particular the analysis of the mineralogical composition, porosity, mechanical strength, and salt load of each type of material. This involves the individual selection of consolidants, repair solutions, and protective coatings, taking into account their vapor permeability, hygroscopicity, and chemical compatibility with the original materials. This approach is critical to ensure long-term stabilization of the masonry and stone decoration, as well as to minimize the risks of secondary damage.

In addition, the complexity of the historical facades' material structure necessitates the phased planning of restoration interventions, where each technological solution should be based on the principles of minimal intervention and material compatibility. This highlights the key role of interdisciplinary interaction between restorers, materials scientists, engineers, and biodegradation specialists to develop adapted, scientifically sound conservation strategies.

At the same time, the variety of materials in combination with different operational and microclimatic conditions leads to the formation of a wide range of damage, including frost-salt damage, deep weathering of seams, biodestructive colonization, chemical corrosion, exfoliation of plaster, and degradation of painted layers. It is this multiplicity and interaction of damage types that further complicates restoration processes and necessitates the need for individualized, complex technological solutions.

Integrated monitoring of the physical condition of the premises and structural and decorative elements of the buildings of the architectural ensemble of the Residence of the Metropolitans of Bukovina and Dalmatia indicates the following: functional use and good-quality operation, in general, contribute to their preservation.

At the same time, the technical condition of individual sections of the facades and roofs is characterized as requiring conservation work of varying degrees of complexity due to a number of characteristic problems.

Destruction analysis. Damage to brickwork

Destruction of bricks due to wetting and subsequent salt crystallization. A significant part of the buildings in the Residences of the Metropolitans of Bukovina and Dalmatia complex exhibit lesions characteristic of poor-quality foundation waterproofing. This not only worsens the visual object's value but also creates conditions for the further development of biodegraders, which additionally accelerates the degradation of materials (Fig. 1).

Fig. 1. Wetting and contamination of the facade surfaces of the outbuildings of the Seminary Building due to capillary wetting

The absence or degradation of foundations' horizontal and vertical waterproofing is one of the main reasons for capillary wetting of the walls of historical and modern buildings. In such conditions, moisture from the soil rises along the capillary system of the masonry, which leads to chronic wetting of the lower zones of the walls. Capillary suction ensures a constant flow of not only water, but also dissolved salts, which migrate into the thickness of the masonry and crystallize in the pores and on the surface of the materials. This creates conditions for intensive salt weathering, destruction of mortar joints, and progressive degradation of bricks and natural stone. Increased humidity of materials significantly changes their physical and mechanical properties, reducing compressive and shear strength, as well as increasing sensitivity to freeze-thaw cycles. Moisture-saturated joints and stone elements become more vulnerable to frost damage, which accelerates the formation of microcracks, loss of cohesion, and local collapses of surface layers. In the long term, this can lead to a decrease in the bearing capacity of walls, the development of deformations, and an increase in the risk of structural damage. In addition to physical degradation, capillary moistening has a significant negative impact on the aesthetic perception of buildings. Constantly moistened areas contribute to the formation of efflorescence, dark spots, biofilms, and microbiological colonies, which distort the historical appearance of facades and interiors.

Severe leaching is one of the most serious forms of degradation of historic brickwork and stone surfaces, as it is closely linked to moisture transport, salt crystallization cycles, and the porous structure of mineral building materials. The repeated processes of dissolution and crystallization create crystallization pressure in the pores, which leads to the breakdown of the grain structure, surface delamination, loss of cohesion, and gradual weakening of both brick and stone substrates. On historic facades, leaching often occurs due to capillary rise of moisture, previous unsuitable repair mortars, atmospheric pollution, and long-term moisture penetration, which makes the phenomenon particularly persistent and difficult to eliminate.

Thus, ineffective waterproofing of foundations is a systemic risk factor that triggers a chain of interconnected degradation processes from salt and frost damage to biodegradation and loss of structural reliability. This emphasizes the need for a comprehensive approach to diagnosing the moisture-salt regime and implementing engineering and materials science-based measures to restore or create effective waterproofing as a key condition for the long-term preservation of building structures. On the facades of buildings, fences, and retaining walls, degradation of brickwork and destruction of bricks due to moistening and subsequent crystallization of salts are observed.

Elimination of heavy leaching is extremely difficult, since surface cleaning does not eliminate sources of soluble salts and moisture. Effective conservation requires a comprehensive approach that combines moisture control, salt removal treatments, the use of compatible repair solutions, and long-term management of operating conditions. However, the high variability of salt composition, pore structure, and material heterogeneity of historic masonry significantly limits the predictability of treatment results. As a result, leaching-related degradation remains a major obstacle to the sustainable conservation of historic facades and requires continuous monitoring and adaptive conservation strategies.

Establishing the mechanisms of salt crystallization, moisture transfer, and microcracking, which are critical for facade masonry and stone decoration. These approaches are directly relevant for the analysis of the condition of historical facades and interior paintings, as they allow us to justify the choice of compatible materials for injections, masonry dressing, and consolidation of foundations for murals [9], [12-17].

Biodegradation: biological colonization (algae, cyanobacteria, fungi, and bacteria) is one of the key mechanisms of biodegradation of porous mineral materials. Microorganisms cause both chemical degradation (through the formation of organic acids, chelation of calcium, magnesium, and iron ions) and physical destruction (expansion in pores, formation of biofilms, and moisture retention). This is especially dangerous for bricks, limestones, sandstones, and lime plasters, where increased porosity promotes deep penetration of biocolonies and accelerated destruction of the material structure. Such processes are directly related to the development of efflorescence and secondary salts, which often accompany biological damage [11], [24].

Biodegraders are a critical factor in the degradation of brickwork and natural stone facades, as they activate chemical corrosion of minerals; increase porosity and capillary wetting; indirectly enhance the formation of efflorescence and salt crystallization; and accelerate the physical destruction of surface layers (Fig. 2).

