Universal Library of Innovative Research and Studies | Research Article

ISSN: 3065-0003

Open Access | PP: 09-14

DOI: https://doi.org/10.70315/uloap.ulirs.2022.002

Modern Construction Technologies in the Reconstruction of Architectural Objects: Balance between Authenticity and Innovation

Artem Myronenko

San Diego, California, USA.

Abstract

The study presents a comprehensive analysis of the relationship between the use of advanced construction technologies and the challenge of preserving authenticity in the restoration of architectural heritage sites. The relevance of the topic is determined by increasing tensions between the need to extend the service life and functional readaptation of historic structures and the risk of losing their material and intangible character as a result of overly invasive technological interventions. The aim of the study is to conduct a holistic analysis of the interdependent relationships between modern construction technologies and the criterion of authenticity in the tasks of restoring architectural monuments. The methodological foundation consists of a systematic analysis of specialized publications, which examine the possibilities of applying digital modeling technologies (BIM), laser scanning, additive manufacturing, and new composite materials in restoration practice. As a result, a multi-level methodology for assessing the authenticity of an object is described, and an algorithm for selecting technological solutions is considered, taking into account the historical and cultural value of the monument, its technical condition, and the planned functional load. It is concluded that the judicious integration of innovative technologies not only prevents a decline in the genuineness of the building but can also enhance its level by minimizing physical intervention, accurately reproducing lost elements, and generating detailed digital documentation. The practical significance of the study is manifested in its applicability for conservation architects, engineers, monument guardians, and specialists in the field of construction sciences.

Keywords: *Reconstruction, Architectural Heritage, Authenticity, Innovative Technologies, BIM, Laser Scanning, 3D Printing, Restoration, Heritage Preservation, Digital Twins.*

INTRODUCTION

Reconstruction of architectural heritage objects in the twenty-first century is regarded as a multifaceted task intersecting the boundaries of disciplines such as historical scholarship, visual arts, engineering design and materials science. The relevance of research in this area is determined, on the one hand, by the gradual deterioration and destruction of a portion of the world's cultural heritage, and on the other, by the rapid development of construction-industry technologies opening new avenues for its preservation and functional adaptation. Concrete Restoration Market was valued at USD 15.0 billion in 2021 and is projected to reach USD 20.4 billion by 2026, growing at a cagr 6.2% from 2021 to 2026. The high growth of concrete restoration can be attributed to the growing number of construction repair projects globally due to the rising population, rapid urbanization, and increased economic growth in some regions. Emerging markets like China, the UAE, and India are showing remarkable growth due to the aforementioned factors. This has been a decisive factor in the concrete restoration market growth, especially in regions like North America and Europe, where concrete restoration products' usage is relatively high. By 2026, many new companies will emerge from China, having low-cost concrete restoration products and. thus, offer heavy competition to the existing market players[1]. At the same time, such dynamics pose a fundamentally important problem for researchers and practitioners — how to implement advanced restoration methods without undermining the fundamental postulate of conservation theory — the authenticity of the artistic and historical object? To date, the scientific literature lacks a comprehensive methodology capable of equally assessing the technological viability of restoration techniques and their impact on the preservation of the intangible characteristics of a monument. Existing conceptual and applied approaches are generally fragmentary: they either conduct in-depth analyses of the technical parameters of materials and structures or focus on the philosophical and methodological aspects of the concept of authenticity, without providing their adequate integration into a unified research paradigm.

The **aim** of the study is to conduct a comprehensive analysis of the interdependent relationships between modern construction technologies and the criterion of authenticity in the tasks of restoring architectural monuments.

The **novelty** of the proposed approach lies in the formation of a systematically organized set of criteria for the selection of restoration technologies, based on a multilevel gradation of authenticity indicators that extends far beyond the classical dichotomy original – copy.

In the role of an initial **hypothesis** it is asserted that the methodically calibrated integration of digital three-dimensional modeling tools, additive manufacturing processes, and modern composite materials is capable of ensuring maximum preservation and viability of the reconstructed object. This is achieved by guaranteeing structural stability, full material compatibility, and high-precision documentation of each stage of restoration, provided there is strict reliance on the historical and cultural context and the ethical standards of professional practice.

