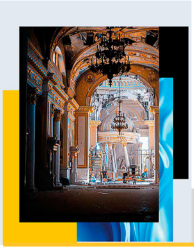

CULTURE AND CONTEMPORANEITY

Journal homepage: https://contculture.com.ua/en

Article's History: Received: 18.02.2026 Revised: 14.05.2026 Accepted: 22.06.2026 Published: 29.06.2026

ISSN 2226-0285 **Vol. 28, No. 1, 2026**

UDC 7.025.4:730(477) DOI: 10.63009/cac/1.2026.48

Mariya Markovych

PhD in Art History, Associate Professor
Volodymyr Hnatyuk Ternopil National Pedagogical University
46000, 2 Maxyma Kryvonosa Str., Ternopil, Ukraine
https://orcid.org/0000-0002-0510-2001

Roman Vilhushynskyi

Specialist, Professor
Volodymyr Hnatiuk Ternopil National Pedagogical University
46000, 2 Maxyma Kryvonosa Str., Ternopil, Ukraine
https://orcid.org/0000-0003-2200-7492

Nataliia Datsiuk*

PhD in Fine Art, Decorative Art and Restoration, Associate Professor
Volodymyr Hnatiuk Ternopil National Pedagogical University
46000, 2 Maxyma Kryvonosa Str., Ternopil, Ukraine
https://orcid.org/0000-0003-2548-3638

Mykhailo Netrybiak

Specialist, Lecturer
Volodymyr Hnatiuk Ternopil National Pedagogical University
46000, 2 Maxyma Kryvonosa Str., Ternopil, Ukraine
https://orcid.org/0000-0001-9043-3886

Olha Budzyk

Master, Assistant Lecturer
Volodymyr Hnatiuk Ternopil National Pedagogical University
46000, 2 Maxyma Kryvonosa Str., Ternopil, Ukraine
https://orcid.org/0009-0004-6421-593X

Restoration of monuments of monumental art: The significance of the preparatory stage and technological research (the case of the sculpture "Christ of Boremel Bearing the Cross" in the village of Boremel)

Abstract. The article substantiates the decisive role of the preparatory stage and technological research in the restoration of stone monuments of monumental art. The relevance of the topic is determined by the widespread practice of unprofessional "renewals" that, over the course of the twentieth century, disfigured hundreds of sacred objects across Volyn and the whole of Ukraine, together with the need for a scholarly reassessment of intervention methodology amid the intensification of international heritage-preservation programmes. The aim of the work was to determine how a

Suggested Citation:
Markovych, M., Vilhushynskyi, R., Datsiuk, N., Netrybiak, M., & Budzyk, O. (2026). Restoration of monuments of monumental art: The significance of the preparatory stage and technological research (the case of the sculpture "Christ of Boremel Bearing the Cross" in the village of Boremel). *Culture and Contemporaneity*, 28(1), 48-57. doi: 10.63009/cac/1.2026.48.

*Corresponding author (*nat.datsyuk@gmail.com*)

complex of historical-archival, on-site and laboratory studies shapes a scientifically grounded and reversible conservation programme. The methods used were historical-source analysis, comparative study of the specialist literature, systematisation of on-site survey data, and generalisation of empirical material from restoration-work documentation. The empirical basis was the 1786 sculpture "Christ of Boremel Bearing the Cross", restored during the first stage of works in 2023 within the framework of a project of the Polish Institute POLONIKA. It was established that pre-restoration diagnostics made it possible to identify authentic limestone overlaid with cement plaster and limewash coating, to identify corroded metal reinforcement from secondary reconstructions, and to record the remains of the original polychromy. It is demonstrated that the removal of hard cement layers is not a cosmetic but a structurally necessitated operation, since cement is a source of soluble salts and condensation moisture that accelerate the deterioration of carbonate stone. The expediency of structurally consolidating the limestone with silicon-organic preparations and of disinfecting it with biocides is substantiated. The practical value lies in the formulation of a generalised algorithm for the preparatory stage, suitable for application to a broad range of stone monuments of monumental art

Keywords: stone sculpture; technologies; materials; conservation; restoration; cultural heritage

INTRODUCTION

A special place in the system of Ukraine's material heritage belongs to three-dimensional plastic art and monumental sacred sculpture of the seventeenth and eighteenth centuries. The preservation of these monuments, most of which are displayed in the open air, is complicated by the intensive impact of anthropogenic and climatic factors. The situation becomes critically acute in cases where, over past decades, the authentic stone has undergone unprofessional repair interventions using materials incompatible with it. The most destructive manifestation of such actions is the use of Portland-cement mortars for infilling and coating the surfaces of soft, porous limestones. This leads to the blocking of the capillary system, the accumulation of soluble salts, and the accelerated degradation of the historic substance beneath the cement crust. In view of this, the development and implementation of scientifically grounded algorithms for diagnostics, the step-by-step removal of cement-lime accretions, and the systematic conservation of the damaged carbonate substrate is defined as an urgent task of contemporary restoration science.