Biodegradation of brickwork by fungi. Fungal colonization of historic brick leads to mechanical damage through hyphal growth in pores and chemical degradation through organic acids (oxalic, citric, etc.). GC-MS, a highly sensitive analytical method combining the separation of mixtures (GC) with their identification (MS), is used to analyze volatile and semi-volatile organic compounds by separating them by retention time and then identifying them by ion mass, and SEM-EDX, a materials analysis method combining high-resolution surface imaging (SEM) with qualitative and quantitative elemental composition (EDX/EDS), which determines the morphology, particle size, impurities, and phases on solid samples (metals, polymers, and minerals), confirmed the demineralization and loss of cohesion of the ceramic matrix due to the action of biodegraders [11].

Fig. 2. Destruction of seams and brickwork surfaces by plants and the process of their removal (photo by K. Varvarych, 2025)

Intensive weathering and destruction of brickwork joints with local deepening up to 10 cm. The causes and consequences of deep degradation of brickwork joints lie in deep weathering and destruction of mortar joints in brickwork, which in places reaches a depth of up to 10 cm (Fig. 3). This phenomenon is a consequence of the complex action of physical, chemical, and physicochemical processes, associated primarily with moistening, cyclic freezing-thawing, and crystallization of soluble salts. As shown in fundamental studies of the degradation of historical solutions, the presence of moisture in the pores and capillaries of the mortar leads to the formation of ice lenses and internal stresses in the process of the phase transition of water into ice, which causes micro-crack formation, loss of cohesion, and gradual dispersion of the solution material. Internal damage caused by ice crystallization in pores is one of the most important factors limiting the service life of historical structures [12].

Fig. 3. Seams' weathering and decorative and masonry elements' destruction under the atmospheric factors' influence. Seminary building of the Bukovina and Dalmatia Metropolitans' Residence. Research of the Yuriy Fedkovych Chernivtsi National University Master students (Yerokhin B., Ilichuk M., Mazur O., supervisor I.V. Korotun, 2015)

Crystallization of soluble salts (sulfates, chlorides, and nitrates) in the pores of the solution creates crystallization pressure that exceeds the strength of lime solutions and leads to deep destruction of the joints (subflorescence) [12], [13].

Damage to the stone parts of facades. The general condition of significant areas of the stone surface is determined as unsatisfactory. The stone is affected by the effects of weathering, microcracking, pollution, and biological destruction. There are fragmentary losses of the stone surface in the form of mechanical chips. Significant areas of the stone surface have significant contamination, damage by fungus, and lichen. In hard-to-reach areas of cornices and pediments, stone destruction occurs due to self-seeding vegetation (grass, trees).

Partial violation of the stability of the walls. Violation of the technical condition of the above-ground and underground drainage elements (stormwater drainage) led to partial subsidence of the foundations and deformation of the external walls of the gallery between the Seminary building and the Church of the Three Saints, the entrance vimperg and the tracery of the main facade of the Seminary Church of the Three Saints.

A significant factor in the damage to the stone is pollution. The nature of the factors of surface pollution is diverse. As a rule, the stone is covered with a layer of centuries-old pollution, consisting of dust particles, efflorescence, soot, rust, resinous and oily layers, as well as organic substances secreted by plants. Pollution consists of dust particles containing silicates, coal, soot, organic fibers, and toxic compounds. On the surface of the stone, the dust layer actively adsorbs moisture, gases, and microorganisms from the air. Contaminants are retained and penetrated by electrostatic forces, moisture, and diffusion. This makes the contaminants persistent and difficult to remove. The chemical and biological products resulting from these processes penetrate the pores of the stone and destroy it.

There are also contaminants in the form of grease stains, resins, rust, and paint. Coloring substances penetrate into the pores and form such strong bonds that their removal is accompanied by a high risk of surface damage.

The intensification of damage to stone facade parts is associated with such man-made causes as atmospheric pollution of the urban environment – increased air content of sulfur dioxide (SO_2), nitrogen oxides (NO_x), soot, heavy metals, and light organic compounds contribute to the formation of acid rain. This leads to sulfation, nitration, and carbonization of the stone surface layer, the black crusts' formation, and the mineral structure bonds' destruction (Fig. 4a).

Fig. 4. Chemical and biological damage to the limestone surface on the Seminary Complex's facades (photo by I. Korotun, 2026)

The change in microclimate due to man-made heating, or the so-called "urban heat island effect," increases the amplitude of daily and seasonal temperature fluctuations, which increases thermal stress in stone elements and causes their microcracking. The metal elements used to fasten facade elements work to "rupture" the body of the stone elements, which leads to their destruction (Fig. 5).

Fig. 5. Destruction (stone body's rupture) of limestone from contact with the gate iron fasteners. Gallery of the Seminary Building of the Residence of the Metropolitans of Bukovina and Dalmatia (photo by I. Korotun, 2015)

Increased humidity and hygroscopic contamination of surfaces – due to leaks from communications, irrigation of territories, inefficient drainage systems, or uncontrolled operation of adjacent construction sites leads to an increase in the level of capillary moistening of walls. This activates salt processes (crystallization pressure) and biocorrosion. Microcracks in the structure of the stone and loosening of mortar joints contribute to accelerated erosion of the material.

Technogenic electrochemical influences – the presence of engineering networks (electrical communications, underground cables, and metal elements of the facade) creates electrical potentials that can provoke local corrosion of mineral material, especially in the presence of moisture.

Improper or aggressive maintenance – the use of inappropriate chemical cleaning agents (acid washes, deep abrasive sandblasting, cement-based or polymer-based sealants)—disrupts vapor permeability and leads to secondary damage to the stone surface.

The group of biological destroyers includes bacteria, fungi, lichens, grasses, shrubs, trees, and mosses. Plants cling to the microcracks of the stone with their root system (Figs. 2, 4b). Over the years, plant growth and thickening of the roots expand the cracks and destroy the stone [16], [24].

The vital activity products of the mold fungi, lichens, and bacteria destroy the surface layer of the stone, leading to its peeling and erosion.

