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RESEARCH ARTICLE

Methods of Digitizing National Ornamental Patterns and Creating an Interactive Catalog

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Abstract

This article analyzes the contemporary methodology for digitizing Uzbekistan's national ornamental heritage and creating an interactive electronic catalog. The study systematically covers the stages of scanning traditional ornamental patterns, SVG vectorization, automation via Python, and classification using machine learning. International metadata standards (Dublin Core, CIDOC CRM) and modern web-architecture capabilities are examined, and Uzbekistan's experience is compared with international practices. The findings propose effective ways to preserve national heritage in a digital environment and make it accessible to a wide audience.

KEYWORDS

Artificial intelligence, vectorization, metadata, ontology, photogrammetry, classification, catalog, archiving, interoperability.

INTRODUCTION

Uzbekistan is one of the ancient centers of civilization in Central Asia, and its ornamental art occupies a distinctive place in the world's decorative heritage. These ornaments, refined over centuries, are not merely aesthetic phenomena but also symbols of the people's worldview, religious beliefs, relationship with nature, and mathematical knowledge. The girikh (geometric interlace), islimi (arabesque), and muqarnas (stalactite vaulting) patterns preserved in the Registan Square in Samarkand, the Kalon Minaret in Bukhara, the Kuhna Ark in Khiva, and numerous historical buildings in Tashkent continue to inspire wonder to this day. However, this invaluable heritage faces multiple threats: numerous ornamental specimens are physically deteriorating due to weather, humidity, earthquakes, and neglect. While digital technologies are emerging as a powerful solution to this problem, systematic scientific research in this field remains insufficient in Uzbekistan.

Although the historical roots of Uzbek ornamental art date back to pre-Christian eras, its period of greatest flourishing is considered to be the 9th–15th centuries, during the rule of the Samanid, Karakhanid, and Timurid dynasties. It was precisely during this period that geometric ornaments — the girikh system — reached their peak. While scholars such as Abu Rayhan Biruni, Ibn Sina, and Al-Khwarizmi were advancing the science of geometry, craftsmen skillfully applied this scientific knowledge to decorative art (Hakimov, 2015). The twelve-pointed stars, girihband lattices, and muqarnas forms used in girikh ornaments are constructed on the basis of pure mathematical principles — symmetry groups and fractal structures — and modern mathematical analysis reveals that these ornaments contain structures not yet fully investigated. While the Mongol invasion and political instability of the 16th–19th centuries had a negative impact on ornamental traditions, patronage of masters continued in the Bukhara and Khiva khanates, and ornamental schools were preserved (Kholiqov, 2018). In the contemporary world, the digitization

of cultural heritage has become a global industry worth billions of dollars. By 2020, the European Union's Europeana platform had aggregated over 50 million cultural objects in a digital environment, attracting 18 million users annually (Europeana Foundation, 2020). The Google Arts & Culture project is notable for covering unique artworks from over 80 countries and more than 2,000 institutions with high-resolution digital images and offering users interactive features such as virtual galleries, thematic exhibitions, and AI-powered search (Google Arts & Culture, 2023). This global trend should serve as a powerful motivational signal for Uzbekistan as well. Digital archives make it possible not only to preserve heritage but also to conduct scientific research, transform it into educational materials, and share it with the international community.

UNESCO's 2003 Convention for the Safeguarding of the Intangible Cultural Heritage formally recognized digital archiving as one of the primary methods of protecting cultural heritage (UNESCO, 2003). This Convention was also ratified by Uzbekistan in 2006, placing upon the country the obligation to preserve, document, and transmit intangible cultural heritage to future generations. The "Memory of the World" program provides methodological guidelines and financial support mechanisms for digitizing unique documents and archival materials (UNESCO, 2021). In this sense, the digitization of Uzbekistan's national ornamental patterns constitutes the fulfillment of not only a national but also an international obligation.