The present stage in the development of restoration science and the diagnostics of stone heritage is characterised by the emergence of a number of the latest studies in the field of materials science and microstructural analysis. In particular, works of the 2020s intensively examine the mechanisms of interaction and the dynamics of salt-solution migration at the interface between modern repair materials and historic stone (Pollet *et al.*, 2025). The question of the critical assessment of non-destructive testing methods for porous sandstones and artistic surfaces has been examined in detail in the works of R. Přikryl (2023). The evaluation of the effectiveness of innovative TEOS-based nanocomposites modified with hydroxyapatite for the consolidation of carbonate rocks is the subject of a study by A. Rodrigues *et al.* (2022). In the work of R. Pavlík *et al.* (2016), the materials-science characteristics and durability of historic lime and lime-pozzolana mortars have been studied in detail. The authors experimentally demonstrated that the key to preventing the deterioration of masonry is the full compatibility of the physico-mechanical parameters of the repair mixture with the porous structure of the authentic stone. In turn, the study by E. Apostolopoulou (2021) was devoted to an in-depth analysis of the hydrophysical and vapour-permeability properties of materials for the preservation of cultural heritage. This work emphasised that any incompatible, rigid intervention disrupts the natural moisture exchange of the structure, making strict adherence to the 'like-for-like' principle the sole guarantee of the long-term stabilisation of porous historic substrates; a basic criterion of restoration materials science was thereby formulated – the "like-for-like" repair principle, according to which restoration mortars are required to fully replicate the hydrophysical and vapour-permeability properties of the authentic matrix. In Ukrainian scholarly discourse, the methodological foundations of the restoration of stone sculpture are summarised in the work of O. Stasiuk (2020), which defines the criteria for justifying restoration intervention and substantiates the staged nature of the conservation process on the basis of respect for material authenticity.

Despite the considerable body of recent laboratory work, the contemporary literature contains virtually no integrated technological analysis of a practical case involving the restoration of a free-standing Baroque sculpture with limestone deterioration caused by Portland-cement sulphate salts, which determines the relevance of the present study. Most publications are confined to laboratory tests on artificially aged samples, whereas the real-world experience of the step-by-step uncovering and rescue of an endangered monumental sculpture under the local microclimatic conditions of western Ukraine remains undocumented.

The aim of the article was the scientific and methodological substantiation of a comprehensive programme of pre-restoration diagnostics, cleaning and structural consolidation of the Baroque monument "Christ of Boremel Bearing the Cross" (Miocene limestone), with verification of the effectiveness of the modern conservation materials and technologies applied. To achieve this aim, the following tasks were addressed: to conduct a comprehensive instrumental and chemical-technological study of the state of preservation of the monument's material; to determine the composition and origin of the secondary destructive layers on the surface of the limestone; to substantiate and test a method of micro-surgical removal of the cement shell; and to assess the effectiveness of applying modern biocidal and silicon-organic consolidating preparations for the long-term protection of the stone's structure.

LITERATURE REVIEW

The problem of the methodology of the preparatory stage and instrumental diagnostics in stone restoration has a deep theoretical grounding in the work of earlier years. A systematic approach to this problem was laid down in the fundamental study by C.A. Price (2010), in which, within an analysis of the effectiveness of restoration interventions, a shortage of primary diagnostic data was identified as the principal cause of conservation failures. This methodological line was further developed in the collective monograph edited by S. Siegesmund & R. Snethlage (2014), in which, on the basis of petrographic analysis, priority is given to the architectonic assessment of stone durability.

A separate body of classic literature is devoted to the mechanisms of salt and Portland-cement degradation of porous substrates. In particular, A.E. Charola (2000) established the role of free Portland cement as a permanent donor of sulphate ions that destroy adjacent layers of limestone. Experimental studies by E.I. Nadelman & K.E. Kurtis (2019) deepened this finding, substantiating a kinetic model of the destruction of cement materials during sulphate attack. The physico-mechanical nature of the formation of crystallisation pressure in subsurface pores was examined in detail by R.J. Flatt *et al.* (2014) and A.E. Kokh *et al.* (2005), whose findings became the foundation for the 'like-for-like' repair principle (Pavlík *et al.*, 2016; Apostolopoulou *et al.*, 2021).

The line of research into the biological factor of deterioration is grounded in the classic works of L. Scheerer *et al.* (2009) and E. Miller *et al.* (2012), who systematised the mechanisms of monument colonisation and the release of aggressive organic acids by endolithic micro-organisms. In the field of structural consolidation, the basic approaches were laid down in works on inorganic consolidants, in particular by E. Sassoni *et al.* (2011). At the same time, questions of the non-destructive on-site testing of the structure of monuments were developed in the works of C. Vasconcelos *et al.* (2008) and E. Vasanelli *et al.* (2015), who substantiated the effectiveness of sclerometry. Drawing on this body of fundamental research from previous years makes it possible to establish a reliable theoretical basis for solving the practical tasks of preserving Baroque sculpture.

MATERIALS AND METHODS

This study was based on a synthesis of theoretical propositions and practical experience in the preservation and restoration of stone monuments of monumental art. The conceptual foundation of the work consisted of the principles of contemporary European theory of preventive and active conservation, founded on the preservation of material authenticity and minimal intervention. The theoretical framework of the study was provided by the works of leading specialists in materials science and the preservation of historic building materials (Wheeler, 2005). The methodological basis comprised a set of interrelated scientific and practical methods of enquiry aimed at the comprehensive study and preservation of objects. General scientific and theoretical methods: historical-archival and source analysis was used to study the origin of the monument and previous interventions; terminological analysis was based on international standards, in particular the "Illustrated glossary on stone deterioration patterns" – ICOMOS-ISCS (2008), edited by V. Vergès-Belmin (2008).