Limestone, as one of the most common materials for the stone decoration of historical buildings, is particularly sensitive to atmospheric and chemical-physical weathering. Under the influence of precipitation, polluted air, wetting-drying, and freezing-thawing cycles, there is a gradual dissolution of the calcite matrix, an opening of the pore structure, and a loss of microstructural integrity of the surface layers. This leads to a gradual decrease in the relief of carved elements, smoothing of profiles, and loss of details of stone decoration, which has both material and aesthetic consequences.

Also, a special manifestation of the degradation of the limestone surface is the so-called "wild patina," which is formed as a result of uneven weathering, local accumulation of contaminants, biological colonization, and salt deposits. Such a patina is not a stable protective film, but, on the contrary, an indicator of active destruction processes, since it is accompanied by increased hygroscopicity, moisture accumulation, and increased chemical corrosion of the calcite phase. As a result, the "wild patina" masks the real state of the material, complicates the diagnosis of the degree of degradation, and contributes to further loss of material, which emphasizes the need for its scientifically based analysis and a controlled approach to cleaning and consolidating the surface of limestone elements (Fig. 6).

Fig. 6. Structural changes and destruction of limestone surfaces: "wild patina." Gallery of the Seminary Building of the Residence of the Metropolitans of Bukovina and Dalmatia (photo by I. Korotun, 2025)

Restoration of brickwork involves the following types of work: preparatory and executive.

At the preparatory stage, scientific and design research is carried out, and design and estimate documentation is developed. At this stage, stratigraphic, petrographic, and chemical studies are carried out with the corresponding conclusions and recommendations. Execution of working documentation. Photo fixation, measurement drawings, and design drawings are carried out, including a cartogram of brickwork losses and damage (Fig. 7).

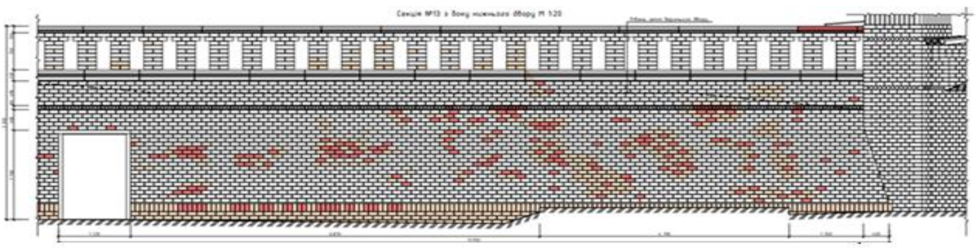

Fig. 7. Cartogram of damage to the brickwork of the surface of the retaining wall, made by students under the supervision of I. Korotun, 2020

1. Replacement of destructured and heavily salted bricks.
2. Injection of cracks and voids in external masonry.
3. Cleaning the external surface of bricks from contamination.
4. Filling cavities, chips, and joints of wall masonry.
5. Tinting of areas of inserted bricks with a special solution.
6. Strengthening with reinforcing solutions of loose, brittle bricks.
7. Hydrophobization (giving water-repellent properties) of the brick surface.

To eliminate such defects in bricks as cavities and potholes, puttying with a solution is used, which in volumetric parts has the following components: lime dough – 1 part, cement – 0.5 parts, brick crush – 3 parts, and pigment (iron red, red, or iron oxide pigment) – to the desired color. The solution is mixed with water with the addition of polyvinyl acetate emulsion in a ratio of 1:4 by volume. Polyvinyl acetate emulsion (PVA) is a universal adhesive product, a mixture consisting of a dispersion of polyvinyl acetate $[-CH_2-CH(OCOCH_3)-]_n$ dissolved in water, with the addition of emulsifiers (often polyvinyl alcohol) and plasticizers (such as dibutyl phthalate).

Before puttying, the brick is thoroughly cleaned of destruction products, brick chips, and dust to a "healthy" surface. Immediately before starting work, the brick is moistened with water. Puttying is performed in layers, each layer no more than 0.5 cm thick. The next layer is applied after the previous one has hardened. During work and after completion (within 2 days), the putty layer must be periodically wetted to improve hardening and prevent mortar shrinkage.

Strengthening and restoration of brickwork joints. Weathering areas of brickwork joints must be filled with mortar. As noted, the depth of weathering is 10 cm, and the height of the joints is from 1 to 1.5 cm. Mortars are used to fill joints, with a composition close to the original. Mortars can be mixed with cement, stone chips, and brick crush.

The composition of mortars for filling joints, in parts by volume:

1. Lime paste – 1, Portland cement – 0.3, sand – 3, brick crush – 1.
2. Lime paste – 1, Portland cement – 0.3, sand – 3, fine stone – 0.5.

If necessary, alkali-resistant pigments are added to the mortars. For better adhesion of the mortar to the base, polyvinyl acetate emulsion (5%) of the volume of the mortar should be added to it.

Technology of puttying joints. Before work, the walls are thoroughly cleaned and washed; dirt and products of the destruction of bricks and mortar are removed. All remnants of the destroyed mortar must be removed from the joints. First, vertical joints are cleaned, then bedding.

Before starting work, the masonry is moistened with water. The joints are filled in layers to a depth of no more than 1–2 cm. The applied solution is carefully compacted. The next layer is applied after the previous one has hardened.

The number of layers depends on the depth of the seam. During the work and after completion, for two days, it is necessary to periodically moisten the masonry for better hardening and prevention of shrinkage of the mortar. Small areas of filling the joints are performed manually.

The processing of the joints is performed carefully, without contaminating the brick surface. Immediately after filling the joint, the brick surface must be wiped with a damp cloth to remove the remains of the mortar. The next day, the brick surface is cleaned with a brush.

After applying the last layer, the surface of the seam is embroidered under the ruler with black facade paint.

Toning of masonry areas and individual bricks that differ from the general tone of the wall should be performed with solutions containing the following: binders, adhesives, and liquid potassium glass; fillers such as chalk and special cements (alumina and white); and weather- and alkali-resistant pigments.