MATERIALS AND METHODS

Contemporary approaches to the digital documentation of historical objects are based on the integration of threedimensional scanning and building information modeling (BIM) methodologies. Thus, Rocha G. et al.[2] proposed a comprehensive scantoBIM workflow that, starting from a point cloud, constructs a parametric model accounting for both the geometry and the materialization of structural elements; a similar emphasis on automating the rapid prototyping process is made by Bertola G.[5] in the creation of a physical replica of building archive fragments. In this context, Mansuri L. et al.[10], within the framework of a scientometric analysis, recorded the growth in the use of 3D scanning and geospatial technologies in cultural heritage, identifying three main clusters: documentation, restoration and multimedia presentation. Specialized cases of 3D method application are provided in the work of Siu S. L. K.[11], who demonstrated the effectiveness of scanning objects damaged by natural catastrophes and integrating the obtained data into restoration work plans.

Virtual and augmented reality expand the possibilities for the analysis and interpretation of cultural objects. Thus, Hajirasouli A. et al.[3] developed a theoretical innovative VRbased platform that allows not only the recreation of the digital environment of vanishing monuments but also provides interactive engagement for specialists and the broader public. In their model digital reconstruction becomes a means of posthumous preservation and an educational resource, which aligns with the conclusions of UNESCO [14] on the role of cultural indicators in sustainable development.

Alongside the development of digital techniques, methods for structural health monitoring and the application of modern materials in reconstruction are being actively investigated. Abulencia A. B. et al. [6], in a review of geopolymers, demonstrated their potential as a sustainable alternative to traditional cement in the reinforcement of unreinforced stone structures, noting high adhesion and resistance to aggressive environments. Bao Y. et al. [7] summarized the achievements of the datadriven approach to structural health monitoring (SHM), emphasizing the role of machine learning in the detection of early signs of degradation. These findings coincide with those of GopinathV. K., Ramadoss R.[8], who highlighted the combination of sensor networks and cloud platforms for continuous monitoring of facades and foundations. The comprehensive market picture is further reinforced by data from Grand View Research on the scale of the concrete structure restoration market, which notes an annual increase in demand for innovative repair mixtures and technologies [1].

Another direction is sustainable design in reconstruction. Ali U. et al.[4] demonstrated a GISoriented multilayer approach to the energy modeling of residential buildings, which enables the evaluation of energy efficiency metrics at both micro and macrolevels. Similarly, Khan S. A., Koç M., Al-Ghamdi S. G.[13] conducted a systematic review of the capabilities of 3D concrete printing, emphasizing the potential of this technology for the formation of complex architectural forms with minimal waste, while noting challenges in the standardization of materials and processes.

The normative and conceptual framework of reconstruction is based on the principles of authenticity and sustainable development. The Nara Document of the International Council on Monuments and Sites [9] addresses issues of balancing historical values and contemporary interventions, introducing the criteria of spiritual and material authenticity. Similar provisions are supported by the FIEC program Rebuilding a brighter tomorrow [12], which focuses on innovative construction solutions combining heritage preservation and the implementation of new technologies. In its thematic indicators UNESCO emphasizes the necessity of integrating cultural values into the United Nations Sustainable Development Goals [14].

In summary it can be noted that despite evident progress, the literature contains several contradictions. On one hand, the influence of digital models and artificial intelligence is growing, posing a risk of detachment of restoration from the physico-chemical characteristics of authentic materials [2, 4, 10], on the other hand, additive technologies may excessively reinterpret historical forms, exceeding the bounds of original techniques and materials [5, 11]. Issues of long-term environmental sustainability and regulation of new composites are addressed fragmentarily [1, 13], and the socio-cultural consequences of large-scale digital interventions remain almost unexamined. Moreover, there is a lack of comprehensive standards for integration of monitoring, digital modeling and authorized repair technologies, complicating the translation of successful pilot solutions into widespread restoration practice.

RESULTS AND DISCUSSION

Modern theory of restoration and construction technologies is based on the synergy of digital design and analysis methods, high-precision instrumental techniques for diagnosing the condition of structures and innovative materials that ensure reversibility and compatibility of interventions with the historical environment. At its core lies a multi-level model for assessing the strength and deformation stability of aged masonry and frameworks, developed through the combination of three-dimensional laser scanning, photogrammetry and integrated monitoring sensors, which enables the creation of a digital twin of the object for conducting virtual tests and optimizing conservation measures. The model further incorporates the properties of the latest composite reinforcement systems (carbon and basalt composites, microcements modified with nanofractions) that harmonize with the thermo-hygroscopic characteristics of heritage buildings, ensuring long-term safety and minimal alteration of the authentic structure. The logic of intervention follows the principle of minimal intrusion: each constructive operation is modelled with consideration for potential reversible disassembly and respect for cultural-historical value, supported by international ICOMOS standards and the Venice Charter, as well as adaptive recycling of prefabricated elements and the implementation of BIM platforms for managing the life cycle of reconstructed objects.