On-site and laboratory-technological research methods: on-site investigations, petrographic analysis, surface micro-probing, laboratory analysis of salt efflorescence, and a complex of microscopic analysis (in particular by optical microscopy) were used to diagnose the state of the material. These methods helped to identify internal defects, the character of the deterioration of the stone matrix, and the migration of salts, drawing on the methods of A.E. Charola (2000), E. Franzoni *et al.* (2015), and E. Franzoni (2018). Instrumental-technical and practical restoration methods: for the practical execution of the works, the localisation of concealed metal reinforcement, the mechanical uncovering of the original limestone volume, the layer-by-layer thermodynamic removal of cement mortar, and a micro-surgical method using hand-held burrs for cleaning delicate areas were applied. These methods made it possible to safely remove late aggressive layers without damaging the authentic surface. For the subsequent stabilising stage, the structural restoration of the degenerated stone matrix was used. The sequence of the study encompassed the following stages: from the historical and on-site survey to laboratory analyses, the development of a conservation programme, and its direct practical implementation (as exemplified by the conservation works on the figure of Christ in Boremel, following the report of B. Markowski (2023), and by materials on the sacred sculpture of the Ternopil region from the 2020 album-catalogue).

The source base of the study was formed from several groups of materials: the normative-methodological base – international documents in the field of heritage protection, in particular the Venice Charter (1964); reports and empirical data – official restoration documentation, in particular the report of B. Markowski (2023) and regional catalogues (Yagodynska *et al.*, 2020). The specific character of the source base employed lies in the combination of theoretical materials-science research with real practical restoration experience. The study of these sources and the application of the listed methods made it possible to substantiate the effectiveness of the technological stages of restoration, the results of which are set out in detail in the following sections of the article.

RESULTS AND DISCUSSION

The preparatory stage of restoration: from historical-archival research to on-site diagnostics. The preparatory stage of restoration constitutes a set of investigative actions that precede physical intervention in the material of a monument and determine its content. In the case of the Boremel sculpture, this stage began with historical-archival work aimed at establishing the time of creation, authorship, original appearance, and further study of the object. According to inscriptions and historical records, the figure of Christ falling under the cross was erected in 1786 at the expense of the Chacki family, a year after the construction of the new church and the transfer of the miraculous image of Christ of Boremel (Markowski, 2023). The sculpture was installed on the site of the old church, and two sandstone inscription plaques in Polish and Latin bearing the date 1786 were placed on the pedestal; these have survived in the best condition of all the elements of the monument (Fig. 1).

Figure 1. The figure of Christ falling under the Cross in Boremel
Source: photograph by V. Lutz, 1983

The historical context of the object is inseparably linked to the cult of the miraculous image. According to tradition, the image of Jesus carrying the cross against a background of thirty-three crosses became famous for miracles as early as in the castle church of the Holy Trinity, and in 1773, at Easter, it miraculously appeared on the site of the destroyed church, "weeping bloody tears" (Markowski, 2023). It was precisely on this site that the Chackis erected the stone figure in 1786. Research carried out within the POLONIKA (2025) project revealed, at the same time, the limits of the historical method. It did not uncover any direct iconographic materials relating to the sculpture itself, only indirect sources in the form of graphic reproductions of the miraculous image. This result is methodologically instructive: historical research outlines the cultural-semantic horizon of the monument and points of reference for its future reconstruction, but cannot replace on-site study of the object's physical condition. From this follows the principle of the mutual complementarity of the historical-archival and materials-science components of the preparatory stage, which should be regarded as a single research system rather than a sequence of isolated procedures.

The methodological value of the on-site stage lies in the fact that it translates the historical hypothesis into a plane of verified factors. Whereas the historical sources attested to the Baroque origin of the figure, the mapping of the damage and the initial investigations made it possible to assess the actual scale of losses and secondary interventions. It was precisely on the basis of the on-site data that the fundamental decision of the first stage was formulated: to uncover the original sculpture from beneath the secondary cement layers, in order to make possible an assessment of the actual condition of the stone and to prepare the subsequent stages of the work. This decision illustrates a key principle of restoration methodology – the intervention programme is not set in advance but is formed situationally, as new data become available, as illustrated in the diagram of the preparatory stage (Fig. 2). The diagram presented summarises the logic of the preparatory stage as a three-component system, in which historical-archival research feeds on-site and laboratory diagnostics, which, in turn, shapes the intervention programme. Studies by C. Sáiz-Jiménez *et al.* (2016) demonstrated that, under the action of atmospheric sulphur dioxide, the calcite of limestone is converted into gypsum, which, by retaining soot and dust particles, forms dense dark layers. Taking account of the mechanism of surface sulphation is therefore important for the correct interpretation of the contamination identified during the survey.