Tinting is performed through sequential operations:

1. Dust removal.
2. Priming with a diluted coloring solution.
3. Painting (tinting).

The main requirement when painting is to obtain, if possible, a thin and uniform layer without flows and leaks. The applied layer should not be sprayed or shiny. To fix the paint layer on the surface, it is necessary to impregnate the tinted areas with solutions based on organosilicon compounds.

Strengthening the destroyed (brittle) surface of the brick. For strengthening, it is recommended to use solutions based on polymer materials that improve the physical and mechanical properties of the material; have high penetration into the depth of the material; do not change the color and texture of the surface; and polymerize in air.

These requirements are met by organosilicon solutions based on ethyl silicates and polymethylsiloxanes. It has been experimentally proven that structural strengthening is provided by an adhesive composition based on cyanoacrylate glue, a low-viscosity monomer, with a short hardening time.

For reinforcement, a universal cyanoacrylate super glue intended for household use and repair work, "Ciakrin 90" is used [24].

The technology of applying a reinforcing solution (glue). The brick surface is cleaned and degreased; it must be clean and dry. The glue is applied evenly, 1–2 drops at a time to form a thin film, 3–5 times depending on the porosity and degree of destruction of the brick. The solution is applied until fully saturated, as evidenced by the appearance of shine from excess glue on the surface. The excess is removed with a rag soaked in acetone.

If parts of the brick are glued together, then 1–2 drops of glue are applied to form a thin film, after which the surfaces to be glued should be firmly pressed for a few seconds. After 30 seconds, an adhesive seam is formed, and full polymerization requires 24 hours. For better bonding, it is recommended to keep the parts of the brick in a pressed state under pressure. Excess glue (white spots on the surface) can worsen the characteristics of the seam, so it must be removed with acetone.

Cleaning the surface of brickwork mechanically. Sandblasting of brick surfaces can be used only if the surface of the brick and the seams are not weathered, and the brick and the material in the seams are strong and dense. The strength of the sand stream is established experimentally. After cleaning, it is necessary to wash the wall surface and, after drying, treat it with strengthening and water-repellent solutions to protect against destruction.

Steam-water cleaning of the surface should be carried out in two stages: steam cleaning and washing off dirt with hot water. In case of severe contamination, steam-water-jet treatment is combined with mechanical cleaning with stiff-bristle brushes with short piles.

If efflorescence appears on the cleaned surface before washing, it should be cleaned with bristle brushes. Then rinse with water and dry after each wash until the salts are completely removed. If efflorescence remains on the surface, it is necessary to wash off the salts with a weak, 1% solution of hydrochloric acid, followed by washing with cold water with the addition of 1–2% soda to a neutral environment on the treated surface.

In case of general surface contamination, steam cleaning at a temperature of +100°C is recommended, followed by washing with hot water (60–70°C) and cold water until the surface is clean.

Chemical cleaning methods. For heavily soiled areas of the brick, it is recommended to use a washing with an aqueous solution of ammonium fluoride (AF) with the addition of synthetic detergents (SD).

Composition of AF wash: ammonium fluoride acid: 150–200 g; SD: 5–10 g; water: 1 l. Preparation of wash: ammonium fluoride acid is poured into a plastic container, dissolved in water (+350 ± 5°C), and filtered through two layers of gauze. Before use, SD is added. The finished solution is stored for no more than a day.

Technology of cleaning with AF wash. The surface is pre-moistened with water to reduce the wash absorption. The wash is applied with a damp brush. After 5–10 minutes, the surface is cleaned with a stiff nylon brush and moistened with water. The remnants of the wash are washed off with plenty of water. The cleaning process is accelerated by using mechanical brushes. To prevent metal corrosion, it is not recommended to use brushes made of ferrous metal. If the cleaning is insufficient, the operation is repeated. Wash consumption is 500 g/m^2.

Satisfactory results in cleaning the surface from soot and other contaminants are obtained by using a 5–10% hydrochloric acid solution, followed by rinsing with water.

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Hydrophobization of brickwork. The best preservation of the masonry surface is facilitated by hydrophobic protective material treatment with vapor-permeable water-repellent coatings. Such coatings are mixtures of organosilicon compounds of a solution of a highly effective organosoluble water repellent GKZh 136-157M (GKZh-94M) based on polymethylhydridesiloxanes with various fillers in organic solvents and aqueous solutions of potassium methylsiliconate GKZh-1K.

Technology of applying solutions. Hydrophobic solutions are applied to a surface that has been thoroughly cleaned of dirt and efflorescence and has been dried (for at least 3 days). It is recommended to treat brickwork with hydrophobic solutions in dry weather, at a temperature not lower than +5°C. Before using solutions, it is worth carrying out a test treatment on a small area of the surface. Hydrophobic solutions should be applied evenly over the entire surface without gaps until completely saturated, avoiding leaks. Hydrophobic agent GKZh 136-157M (GKZh-94M) is used after dilution with one or a mixture of several hydrocarbon solvents (white spirit, solvent, acetone, or ethyl methyl ketone) in the following proportions: 1 liter of GKZh 136-157M (GKZh-94M) – 10 liters of solvent. The solution is applied by spraying, brushing, or dipping. The solution consumption depends on the surface porosity of the treated material. The average consumption is 0.2–0.4 l/m² [24].

Conservation and restoration of stone elements. Stone details (plinths, stairs, and decorative inserts) are preserved using lime and silicate consolidants. The selection of materials is carried out based on the laboratory tests, taking into account the depth of penetration and the absence of a negative impact on the color and the stone texture.

Sequence of work:

Stage 1 – cleaning the stone surface from contamination with the biodegraders and tree sprout removal.

Stage 2 – completing the lost areas and injecting cracks and seams.

Stage 3 – strengthening the stone by applying a protective layer.

Performing stage 1. Cut out the trees with a sharp tool, and remove the root system in parts without damaging the stone structure. If the root system has penetrated deeply into the stone structure, you can use chemical plant root removal from the masonry seams without hazardous substances that can harm the object or the environment.