The conducted analysis of existing research enabled the description of a conceptual framework model that systematizes the decision-making process when selecting contemporary technologies for the restoration of architectural heritage. The foundation of this model is the rejection of the simplified dichotomy of authentic–inauthentic in favour of a multistage mechanism for interpreting authenticity. Drawing on the key propositions of theoretical studies [9, 10], the model identifies four fundamentally distinct levels of authenticity, each corresponding to its own set of methodological approaches and requirements when planning restoration interventions (table 1).

Table 1. Multi-level model for assessing the authenticity of a heritage object (compiled by the author based on the analysis of [9-11]).

Authenticity level	Description	Key analytical questions	Relevant technologies
Material authenticity	Authenticity of the original materials and structural components of the object; preservation of the material memory.	What materials is the object constructed from? What is their degree of preservation? Is conservation feasible or is replacement required?	Non-destructive testing (NDT), chemical analysis of materials, conservation technologies, laser cleaning.
Design/formal authenticity	Correspondence of the object's form, geometry, decoration, and spatial organisation to the author's original intent or to the most valuable historical period.	To what extent does the current form reflect the historical appearance? Which elements have been lost? Is reconstruction required?	Laser scanning, photogrammetry, HBIM modelling, 3D printing for element reconstruction.
Functional authenticity	Preservation or adaptation of the historical function of the building.	What was the object's original purpose? Can it be preserved, or must it be adapted to new requirements?	Integration of modern engineering systems (HVAC, electrical), accessibility technologies (concealed lifts, ramps).
Associative authenticity (spirit of place)	Intangible aspects: the object's connection to historical events and personalities; its role in the cultural landscape, spirit of place.	Which events and meanings are associated with this place? What shapes its unique atmosphere? How can it be preserved during renovation?	Virtual and augmented reality (VR/AR) for narrative creation, sensitive lighting design.

Implementation of the proposed evaluation matrix shifts the fundamental problem of determining whether an object is authentic onto a more refined plane: which specific parameter of authenticity is critical for the case at hand and how the applied technology will contribute to its preservation or enhancement. In other words, the focus moves from the generalized category of authenticity to a differentiated selection of technical methods depending on the object's priority characteristics. Thus, in the conservation of a ruined castle the material-tangible authenticity and the retention of its unique spirit of place will play the key role, whereas in the adaptation of a historic building within a metropolis's business district the functional coherence of new structural solutions with the historic appearance and the design continuity of previous architectural concepts come to the fore.

Based on this multi-level concept, a decision-support algorithm has been developed (Figure 1), representing a detailed, step-by-step scenario for technology selection. Each stage of the algorithm includes analysis of the initial state, establishment of the dominant criteria of authenticity, comparison of possible technical approaches and their evaluation in terms of compliance with the established priorities. As a result, an objectivized procedure is applied that minimizes subjective assumptions and ensures replicability of decisions in various contexts of restoration and reconstruction.

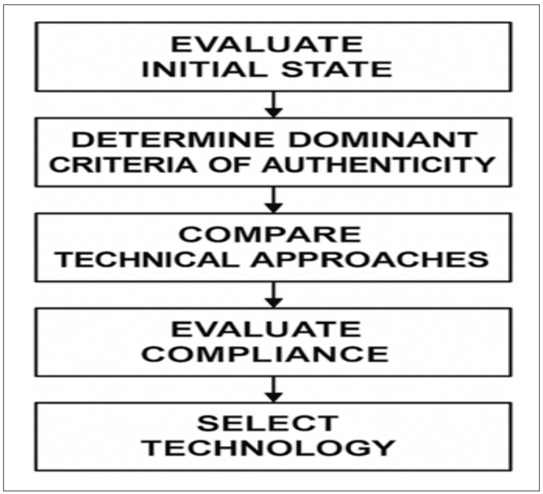

Fig. 1. Algorithm for making decisions on the choice of reconstruction technologies (compiled by the author based on the analysis of [2, 3, 6, 8]).

In the first stage a comprehensive diagnostic assessment is implemented employing the full spectrum of modern instrumental methods: from detailed visual inspection to ground-penetrating radar surveying [7] and subsequent construction of a virtual copy of the object – a digital twin [2, 3]. The result is a high-precision and fully functional HBIM model accumulating data on structural configuration, characteristics of applied materials and detected defects [4].