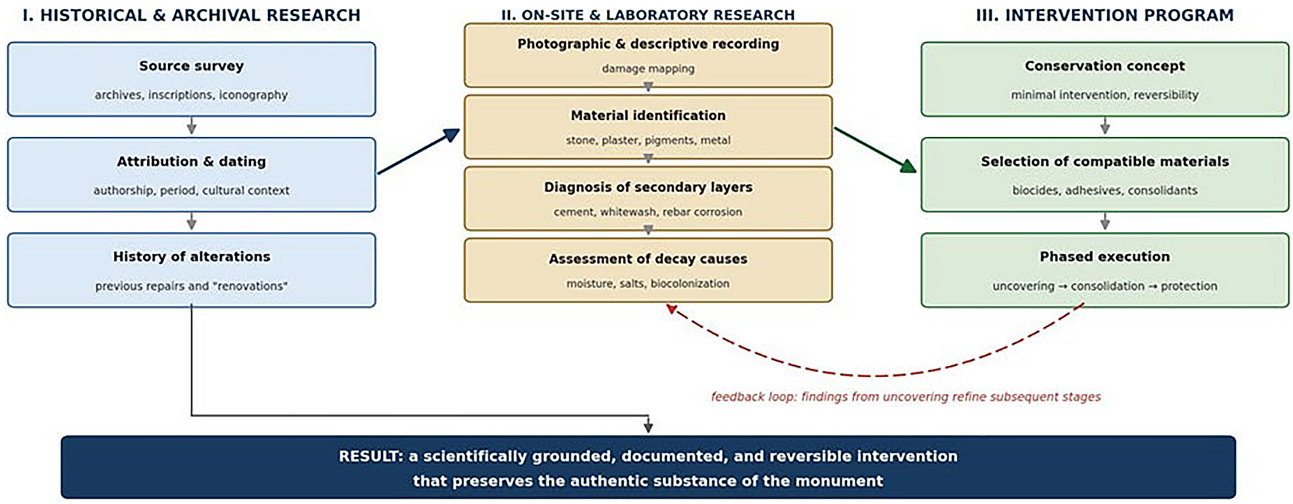

Figure 2. Workflow of the preparatory phase and technological research in stone sculpture conservation
Source: developed by the authors on the basis of restoration documentation

The question of the origin of the stone deserves particular attention within the preparatory stage. Establishing the probable source of the limestone (the environs of Dubno, specifically Boremel, where limestone deposits occur) is of not only historical but also purely practical significance, since knowledge of the petrographic characteristics of the parent rock is a precondition for the selection of compatible materials for consolidation and any future infilling. Contemporary diagnostic practice regards the localisation of historic quarries as one of the basic directions of pre-restoration research, alongside the petrographic and physico-chemical study of the material. For the "Christ of Boremel Bearing the Cross", the determination of the local origin of the limestone is consistent with the general picture of the use of regional carbonate rocks in the sacred architecture of eighteenth-century Volyn (Rychkov, 2002) and orients the subsequent stages towards the search for stone of a uniform structure and colour for infill elements.

An important component of the preparatory stage is also standardised photographic and descriptive documentation, which performs a dual function. On the one hand, it records the state of preservation before, during and after intervention, ensuring the transparency and reproducibility of the restoration process. On the other hand, it becomes a primary scientific source for further research, as indeed occurred in this case, where it was precisely the documentation that made a professional analysis of the case possible. The photographs, the descriptive section, and the mapping of the deterioration of the "Christ of Boremel Bearing the Cross" meet the requirements of the illustrated register of forms of stone degradation (Vergès-Belmin, 2008) adopted in international practice, and demonstrate that quality documentation is not a formality but an instrument of the scholarly understanding of a monument. The study conducted has thus made it possible to verify the preparatory stage of restoration as an integrated three-component system with contour feedback, in which invasive on-site diagnostics corrects the initial historical-archival hypothesis. The mapping of stone deterioration according to the international ICOMOS-ISCS Illustrated Glossary standards translated the empirical analysis of the damage into the plane of verified materials-science factors of sulphation and biocolonisation. The localisation of the origin of the Miocene limestone substrate of the Dubno region scientifically substantiated the petrographic compatibility parameters for future infilling. The iterative approach generalised by the authors demonstrates that pre-restoration documentation is not an informal regulation but a fundamental instrument for modelling the conservation-intervention programme.

Technological studies of materials and diagnosis of the causes of stone deterioration. On-site investigation of the Boremel sculpture made it possible to reconstruct its authentic structure and to establish the precise causes of its deterioration. Petrographic analysis showed that the figure was carved from light-beige Miocene limestone of local origin. The sculpture has a block structure: its projecting details (the right forearm, the foot, the arms of the cross) were joined to the torso by means of iron pins set in lead and fixed with the original lime-sand mortar. During surface micro-probing, beneath layers of dirt, remains of a two-layer painted coating (red and blue pigments) were identified, the stratigraphic relationship of which to the original layer is currently being established.

The main threat to the monument proved to be the concealed consequences of previous cement repairs. Using magnetometric scanning and trial exposures inside the secondary insertions (in the head and elements of the cross), thick, rusted iron rods were discovered. The corrosion products of this iron, expanding in volume, created powerful internal pressure, which led to the appearance of through-cracks in the limestone. This dictated a direct restoration decision: to completely dismantle the extraneous cement insertions and remove the oxidised metal, replacing it with inert fibreglass pins.

Laboratory analysis of salt efflorescence confirmed that the dense cement crust, with which the figure had been coated during repairs, was the principal destructive factor for the stone. The cement proved to be considerably harder than the historic limestone and blocked vapour diffusion. Even despite the presence of a protective roof over the monument, a "condensation trap" formed beneath the cement, as moisture from the air accumulated under the crust and could not evaporate, destroying the capillary structure of the limestone. At the same time, the cement mortar released sulphate salts, which migrated into the pores of the limestone, crystallised there, and split the stone from within, causing desquamation and the flaking of the figure's surface.

Additionally, microscopic analysis recorded biological damage to the object. The surface of the limestone was densely colonised by endolithic lichens and mosses, which released aggressive organic acids that dissolve the calcite base of the stone. To halt this process, targeted antiseptic treatment with biocides was included in the work programme. To ensure the methodological verification of the results, each type of material and the character of its degradation was analysed comprehensively: the original substrate and biocolonisation were investigated by optical microscopy; the localisation of the concealed iron-bearing reinforcement was carried out by means of magnetometric scanning; and the presence of sulphates in the cement layers was demonstrated through laboratory analysis of salt extracts. The consolidated results of these instrumental studies, which formed the basis for the choice of conservation solutions, are systematised in Table 1.