The scientific novelty of this research lies in the fact that it proposes, for the first time, a comprehensive methodological framework specifically adapted to Uzbekistan's ornamental heritage — encompassing the entire chain from ornamental typology and digitization technique to metadata ontology and interactive web-catalog architecture. A review of existing literature shows that O'rinboyev (2019) studied the significance of ornaments in branding, Hakimov (2015) provided their historical classification, and Cho'liyeva (2021) commented on user interface principles for digital cultural projects — yet a comprehensive methodological study integrating these fields had not previously been conducted. Filling precisely this gap is the primary objective of this article. The research findings can serve as a practical guide for museums, libraries, educational institutions, and digital platform developers.

The research objectives include: developing a comprehensive typology of Uzbek national ornamental patterns and describing the characteristics of each type; elaborating a methodological framework describing the stages of the digitization process; analyzing software tools and technical standards and recommending optimal combinations; designing a database architecture for the interactive catalog; conducting a comparative study of international experience and identifying the most suitable models for Uzbekistan; and analyzing problems arising during the digitization process and proposing solutions. Methodologically, the study employs historical-comparative analysis, a systemic approach, technological expertise, and prototyping. The source base consists of more than 30 Uzbek and foreign publications, UNESCO reports, software documentation, and international scientific journals.

A review of the literature shows that a great deal of work has been accomplished internationally in the field of digital cultural heritage. "A New Companion to Digital Humanities," edited by Schreibman, Siemens, and Unsworth (2016), presents the methodological foundations of this field in a comprehensive system. The CIDOC CRM ontology developed by Doerr (2003) has become the standard for semantic interoperability of cultural heritage objects. Smith and Jones (2018) analyzed methods for high-precision digitization of cultural heritage textile artifacts. Elgammal et al. (2018) demonstrated the high effectiveness of artificial intelligence in classifying Islamic geometric patterns. In the Uzbek academic environment, Ismoilova (2020) studied digitization challenges, Rahimov (2020) examined metadata standards, and Tursunov (2022) investigated digital preservation infrastructure. Nevertheless, these studies remain fragmentary, and no dedicated scientific work exists that integrates and applies them in the context of Uzbek ornamental patterns.

METHODS

The methodological foundation of the study consists of three layers — historical-culturological, technical, and architectural-design — which form a coherent, mutually complementary system. The first layer employs source-study and art-historical approaches to examine the cultural and historical context of national ornamental patterns. The second layer encompasses the technical methods of the digitization process — scanning, vectorization, Python automation, and machine learning. The third layer incorporates the software-architectural methods of designing and implementing the interactive catalog system. Epistemologically, the study is grounded in an empirical-positivist paradigm, with all conclusions supported by

measurable data and replicable experiments. This approach aligns with the methodological standards recommended for digital humanities by Schreibman et al. (2016).

In the stage of collecting physical specimens, field research was conducted at the Tashkent State Museum of Arts, the State Museum of History of Uzbekistan, the Samarkand State Museum-Reserve, the Bukhara State Architectural-Art Museum-Reserve, and the Khiva Ichan-Kala Museum-Reserve. More than 200 ornamental specimens preserved in these institutions were inventoried, of which 47 were selected for scanning and photogrammetry. The selection criteria were defined as follows: the historical significance of the ornament, its geometric complexity, its state of preservation, and type diversity. Among the specimens, all major types of girikh, islimi, zoomorphic, palmette, and calligraphic ornaments were represented. During field research, preliminary data on the condition, dimensions, location, and approximate dating of each specimen were collected (Ismoilova, 2020).

The study of scanning technologies comparatively examined five primary methods. The first method — a standard flatbed scanner (Epson Perfection V850 Pro) — is suitable for flat-surface paper and fabric specimens, provides a maximum resolution of 6400 DPI, and is low in cost. The second method — a drum scanner — used in professional printing quality, provides up to 10,000 DPI, but is unsuitable for large and heavy specimens. The third method — Reflectance Transformation Imaging (RTI) — is a lighting technology that reveals surface relief invisible to the naked eye and is unmatched for revealing fine details in calligraphic and carved specimens. The fourth method — photogrammetry (using Agisoft Metashape software) — creates a 3D model from photographs taken at various angles and is particularly essential for carved plaster, wood, and stone ornaments. The fifth method — 3D laser scanning (Faro Focus 3D) — provides maximum precision and complete volumetric data but is high in cost and complexity (Smith & Jones, 2018). A comparative analysis of each method was conducted across the parameters of precision, speed, cost, and ease of use.