Stop plant growth and dry out the root system without destroying the stone using professional biocides. Ready-made restoration products based on quaternary ammonium compounds (QAC), benzalkonium chloride, or benzalkonium chloride (retail). They penetrate the pores of the masonry, destroy the cell membranes of plants, and dry out the above-ground parts and roots. They are used after mechanical stem removal to stop regrowth.

Professional herbicide glyphosate. The drug enters the plant through the leaves, penetrates the root system, and blocks the production of amino acids necessary for the life of the plant. This leads to the gradual death of weeds, especially perennial ones, after 7–10 days or longer. It is carried out pointwise, only by a certified specialist. The use of acids (acetic, hydrochloric, and sulfuric) is strictly not recommended because they destroy limestone, sandstone, and salt solutions (copper sulfate and sodium salts) that cause salt deposits and weathering and household bleaches or “universal” agents such as chlorine, which cause degradation of the stone surface. The use of these substances harms the masonry more than the roots of plants.

The chemical method of removing the root system is performed according to the following algorithm. After mechanical pruning of the visible part locally (brush, paintbrush, or swab), apply a professional biocide. Wait for the root system to dry (1–3 weeks). Carefully remove dry roots from the seams. If necessary, carry out repeated biocidal treatment.

Clean the stone dry or wet (depending on the condition) from dust, biological layers, and efflorescence. This process can be performed in several ways.

Method 1. Removal of contaminants is carried out by washing with water mixtures using detergents. First, dust, debris, and cobwebs are removed with brushes. Then the surface is moistened, and a detergent is applied with brushes. The composition of the concentrated detergent is 10 ml of soap, 100 ml of distilled water, and 1 ml of ammonia (0.88). Instead of soap, it is possible to use a detergent, for example, dishwashing detergent. The detergent solution is applied with stiff brushes in deep depressions; it is applied and cleaned with wooden sticks and scrapers. After that, it is thoroughly washed off, collecting water from the surface.

You can use the SMK-6 ALANA stone cleaner (Ukraine). After 5–10 minutes of treatment, rinse the surface thoroughly with water.

Method 2, mechanical, is carried out using sandpaper or a sandblasting machine. The use of mechanical means can damage the stone surface, so the work should be carried out carefully, studying the pressure indicators of the supply of a mixture of abrasive material (for example, sand) and air to the treated surface.

Work on cleaning the stone surface from contamination with the removal of biodegraders and tree sprouts is carried out from top to bottom.

Stage 2 – completing the lost areas and injecting cracks and seams. Injection is the process of filling cracks or cavities in stone elements or seams of structures with a special solution under pressure or by capillary suction in order to restore the monolithicity of the material, prevent moisture penetration, reduce further destruction, and stabilize the structure without replacing the original substance.

Before starting the injection, it is necessary to assess the nature of the cracks: active (growing) or stable, through or superficial, and dry or wet.

Clean the cracks: mechanically (brushes, compressed air, vacuum cleaner); rinse with distilled water or alcohol (for dehydration). Seal the surface: close the crack from the outside with clay, lime dough, or wax, leaving injection holes every 15–30 cm.

Choice of injection material. The solution is selected based on the principle of compatibility with the original stone and old binders.

Recommended composition of the injection solution for filling cavities and gaps. Basic lime-calcite mixture: lime paste $Ca(OH)_2$, 1 part; microcalcite – white marble sand – crushed limestone (retail name – granular limestone for the garden), finely ground calcium carbonate (limestone, chalk, marble) $CaCO_3$, < 0.1 mm, 0.5 parts; quartz sand or crushed stone, 2 parts; distilled water to obtain a fluid suspension (milk viscosity); if necessary, 1–2% ethyl alcohol or a surfactant to improve wettability.

The given solution has high vapor permeability, is compatible with most limestone and sandstone materials, and does not cause salt formation.

The implementation technology involves the following stages. Installation of injectors (packers) in pre-drilled holes (diameter 6–10 mm, depth 2/3 of the wall thickness). Gradual injection from the bottom up, with a pressure of 0.05–0.2 MPa, or manually with a syringe. Control of the solution output through adjacent holes. Slow drying without sharp fluctuations in temperature and humidity. Removal of excess solution after setting [5].

Typical mistakes when performing injection: use of cement or resins in soft historical stone (leads to delamination); excessive pressure (can widen cracks); and injection into wet or salt stone (leads to salt crystallization). Insufficient crack cleaning reduces adhesion.

To prevent the solution from leaking under pressure, the outer crack surface must be sealed with a temporary sealant. Lime paste can be used: a paste of slaked lime and fine sand. Or soft, plastic clay, without salt impurities, can be mixed with fine sand for stability. Wax rods or pastes: for small decorative elements. Paraffin or special polymer pastes: for harsh conditions where water resistance is required.

At the stage of developing a case for restoration work, consider the need for comprehensive material diagnostics to select compatible repair solutions and conservation materials. Programming work without a detailed analysis of the original materials can lead to stress concentration, impaired vapor permeability, and exposure to the risks of physicochemical incompatibility and accelerated degradation [19], [22], [23].

Important: the temporary material must be compatible with the stone and easily removed after the solution dries.

Tamping technology. Identify areas of leakage and find cracks through which the solution can leak; fill the outer layers – press the softened sealant or dough with a finger or spatula to create a "damper" on the surface. Create injection holes: leave spaces for injection of the solution through syringes or packers. Fixing the temporary tamping: compact the material so that it holds and does not move under pressure. Checking for tightness: use a small syringe or hose to apply a little water into the crack; if the water does not leak out, the seal is ready [5].

Stage 3 – strengthening the stone by applying a protective layer. The surface must be dry, since moisture prevents the penetration of silicates.