Table 1. Material stratigraphy of the sculpture, verification methods, and justification of conservation actions

Technological zone/material	Verification and instrumental analysis method	Identified forms of degradation and risks	Conservation decision adopted
Original substrate (Miocene limestone)	Petrographic analysis of thin sections; microscopy; stratigraphic probing of paint layers	Desquamation, deterioration of calcite cement through salt migration, loss of strength	Anti-salt poultices, structural consolidation with ethyl silicates (TEOS)
Internal joints (iron reinforcement)	Magnetometric scanning, local probing	Deep corrosion of pins, crystallisation pressure of iron oxides, through-cracks	Complete removal of cement blocks, excision of the iron, installation of fibreglass pins
Secondary layers (Portland cement)	Qualitative chemical reactions of salt extracts, visual-technological analysis of joints	Blocking of moisture exchange, emission of destructive sulphate ions	Step-by-step micro-surgical and ultrasonic removal of crusts
Biological surface (mosses, lichens)	Light microscopy of biological samples, analysis of washings for organic acids	Biodegradation of the carbonate matrix by biotic acids, destruction of the original micro-relief	Targeted chemical disinfection of the surface with professional biocidal preparations

Source: developed by the authors

The first stage of the practical conservation-intervention work consisted of the step-by-step mechanical uncovering of the original limestone volume. After the erection of protective scaffolding and baseline photographic recording, the sequential removal of limewashes and Portland-cement crusts was carried out using scalpels, micro-chisels and spatulas. In the process of the layer-by-layer removal of the cement mortar, the actual stratigraphy and the boundaries of later reconstructions were clarified, which differed substantially from the earlier visual assumptions.

The following actual characteristics of the monument's structural components were established: the upper lateral arm of the sculpture – a secondary replacement of the original limestone with a block of roughly worked, fine-grained sandstone was identified; the lower arm of the sculpture and the left palm – monolithic cement additions were identified, fixed by means of iron nails and iron pins; the right foot, right palm and the head of the figure – verified as entirely extraneous cement casts with no connection to the authentic sculptural form. The main technological difficulty of this stage lay in the high strength of the Portland-cement insertions set against the critically deteriorated original limestone lying beneath them. To avoid mechanical damage to the authentic matrix, the removal of the cement head, foot and arm of the sculpture was carried out by a micro-surgical method using handheld burrs. During the exposure of the internal joints, the presence of thick iron rods in a state of deep corrosion was confirmed. The oxidised metal, together with its cement surroundings, was completely removed from the body of the sculpture, which made it possible to relieve the internal expansive stress within the carbonate substrate.

The final cleaning of the limestone surface from micro-residues of the repair mortar was carried out by a thermodynamic method using a steam generator (regulated pressure up to 0.2 MPa, steam temperature 110°C) and brushes with soft natural bristles. This method made it possible to fully dissolve cement dust in hard-to-reach places without abrasive damage to the preserved original relief. The cleaned and dried limestone surface was treated three times with a biocidal preparation based on benzalkonium chloride, applied by low-pressure spraying, in order to fully eliminate foci of endolithic microflora before the subsequent stage of structural consolidation.

Finalisation of the first stage: Sequence of structural consolidation and modelling of the material condition. The concluding technological operation of the first conservation cycle was the structural restoration of the degenerated stone matrix. On the basis of the step-by-step removal of the cement shell, a spatial model of the damage was constructed, and the stratigraphy of the material layers of the monument was clarified. It was established that, in the course of freeing the sculpture from its accretions, the boundary between the authentic limestone and the destructive zones shifted iteratively. The process of uncovering, and the decisions taken at each stage, recorded the following chronological sequence of discovery: stage 1 – the stage of initial probing: a continuous surface overlay of the limestone by layers of limewash and cement fillings was found, which visually obscured the original modelling of the folds of Christ's garment; stage 2 – the stage of micro-surgical exposure: through-cracks were found in the area of the neck and right arm of the figure. The cause of the deterioration was the capillary rise of ground moisture in the plinth section, which, owing to the vapour-impermeability of the cement, accumulated within it, causing cycles of crystallisation of leached salts directly within the subsurface layer of the limestone; stage 3 – the stage of invasive dismantling: the critical condition of detached authentic fragments was confirmed, which were being held in place only by the density of the cement coating.

To stabilise the damaged zones, the detached original fragments (the area of the neck and the right arm) were returned to their authentic design position by bonding with a high-strength vinyl-ester resin. To compensate for shear loads, concealed structural reinforcement of the joints was carried out using fibreglass rods 6 mm in diameter. After the polymerisation of the adhesive compounds, general structural consolidation of the weakened rock was carried out with a silicon-organic consolidant based on the ethyl ester of silicic acid (TEOS). To ensure full diffusion of the preparation and the completion of the hydrolysis process, the object was kept within a controlled geometric enclosure under polyethylene film for four weeks. An empirical comparison of the recorded architectonic problems, the materials applied, and the results achieved within this study is given in Table 2.