In the second stage a historical and cultural expertise is conducted, within which a comparative analysis of the value characteristics of the object is performed and priorities are established among different levels of authenticity (see table 1).

The third stage entails the selection of restoration technologies. For each issue – whether it involves cracking of the wall surface, loss of decorative fragments or the need for floor reinforcement – multiple alternatives are developed. Thus, a lost cornice element may be handcrafted by a conservator, cast in polymer concrete or 3D-printed using additive equipment with specialized restoration mixtures [5]. The final choice is based on a multicriteria evaluation: economic feasibility, execution speed, degree of reversibility of intervention, compatibility of new materials with the historic environment, visual conformity and prospective impact on the operational characteristics of the structure.

The practical effectiveness of the proposed methodology is confirmed in application. For instance, during the restoration of a Gothic cathedral that had lost significant portions of its sculptural ornamentation (gargoyles, pinnacles), the principle of design authenticity remains paramount. In this case, the use of laser scanning to accurately capture the geometry of surviving prototypes, followed by additive manufacturing of replicas in geopolymer concrete reproducing the texture of aged stone, proves to be the optimal solution, surpassing traditional manual modeling in both precision and execution rate [12]. Conversely, in the treatment of an 18th-century wooden church, where the priority is preservation of original material, concealed reinforcement of load-bearing elements with composite rods (FRP) [6] is preferred over complete replacement of decayed beams – this allows maximal retention of authentic timber and minimal intervention.

The transformation of post-reconstruction monitoring methodologies is driven by the active integration of digital technologies. In particular, the use of wireless multimodal sensor systems capable of real-time detection of structural deformations, humidity levels and thermal fluctuations opens opportunities for the construction of complex algorithmic predictive analysis models capable of identifying incipient defects long before their visual manifestation [8]. Direct integration of such data streams into the HBIM representation of the object creates a dynamic, continuously updated model – a digital twin effect enhancing the substantiation of managerial decisions and the responsiveness to potential risks. Despite the advantages of additive technologies, the use of 3D printing for load-bearing structures remains at the experimental trial stage, and questions regarding the durability of such elements in aggressive urban environments remain unresolved [13, 14]. The application of composite materials for structural reinforcement, in turn, calls into question the principle of reversibility of intervention, one of the cornerstone postulates of the Venice Charter.

The algorithm described in this work does not propose a single correct solution but serves as an effective tool for the structured and reasoned search for compromise. It provides a common language for all participants in the process – from engineers to conservation specialists – relying on objective data and clearly formulated evaluation criteria. The final balance is achieved not through intuitive judgments but by means of systematic analysis of pros and cons that takes into account the unique characteristics of each object. Conceptually this harmony is represented as a triangle of sustainable reconstruction (figure 2), the vertices of which are authenticity preservation, technological innovation implementation and assurance of long-term sustainability (including economic, social and environmental components).

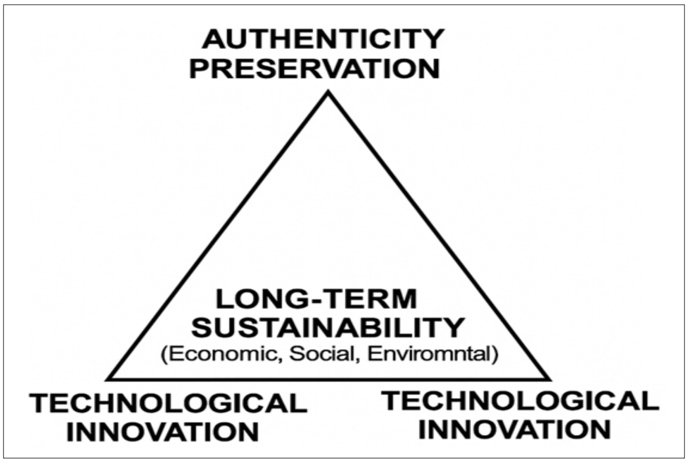

Fig. 2. Conceptual model "Triangle of sustainable reconstruction" (compiled by the author based on the analysis of [8, 13, 14]).

As a result of the analysis conducted it is established that the integration of advanced technologies does not undermine the authenticity of historical objects but, on the contrary, opens new horizons for restoration practice provided their application is deliberate and methodically calibrated

CONCLUSION

The conducted research allowed for a comprehensive examination of the multifaceted problem of implementing innovative construction methodologies in the practice of architectural heritage restoration. It was found that the principal challenge lies not so much in the application of advanced technologies themselves as in ensuring a balanced interaction between their technical efficacy and the preservation of the monument's authentic characteristics.