The generalized technique of using aerosil to strengthen stone during restoration is based on conservation practices and the experience of restoration laboratories. Strengthening the stone of decorative cornices is carried out using Aerosil. This method is a common method in restoration practice, especially for porous mineral materials (sandstone, limestone, etc.). Impregnation with a silicate fixative using Aerosil (colloidal silicon dioxide) is carried out in order to strengthen the structure of weakened or partially destroyed stone.

Materials: Aerosil (Aerosil 200 or an analogue – in retail) – pyrogenic silicon dioxide, a finely dispersed powder; silicate hardener – ethyl silicate (for example, Wacker OH 100, Estel 1000, Silres BS OH 100). Solvent: anhydrous ethanol or a mixture of ethanol with white spirit (depending on the type of stone).

Auxiliary materials: brushes, syringes, or a compressor for aerosol application, a container for preparing the solution, and protective equipment.

Preparation of the fixing solution. Dissolve ethyl silicate (fixing agent, concentration 30–50%), tetramethyl orthosilicate (TEOS), or tetraethyl orthosilicate (TEOS/$Si(OC_2H_5)_4$) in anhydrous ethanol. When in contact with air moisture, it gradually hydrolyzes and forms silicon dioxide (SiO_2), and it is this newly formed silica that "cements" the stone particles. Gradually add aerosil (1–3% by weight) to form a medium-viscosity gel; mix thoroughly until smooth: a thixotropic suspension is formed that holds well on vertical surfaces.

The chemical reaction causes the ethyl silicate to transform through hydrolysis and polymerization into a silica network (SiO_2). This silica fills the pores and binds the weakened grains of the stone, restoring its structure. When performing the work, care should be taken to avoid lumping: add aerosil gradually with intensive mixing [8].

Aerosil is the trade name for pyrogenic silicon dioxide (SiO_2), which is an extremely light micronized powder with high adsorption properties. It is used as a thickener, filler, and stabilizer in the production of adhesives, sealants, paints, and varnishes, as well as in the cosmetic, pharmaceutical, and food industries. But it does not fix the stone on its own, since it does not penetrate deeply into the pores (the particles are too large, 10–40 nm); it does not polymerize in the stone structure. The role of Aerosil is to modify the system. Its functions are to give the solution thixotropy (it thickens when at rest and thins when stirred); to stabilize ethyl silicate, slowing its hydrolysis; to prevent runoff on vertical surfaces; and to evenly distribute the fixative throughout the micropores. That is, Aerosil is not a fixative but a rheological additive that helps ethyl silicate work more efficiently. The cost of Aerosil in retail trade varies depending on the brand and packaging.

The role of the solvent (ethanol) in the mixture: to reduce the viscosity of ethyl silicate; to ensure its better penetration into the pores of the stone; to regulate the rate of hydrolysis (affects the uniformity of polymerization). There are several scientific opinions regarding the addition of white spirit. One study claims that the type of solvent significantly affects the penetration, the efficiency of fixation, and the texture of the formed gel [8]. Another study, "Consolidation of porous carbonate stones using innovative phosphate treatments: mechanical strengthening and physical-microstructural compatibility compared to TEOS-based treatments," for carbonate stones (limestone) indicated that TEOS-based methods have limited effectiveness on calcite/limestone substrates due to the weaker bond of the gel with calcite [23].

Apply by brush, injection, or aerosol (depending on the condition of the stone). In the case of highly porous structures, multiple impregnation is recommended (2–3 layers with an interval of 12–24 hours). The mixture should evenly moisten the surface without forming a shine or film. Polymerization. Keep the stone at a temperature of 15–25°C and a relative humidity of 50–70% for 1–2 weeks. During this time, hydrolysis and condensation of ethyl silicate occur with the formation of silica (SiO_2), which fills the pores.

All materials listed by the authors in the practical recommendations of this article are freely available in retail.

The above methods were tested in the fall of 2025 during local work on removing biological destroyers from the surface of the facing masonry of the facades of the Seminary Church of the Three Saints.

Before using chemical preparations, in particular biocides, consolidants, desalinating compositions, and cleaning reagents, a preliminary assessment of the sensitivity of brickwork and natural stone surfaces to their action is mandatory. Given the mineralogical heterogeneity, variability of the pore structure, and the presence of degradation products, the reaction of materials to chemical influences can differ significantly even within the same facade. In this regard, it is recommended to empirically verify the compatibility and safety of the preparations used by conducting preliminary tests on local test areas.

Such test areas should be selected taking into account the representativeness of the type of material, the degree of degradation, salt load, and biological damage. Within the scope of the tests, it is advisable to evaluate possible changes in color, texture, gloss, and surface microstructure, as well as the potential impact on capillary activity and vapor permeability of the material. In addition to visual assessment, it is recommended to use instrumental control methods (e.g., pH, conductivity, surface hardness, SEM-EDX, or portable spectroscopy), which allow the detection of hidden undesirable reactions between chemical agents and mineral components of the material.

The application of such a step-by-step, empirically validated procedure is a key element of the principles of preventive conservation and minimal intervention, as it reduces the risks of secondary damage, avoids chemical incompatibility, and ensures the long-term stability of brickwork and stone decoration. This approach also contributes to the optimization of the choice of technologies and preparations, ensuring scientifically based and controlled implementation of restoration measures.

Conclusions

The analysis of the destructive processes in the brickwork and stone decoration of the Bukovina and Dalmatia Metropolitans' Residence has shown the complex, multifactorial nature of their damage, caused by a combination of biochemical and environmental factors. It has been established that the main mechanisms of degradation are physicochemical processes associated with moisture accumulation, salt corrosion, and cyclic freezing-thawing, as well as biological damage, which is especially intensively manifested in areas of increased capillary moisture and atmospheric humidification.

The study of the material condition of historical bricks, mortars, and stone decorative elements has revealed systemic damage involving fragmentary losses of varying degrees of brickwork, terracotta decoration, and stone elements.

An additional factor of destruction is biodegraders – fungi, algae, and bacteria, which colonize the surfaces of bricks and stones, forming biofilms and penetrating the pore space. Biological activity causes chemical degradation (due to the release of organic acids and enzymes) and physical weakening of the material structure, which, in combination with high humidity and capillary suction, significantly accelerates the erosion of joints and deepens cavities.