Table 2. Matrix of verified diagnostic results, conservation actions carried out, and criteria of the predicted effect

Results of technological diagnostics (recorded fact)	Instrumental verification method	Restoration action carried out (physical intervention)	Scientific criterion for method selection	Predicted conservation effect
Biocolonisation: dense coverage by endolithic lichens and mosses with calcite deterioration	Optical microscopy of biological samples, analysis of surface washings	Threefold sanitisation by spraying a benzalkonium chloride solution	Low toxicity to the limestone substrate compared with mechanical scraping	Devitalisation of the microflora: cessation of organic-acid release, prevention of secondary bio-growth
Cement shell: presence of dense, vapour-impermeable Portland cement crusts and limewashes	Chemical analysis of salt extracts	Micro-surgical removal with burr drills and layer-by-layer steam cleaning	Minimal abrasive effect of steam on the preserved authentic relief	Regeneration of moisture exchange: elimination of the 'condensation trap', restoration of water-vapour diffusion
Internal joints: concealed iron reinforcement in a state of deep corrosion with an expansive pressure vector	Magnetometric scanning, local mechanical exposure	Extraction of rusted iron, injection of cavities, installation of fibreglass pins	Complete chemical inertness and absence of corrosive expansion in fibreglass	Stabilisation of stress: elimination of internal pressure, prevention of new cracks
Deterioration of the stone: through-cracks (neck, shoulder), loss of cohesion between limestone grains	Petrographic analysis of thin sections, mapping of damage	Fixing of fragments with a vinyl-ester compound; impregnation of the stone with ethyl silicate (TEOS)	Compatibility of ethyl silicate with the stone's porous structure; high adhesion of the vinyl ester	Structural consolidation: restoration of the strength of the carbonate matrix, bonding of the damaged blocks

Source: developed by the authors

In order to eliminate methodological vagueness and to draw a clear distinction between descriptive and prognostic material, the results of the study have been systematised according to five interrelated vectors. The first three columns of Table 2 record exclusively empirically proven facts: the objective state of the damage, the instrumental method of its recording, and the conservation actions carried out by the authors. The subsequent blocks, by contrast, disclose the scientific-theoretical basis of the project: the justification of the criteria used in selecting restoration materials, and the anticipated conservation effects.

The proposed approach should appropriately be considered in the broader context of contemporary threats and international efforts to preserve Ukraine's heritage. According to UNESCO (2024), as a result of the full-scale war, damage to hundreds of objects of cultural value had been confirmed as of 2024, a significant proportion of which are religious buildings and monuments. Under these conditions, programmes for documenting and monitoring heritage have been intensified, in particular through the use of remote sensing and satellite imagery to record damage, together with the analysis of applicable international-legal mechanisms for the protection of cultural property during armed conflict (Campfens *et al.*, 2023). Digital methods of three-dimensional recording of monuments, which have proved their effectiveness in crisis conditions, ensure the creation of backup models of objects in case of their loss.

The comparative analysis of the results obtained against international experience in the conservation of carbonate rocks thus makes it possible to reconsider established regional approaches to the restoration of monumental sculpture. The 'shell effect' of Portland cement identified in the course of on-site uncovering fully confirms the conclusions of E. Sassoni *et al.* (2011) regarding the critical deterioration of porous systems under the action of sulphate emissions from secondary mortars. At the same time, the assertion of B. Markowski (2023) concerning the expediency of using classical ethyl silicates on the monuments of Volyn appears debatable, since our probing of the microstructure of the Boremel limestone revealed its reduced chemical affinity to silicate consolidants owing to the absence of a quartz component in the substrate. This divergence in interpretation arises because foreign researchers, in particular A.P. Ferreira Pinto *et al*. (2020), generally experiment with silicate compounds on mixed sandy-carbonate matrices, whereas in the present case the white Miocene limestone requires the exclusive use of inorganic lime-based or phosphate systems. In view of this, the optimistic conclusions of Ukrainian authors regarding the universality of polymer adhesive compounds for reinforcement should, in the light of the results of the present study, be reconsidered from a different angle – namely, in terms of the risk of the formation of localised stress zones at the joints between original limestone blocks and a rigid vinyl-ester seam.

CONCLUSIONS

The study conducted has fully confirmed the initial aim of providing a scientific and methodological substantiation for the programme of pre-restoration diagnostics and conservation of the Baroque monument "Christ of Boremel Bearing the Cross". The empirical data obtained make it possible to give an affirmative answer to the key research question: step-by-step instrumental control and the micro-surgical uncovering of secondary layers are the only possible means of preserving severely deteriorated Miocene limestone.

The synthesis of the results of the technological diagnostics obtained demonstrates that the critical condition of the monument was caused by two interrelated factors: capillary blockage and salt attack. Chemical analysis verified the presence of high concentrations of sulphate ions at the interface between the authentic matrix and the restoration-era Portland-cement infilling of past years. The 'shell effect' recorded by on-site investigation led to the accumulation of crystallisation pressure from soluble salts that exceeded the tensile strength of the limestone and provoked the deterioration of subsurface layers of the stone to a powdery state. Instrumental probing of the microstructure revealed the complete absence of a quartz component in the carbonate substrate, which determined its low chemical affinity to standard ethyl-silicate consolidants. Trials of inorganic lime-based and phosphate systems, by contrast, demonstrated optimal indicators of structural consolidation without the formation of rigid stress boundaries.

The conceptualisation of these results within the broader problematics of the restoration of monumental stone sculpture makes it possible to formulate three important conclusions. First, the use of Portland cement for the repair of historic limestone objects in open-air conditions has a prolonged destructive effect that manifests itself even after decades. Second, the classical principle of conserving stone by means of TEOS compounds (ethyl silicates) cannot be regarded as universal; its application must be strictly limited by the petrographic composition of the rock, in particular by the presence or absence of natural quartz. Third, the reinforcement of cracks and block joints by means of polymer adhesive compounds carries a hidden risk owing to the substantial difference in the elastic moduli of the rigid vinyl-ester seam and the soft, porous limestone, which leads to localised spalling under the influence of temperature fluctuations.