As a result, a conceptual decision-support model has been described, aimed at formalizing and imparting objectivity to the process of selecting restoration techniques. The model is built upon two interrelated components: a multilevel authenticity assessment system (including material, design, functional, and associative levels) and an algorithmic scenario that guides specialists from the stage of comprehensive digital diagnostics to the iterative selection of the least invasive yet most effective intervention methods.

The posited hypothesis has been confirmed that modern tools — HBIM, laser scanning, additive printing and new composite materials — when rigorously integrated within the framework of the proposed model, not only do no harm to the monument but also contribute to enhancing its overall degree of authenticity. This is achieved through the minimization of work invasiveness, high-precision restoration of lost elements, assurance of long-term structural stability, and the creation of detailed digital documentation, which itself acquires value as part of the historical and cultural heritage.

The proposed approach overcomes the divide between technocratic and conservatively humanistic paradigms of restoration, creating a platform for productive interdisciplinary dialogue and the development of well-founded compromise solutions. The study's findings make a significant contribution to the theory and practice of scientific restoration, providing tools for a more conscious and responsible approach to reconstruction. Further work may be directed toward testing the model on specific sites and analyzing the long-term consequences of applying innovative materials and technologies in historical settings.

REFERENCES

1. Grand View Research. Concrete restoration market size.https://www.marketsandmarkets.com/Market-Reports/concrete-restoration-market-198206216.html (accessed May 1, 2022).
2. Rocha G. et al. A scan-to-BIM methodology applied to heritage buildings //Heritage. – 2020. – Vol. 3 (1). – pp. 47-67.https://doi.org/10.3390/heritage3010004.
3. Hajirasouli A. et al. Virtual reality-based digitisation for endangered heritage sites: Theoretical framework and application //Journal of Cultural Heritage. – 2021. – Vol. 49. – pp. 140-151.https://doi.org/10.1016/j.culher.2021.02.005.
4. Ali U. et al. GIS-based multi-scale residential building energy modeling using a data-driven approach // Building Simulation 2021. – IBPSA, 2021. – Vol. 17. – pp. 1115-1122.
5. Bertola G. BIM and rapid prototyping for architectural archive heritage //Euro-Mediterranean Conference. – Cham : Springer International Publishing, 2020. – pp. 614-623.
6. Abulencia A. B. et al. Geopolymers as sustainable material for strengthening and restoring unreinforced masonry structures: A review //Buildings. – 2021. – Vol. 11 (11). – pp. 1-8. https://doi.org/10.3390/buildings11110532.
7. Bao Y. et al. The state of the art of data science and engineering in structural health monitoring // Engineering. – 2019. – Vol. 5 (2). – pp. 234-242.https://doi.org/10.1016/j.eng.2018.11.027.
8. GopinathV. K., RamadossR. Review on structural health monitoring for restoration of heritage buildings // Materials Today: Proceedings. – 2021. – Vol. 43. – pp. 1534–1538.https://doi.org/10.1016/j.matpr.2020.09.318.
9. International Council on Monuments and Sites. (1994). The Nara document on authenticity.https://icomosjapan.org/static/homepage/charter/declaration1994.pdf.
10. Mansuri L. et al. Scientometric analysis and mapping of digital technologies used in cultural heritage field //Association of Researchers in Construction Management, ARCOM 2019-Proceedings of the 35th Annual Conference. – 2019. – pp. 255-264.
11. Siu S. L. K. Application of 3D scanning technology in restoration of heritage site damaged by natural disaster //The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. – 2021. – Vol. 46. – pp. 685-691.
12. Re-building a brighter tomorrow.https://www.fiec-ar.eu/2021/en/ (accessed May 12, 2021).
13. KhanS. A., KoçM., Al-GhamdiS. G. Sustainability assessment, potentials and challenges of 3D-printed concrete structures: A systematic review for built

environmental applications // Journal of Cleaner Production. – 2021. – Vol. 303. – pp.1-5.https://doi.org/10.1016/j.jclepro.2021.127027.

14. UNESCO. (n.d.). Thematic indicators for culture in the 2030 agenda.https://whc.unesco.org/en/culture2030indicators/(accessed May 12, 2021).

Citation: Artem Myronenko, "Modern Construction Technologies in the Reconstruction of Architectural Objects: Balance between Authenticity and Innovation", Universal Library of Innovative Research and Studies, 2022; 09-14. DOI: https://doi.org/10.70315/uloap.ulirs.2022.002.