Modern research methods (SEM-EDX, XRD, GC-MS, and microbiological analysis) allow for detailed identification of degradation mechanisms, assess the risks of further destruction, and identify critical zones of facades that require intervention. Establishing the causes of damage and localizing high-risk zones allows for building an effective conservation and restoration strategy that takes into account the compatibility of repair solutions with historical materials and control of humidity and salt composition, as well as local bioprotection to limit biodegradation activity.

Systematic monitoring of the condition of facades and joints is particularly important, which includes regular measurement of humidity, salt concentration, biocolonization intensity, and mechanical condition of materials. Such preventive measures allow detecting early signs of degradation, preventing progressive destruction and ensuring timely consolidation and restoration, which is critical for preserving both the structural integrity of the masonry and the aesthetic appearance of historical objects.

Based on the results obtained, comprehensive conservation strategies have been formulated based on the principles of material compatibility and minimal intervention in compliance with authenticity requirements. Methods and formulations for replenishing the loss of brickwork and stone elements of the facade have been proposed. A methodology and use of solutions adapted in terms of physical and mechanical characteristics to historical materials for restoring brickwork joints have also been proposed. Special attention is paid to the means of carrying out current conservation as a key tool for long-term preservation of the monument's authentic substance.

The integration of materials science research into the restoration decision-making process is considered a necessary condition for ensuring the sustainable preservation of the physical and artistic properties of structures. The obtained conclusions have practical significance not only for the further implementation of works on the consolidation of building structures and decorative elements of the UNESCO World Heritage Site – the Residence of the Metropolitans of Bukovina and Dalmatia—but also a broader methodological potential for the implementation of the specified works on objects that have such finishing materials as facing brick and limestone.

References

[1] M. Orlenko and Y. Ivashko, "The Concept of Art and Works of Art in the Restoration Industry," *Art Inquiry. Recherches sur les Arts,* vol. 21, pp. 171–190, Dec. 2019, DOI:10.26485/AI/2019/21/12.

[2] I.C.A. Sandu, P. Spiridon-Ursu, and I. Sandu, "Current Studies and Approaches in Cultural Heritage Conservation Science: Harmonising Terminology in an Interdisciplinary Context," *International Journal of Conservation Science,* vol. 7, no. 3, pp. 591–606, Sept. 2016.

[3] T. Marusyk and I. Korotun, *Architectural Miracle of Chernivtsi,* Chernivtsi: Bukrek Publishing House (in Ukrainian), 2019.

[4] R.F. Kaindl, *History of Chernivtsi from the Earliest Times to the Present*, trans. V. Y. Ivaniuk, Chernivtsi: Zelena Bukovyna (in Ukrainian), 2005.

[5] D. Redl, "Between Vienna and Chernivtsi: On the formation and influence of the historical architecture of the Austro-Hungarian monarchy," *Architectural Heritage of Chernivtsi of the Austrian Period: Proceedings of International Scientific Conference, Chernivtsi, Ukraine, October 1 – 4, 2001,* P. Rykhlo, Ed. Chernivtsi: Zoloti Lytavry (in Ukrainian), 2003, pp. 45–60.

[6] Chernivtsi Regional State Administration; Chernivtsi Regional Military Administration; Department of Ecology and Natural Resources, *Regional Report on the State of the Environment in Chernivtsi Oblast in 2021,* Chernivtsi (in Ukrainian), 2022, pp. 75–74. [Online]. Available: https://mepr.gov.ua/wp-content/uploads/2022/10/Regionalna-dopovid-CHernivetska-ODA-2021.pdf

[7] E. Sassoni, G. Graziani, and E. Franzoni, "An innovative phosphate-based consolidant for limestone. Part 1: Effectiveness and compatibility in comparison with ethyl silicate," *Construction and Building Materials*, vol. 102, part 1, pp. 918–930, Jan. 2016, DOI: 10.1016/j.conbuildmat.2015.04.026.

[8] G. Graziani, E. Sassoni, and E. Franzoni, "Consolidation of porous carbonate stones by an innovative phosphate treatment," *Heritage Science*, vol. 3, Jan. 2015, Art. no. 1, DOI:10.1186/s40494-014-0031-0.

[9] J. Sýkora, "Modeling of degradation processes in historical mortars," 2014, *arXiv:1402.3174*.

[10] M. Furtak, J. Kobylarczyk, and D. Kuśnierz-Krupa, "Concrete in adaptations and extensions of historic objects (on selected examples from Porto)," *Wiadomości Konserwatorskie – Journal of Heritage Conservation,* no. 58, pp. 15–22, 2019, DOI: 10.17425/WK58PORTO.

[11] M.O. Elnahas, D.H. Sheir, O. Amer, and A.M. El Hagrassi, "Gas chromatography–mass spectrometry and scanning electron microscopy study of fungal biodeterioration of historic brick," *Egyptian Pharmaceutical Journal,* vol. 21, no. 4, pp. 482–495, Oct. 2022, DOI: 10.4103/epj.epj_86_22.

[12] N. Shahidzadeh-Bonn, J. Desarnaud, F. Bertrand, X. Chateau, and D. Bonn, "Damage in porous media due to salt crystallization," *Physical Review. E, Statistical, nonlinear, and soft matter physics,* vol. 81, Article Number: 066110, June 2010, DOI:10.1103/PhysRevE.81.066110.

[13] J. Desarnaud, H. Derluyn, L. Molari, S. De Miranda, V. Cnudde, and D. Bonn, "Drying of Salt Contaminated Porous Media: Effect of Primary and Secondary Crystallization on Damage," *Journal of Applied Physics,* vol. 118, no. 11, Article Number: 154901, Sept. 2015, DOI:10.1063/1.4930292.