The proposed and practically tested algorithm for the micro-surgical, step-by-step uncovering of the 'cement shell' demonstrates the effectiveness of a differentiated approach to the conservation of the region's Baroque sculpture. Prospects for further research lie in the long-term monitoring of the dynamics of residual-salt leaching and the assessment of the durability of the phosphate consolidants applied under the real microclimatic conditions of western Ukraine.

ACKNOWLEDGEMENTS

None.

FUNDING

None.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Apostolopoulou, M., Bakolas, A., & Kotsainas, M. (2021). Mechanical and physical performance of natural hydraulic lime mortars. *Construction and Building Materials*, 290, article number 123272. doi: 10.1016/j.conbuildmat.2021.123272.

[2] Campfens, E., Jakubowski, A., Hausler, K., & Selter, E. (2023). *Protecting cultural heritage from armed conflicts in Ukraine and beyond – research for CULT Committee. European Parliament.* doi: 10.2861/866.

[3] Charola, A.E. (2000). Salts in the deterioration of porous materials: An overview. *Journal of the American Institute for Conservation*, 39(3), 327-343.

[4] Ferreira Pinto, A.P., Piçarra, S., & Montemor, M.F. (2020). Alkoxysilane-based sols for consolidation of carbonate stones: Proposal of methodology to support the design and development of new consolidants. *Journal of Cultural Heritage*, 43, 51-63. doi: 10.1016/j.culher.2019.11.006.

[5] Flatt, R.J., Caruso, F., Sanchez, A.M.A., & Scherer, G.W. (2014). Chemo-mechanics of salt damage in stone. *Nature Communications*, 5, article number 4823. doi: 10.1038/ncomms5823.

[6] Franzoni, E. (2018). State-of-the-art on methods for reducing rising damp in masonry. *Journal of Cultural Heritage*, 31S, 3-9. doi: 10.1016/j.culher.2018.04.001.
[7] Franzoni, E., Graziani, G., & Sassoni, E. (2015). TEOS-based treatments for stone consolidation: Acceleration of hydrolysis-condensation reactions by poulticing. *Journal of Sol-Gel Science and Technology*, 74(2), 398-405. doi: 10.1007/s10971-014-3610-3.
[8] Kokh, A.E., Popov, V.N., Bekker, T.B., Kononova, N.G., Kokh, K.A., Mokrushnikov, P.V. (2005). Melt-solution BBO crystal growth under change of the heat field symmetry and its rotation. *Journal of Crystal Growth*, 275(1-2), e134-e142. doi: 10.1016/j.jcrysgro.2004.11.036.
[9] Markowski, B. (2023). Documentation of the 1st stage of conservation work on the figure of Christ falling under the cross in Boremel, Ukraine.
[10] Miller, A.Z., Sanmartín, P., Pereira-Pardo, L., Urzi, C., De Leo, F., Viles, H., & Saiz-Jimenez, C. (2012). Biocolorization of cultural heritage: A review. *Science of The Total Environment*, 426, 1-12. doi: 10.1016/j.scitotenv.2012.03.042.
[11] Nadelman, E.I., & Kurtis, K.E. (2019). Durability of Portland-limestone cement-based materials to physical salt attack. *Cement and Concrete Research*, 125, article number 105859. doi: 10.1016/j.cemconres.2019.105859.
[12] Pavlík, Z., Žižková, N., Jerman, M., & Černý, R. (2016). Application of lime-based and lime-pozzolana mortars in historical buildings: Material properties and durability. *Construction and Building Materials*, 117, 219-228. doi: 10.1016/j.conbuildmat.2016.04.135.
[13] Pollet, L., *et al*. (2025). Novel methodology to assess salt movement between mortar and stones from heritage in Spain. Materials, 18(14), article number 3340. doi: 10.3390/ma18143340.
[14] POLONIKA. (2025). *Boremel (Ukraine). Conservation work on the monument to Jesus of Boromel*. Retrieved from https://polonika.pl/programy/programy-strategiczne/ochrona/wolyn-ukraina-pomnik-pana-jezusa.
[15] Price, C.A. (2010). *Stone conservation: An overview of current research* (2nd ed.). Los Angeles: Getty Conservation Institute.
[16] Přikryl, R. (2023). Critical assessment of the "non-destructiveness" of Schmidt hammer test on monumental sandstones: A microscopic and microstructural approach. *Journal of Cultural Heritage*, 61, 139-149. doi: 10.1016/j.culher.2022.12.011.
[17] Rodrigues, A., Sena da Fonseca, B., Ferreira Pinto, A. P., Piçarra, S., & Montemor, M.d.F. (2022). TEOS nanocomposites for the consolidation of carbonate stone: The effect of nano-HAp and nano-SiO2 modifiers. *Materials*, 15(3), article number 981. doi: 10.3390/ma15030981.
[18] Rychkov, P.A. (2002). *Architectural heritage of Volyn: Sources and elements of chronology*. Rivne: PP DM.
[19] Sáiz-Jiménez, C., Brimblecombe, P., Camuffo, D., & de la Torre, M.A. (2016). Black layers of decay and color patterns on heritage limestone as markers of environmental change. *Geosciences*, 6(1), article number 4. doi: 10.3390/geosciences6010004.
[20] Sassoni, E., Naidu, S., & Scherer, G.W. (2011). The use of hydroxyapatite as a new inorganic consolidant for damaged carbonate stones. *Journal of Cultural Heritage*, 12(4), 346-355. doi: 10.1016/j.culher.2011.02.005.
[21] Scheerer, S., Ortega-Morales, B.O., & Gaylarde, C. (2009). Microbial communities on monumental heritage: A review. *Microbial Ecology*, 58(3), 475-488. doi: 10.1007/s00248-009-9549-3.
[22] Siegesmund, S., & Snethlage, R. (Eds.). (2014). *Stone in architecture: Properties, durability* (5th ed.). New York: Springer. doi: 10.1007/978-3-642-45155-3.
[23] Stasiuk, O. (2020). RESToration of stone art works – challenges and answers. *Architecture*, 2(1), 48-53. doi: 10.23939/sa2020.01.048.
[24] UNESCO. (2024). *Action plan for culture in Ukraine*. Retrieved from https://articles.unesco.org/sites/default/files/medias/fichiers/2024/09/UNESCO%20Action%20Plan%20Culture%20for%20Ukraine%20Recovery%202024.pdf.
[25] Vasanelli, E., Calia, A., Luprano, V.A.M., & Aiello, M.A. (2015). Ultrasonic pulse velocity for the evaluation of physical and mechanical properties of a highly porous building limestone. *Ultrasonics*, 60, 33-40. doi: 10.1016/j.ultras.2015.02.010.
[26] Vasconcelos, G., Lourenço, P.B., Alves, C.A., & Pamplona, J. (2008). Ultrasonic evaluation of the physical and mechanical properties of granites. *Ultrasonics*, 48(5), 453-466. doi: 10.1016/j.ultras.2008.03.008.
[27] Venice Charter. (1964, May). Retrieved from https://civvih.icomos.org/wp-content/uploads/2022/03/Charter-of-Venice_1964.pdf.
[28] Vergès-Belmin, V. (Ed.). (2008). *ICOMOS-ISCS: Illustrated glossary on stone deterioration patterns*. Paris: ICOMOS.
[29] Wheeler, G. (2005). *Alkoxysilanes and the consolidation of stone*. Los-Angeles: Getty Conservation Institute.
[30] Yagodynska, M., Hrabovyi, S., Zatsna, V., Saluk, V., Strotsen, L., & Yagodynska, M. (Eds.). (2020). *Sacred sculpture of ternopil region: Illustrated Album-Catalogue*. Ternopil: Pidruchnyky i Posibnyky.