[14] C. Gentilini, E. Franzoni, S. Bandini, and L. Nobile, "Effect of salt crystallisation on the shear behaviour of masonry walls: An experimental study," *Construction and Building Materials,* vol. 37, pp. 181–189, Dec. 2012, DOI: 10.1016/j.conbuildmat.2012.07.086.

[15] B. Lubelli, R.P.J. van Hees, and T.G. Nijland, "Salt crystallization damage: how realistic are existing ageing tests?," *Proceedings of the 3rd International Conference on Salt Weathering of Buildings and Stone Sculptures (SWBSS 2014),* H. De Clercq, Ed. Brussels: Aedificatio Publishers, 2014, pp. 259–273.

[16] C. Hall and W.D. Hoff, *Water Transport in Brick, Stone and Concrete,* 2nd ed. London: Spon Press / CRC Press, 2012.

[17] S. Pavía and E. Treacy, "A comparative study of the durability and behaviour of fat lime and NHL mortars," *Materials and Structures,* vol. 39, no. 3, pp. 391–398, Apr. 2006, DOI: 10.1617/s11527-005-9033-4.

[18] J.P. Ingham, "Predicting the Frost Resistance of Building Stone," *Quarterly Journal of Engineering Geology and Hydrogeology,* vol. 38, part 4, pp. 387–399, Nov. 2005, DOI:10.1144/1470-9236/04-068.

[19] P.-I. Foca, I. Sandu, G. Deák, A. V. Sandu, F.-D. Gheorghe, I. G. Sandu, "Restoration of Exterior and Interior Finishes of Historical Monuments: Innovative Solutions with Multi-Effect Additive Mortar," *International Journal of Conservation Science,* vol. 16, no. 2, pp. 807–818, May 2025, DOI: 10.36868/IJCS.2025.02.04.

[20] V. Pelin, S. Garofalide, I. Sandu, B. Apavaloaei, and S. Gurlui, "Black Crust Versus Substrate on Historic Stone: A Brief pXRF Study at Golia Monastery (Iași, Romania)," *International Journal of Conservation Science,* vol. 16, no. 4, pp. 1979–1992, Dec. 2025, DOI: 10. 36868/IJCS.2025.04.25.

[21] Y. Ivashko, K. Kuśnierz, M. Krupa, P. Gryglewski, A. Dmytrenko, and I. Sandu, "Ways of Performance and Preservation of Monumental Art Works on the Facades of Architectural Monuments of the 19th – Early 20th Century," *International Journal of Conservation Science,* vol. 12, no. 4, pp. 1209–1232, Dec. 2021.

[22] I. Sandu et al., "New Materials for Finishing of Ancient Monuments and Process of Obtaining and Applying," *International Journal of Conservation Science*, vol. 12, no. 4, pp. 1249–1258, Dec. 2021.

[23] I. Dorofienko et al., *Conservation and restoration of architectural monuments. Methodological manual,* Kyiv-Lviv: Ukrrestavratsiya Corporation, Ukrzakhidproektrestavratsiya Institute (in Ukrainian), 1996.

[24] V. Kutsevych, T. Marusyk, I. Korotun, V. Dyvak, and K. Herych, *Theoretical and Methodological Foundations of Restoration,* Chernivtsi: Ruta Publishing House (in Ukrainian), 2024.

[25] Y. Ivashko et al., "Problems of Plants Revitalization in the East of Ukraine After the War," *International Journal of Conservation Science,* vol. 14, no. 2, pp. 551–562, June 2023, DOI: 10.36868/IJCS.2023.02.12.

[26] J. Kobylarczyk, D. Kuśnierz-Krupa, Y. Ivashko, L. Savelieva, "Methods of Revitalizing Historical Industrial Facilities – International Experience," *Wiadomości Konserwatorskie – Journal of Heritage Conservation*, no. 62, pp. 97–103, 2020, DOI: 10.48234/WK62INDUSTRIAL.

[27] K. Paprzyca, W. Oleś, P. Tišliar, Y. Ivashko, and A. Dmytrenko, "Modern Use of Historical Castles with Underground Premises (On Examples of Castles in Oświęcim and Špilberk in Brno)," *International Journal of Conservation Science,* vol. 16, spec. iss., pp. 409–424, May 2025, DOI: 10.36868/IJCS.2025.si.04.

[28] K. Sobczynska, A. Nadolny, K. Słuchocka, V. Smilka, and O. Ivashko, "Problems of Supplementing the Formed Historic Development with New Objects," *International Journal of Conservation Science,* vol. 14, no. 3, pp. 857–870, Sept. 2023, DOI: 10.36868/IJCS.2023.03.06.

[29] Y. Ivashko et al., "Preparing for the post-war reconstruction of historical monuments in Ukraine: Considerations in regard of the ongoing Polish post-WWII experience and international law on the protection and conservation of historical monuments," *Muzeológia a kultúrne dedičstvo,* vol. 11, no. 1, pp. 55–71, Mar. 2023, DOI: 10.46284/mkd.2023.11.1.4.

[30] A. Wójtowicz-Wróbel et al., "Function as an Opportunity to Preserve Historic Sites: A Study of Szczawnica Using Environmental, Social and Corporate Governance (ESG) Instruments and Artificial Intelligence (AI) Tools," *International Journal of Conservation Science,* vol. 16, no. 4, pp. 1877–1900, Dec. 2025, DOI: 10.36868/IJCS.2025.04.19.
[31] C. Baera et al., "Opportunities Regarding the Innovative Conservation of the Romanian Vernacular Urbanistic Heritage," *International Journal of Conservation Science,* vol. 14, no. 3, pp. 913–936, Sept. 2023, DOI:10.36868/IJCS.2023.03.09.
[32] J. Malczewska, D. Kuśnierz-Krupa, J. Kobylarczyk, Y. Ivashko, and M. Lisińska-Kuśnierz, "Qualitative Analysis of Architectural Education in the Protection of a Historic City, *Wiadomości Konserwatorskie – Journal of Heritage Conservation*, no. 65, pp. 20–25, 2021, DOI: 10.48234/WK65PROTECTION.

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