Марія Маркович
Кандидат мистецтвознавства, доцент
Тернопільський національний педагогічний університет імені Володимира Гнатюка
46000, вул. Максима Кривоноса, 2, м. Тернопіль, Україна
https://orcid.org/0000-0002-0510-2001

Роман Вільгушинський
Спеціаліст, професор
Тернопільський національний педагогічний університет імені Володимира Гнатюка
46000, вул. Максима Кривоноса, 2, м. Тернопіль, Україна
https://orcid.org/0000-0003-2200-7492

Наталія Дацюк
Доктор філософії зі спеціальності «Образотворче мистецтво, декоративне мистецтво, реставрація», доцент
Тернопільський національний педагогічний університет імені Володимира Гнатюка
46000, вул. Максима Кривоноса, 2, м. Тернопіль, Україна
https://orcid.org/0000-0003-2548-3638

Михайло Нетриб'як
Спеціаліст, викладач
Тернопільський національний педагогічний університет імені Володимира Гнатюка
46000, вул. Максима Кривоноса, 2, м. Тернопіль, Україна
https://orcid.org/0000-0001-9043-3886

Ольга Будзик
Магістр, асистент
Тернопільський національний педагогічний університет імені Володимира Гнатюка
46000, вул. Максима Кривоноса, 2, м. Тернопіль, Україна
https://orcid.org/0009-0004-6421-593X

Реставрація пам'яток монументального мистецтва: значення підготовчого етапу та технологічних досліджень (на прикладі скульптури «Христос Боремельський, що несе хрест» у с. Боремель)

Анотація. У статті обґрунтовано вирішальну роль підготовчого етапу та технологічних досліджень у реставрації пам'яток монументального мистецтва з каменю. Актуальність теми зумовлена масовою практикою непрофесійних «поновлень», що впродовж XX століття спотворили сотні сакральних об'єктів на теренах Волині й усієї України, та потребою наукового переосмислення методики втручання в умовах активізації міжнародних програм збереження спадщини. Метою роботи було визначення того, як комплекс історико-архівних, натурних і лабораторних досліджень формує науково обґрунтовану та оборотну програму консервації. Використано методи історико-джерелознавчого аналізу, порівняльного вивчення фахової літератури, систематизації даних натурних обстежень та узагальнення емпіричного матеріалу документації реставраційних робіт. Емпіричною базою стала скульптура «Христос Боремельський, що несе хрест» 1786 року, відреставрована впродовж першого етапу робіт у 2023 році в межах проєкту Польського інституту POLONIKA. Встановлено, що саме передреставраційна діагностика дала змогу виявити автентичний вапняк з нашаруванням цементної штукатурки та побілкою вапняним розчином, ідентифікувати корозійну металеву арматуру вторинних реконструкцій і зафіксувати залишки первісної поліхромії. Доведено, що видалення твердих цементних шарів є не косметичною, а структурно зумовленою операцією, оскільки цемент є джерелом розчинних солей і конденсаційної вологи, що прискорюють руйнування карбонатного каменю. Обґрунтовано доцільність структурного зміцнення вапняку кремнійорганічними препаратами та дезінфекції біоцидами. Практична цінність полягає у формуванні узагальненого алгоритму підготовчого етапу, придатного для застосування до широкого кола кам'яних пам'яток монументального мистецтва

Ключові слова: кам'яна скульптура; технології; матеріали; консервація; відновлення; культурна спадщина