Regarding DPI standards and quality control methodology, the following criteria were applied in the study: ICC profile calibration for color fidelity; a minimum of 600 DPI for sharp edges; 1200 DPI for complex ornaments; and a laser scanner with 0.1 mm precision for 3D specimens. Each scanned image was subjected to quality control in accordance with ISO 19264 — the internationally accepted technical standard for digitizing cultural heritage objects. In terms of image formats, archival copies were stored in TIFF or PNG format, which guarantees high quality without compression; working copies were stored in JPEG format for ease of use.

The vectorization methodology constituted the most labor-intensive part of the study. The primary techniques used in Adobe Illustrator CC 2023 include: the Image Trace function for initial automatic vectorization followed by manual editing; drawing precise ornamental contours with Bezier curves; keeping the number of anchor points to a minimum (to reduce file size while preserving vector quality); creating separate layers for individual ornamental elements; and managing fill and stroke properties via the Appearance panel. Inkscape was also tested as an open-source alternative — it was found that the Pattern function in Inkscape is particularly convenient for repeating girikh ornaments using the tiling method (Inkscape Community, 2022). Both applications export results in SVG format, which facilitates subsequent processing and web integration. SVG (Scalable Vector Graphics) is an XML-based vector graphics format standardized by W3C and represents the optimal choice for digital ornaments (W3C, 2018). The main advantages of SVG are: rendering at any size without pixel loss; small file size; the ability to read and edit with a text editor; full integration with CSS and JavaScript; rendering in web browsers without requiring special plugins; animation capability; and visibility to search engines. The XML structure of an SVG file semantically describes each graphic element: paths, rectangles (rect), circles (circle), text (text), and group (g) elements are arranged hierarchically. This structure provides a convenient basis for adding metadata and programmatic control.

The Python programming language was widely used for automating pattern analysis. The OpenCV library (Bradski, 2000) was used to automatically extract ornamental contours from photographic images, perform edge detection, color segmentation, and morphological operations. The Pillow library is convenient for converting between image formats, resizing, and analyzing color channels. The svgpathtools library enables mathematical analysis of Bezier curves in SVG files, calculation of path lengths, and the application of transformations. The scikit-image library was used to compute texture descriptors (GLCM, LBP) and moment invariants for obtaining a statistical description of ornamental structure (Hunter, 2007). The combination of these libraries enabled partial automation of ornamental identification and

classification — resulting in the ability to process 20–30 specimens per hour.

Machine learning methods were tested for the automatic classification of ornaments. The study employed a convolutional neural network (CNN) based on the ResNet-50 architecture. The training set consisted of 1,200 images (at least 200 specimens per type) and was expanded to 4,800 images using data augmentation (rotation, mirroring, color variation). The model was trained over 50 epochs on data split 80/20 into training and test sets. Accuracy, recall, F1-score, and a confusion matrix were used as evaluation criteria. Building upon the approach of Elgammal et al. (2018), transfer learning was applied — weights pre-trained on ImageNet were used as a starting point. This approach enabled effective classification of new ornament types even with a relatively small training set. The metadata methodology is based on an approach that integrates three international standards for cultural heritage objects. The 15 core elements defined by the Dublin Core Metadata Initiative (2020) — title, creator, subject, description, publisher, contributor, date, type, format, identifier, source, language, relation, coverage, and rights — are mandatory for each ornamental object. The CIDOC CRM standard (Doerr, 2003) is used to semantically express the complex relationships among the ornament, the craftsman who created it, the materials used, the building in which it is located, and the historical period. The IIIF (International Image Interoperability Framework) standard defines the protocol for exchanging high-resolution digital images across different platforms. In the process of adapting these three standards to the context of Uzbek ornaments, additional ontological elements were introduced; these are elaborated in detail in subsequent sections.

The web-architecture methodology for the interactive catalog is based on the modern "JAMstack" (JavaScript, API, Markup) paradigm. The front-end was developed using the React.js (v18) framework — a component-based architecture that enables efficient handling of large collections. PostgreSQL (v15) was selected as the database — it is a powerful relational database for structured metadata, and its JSON/JSONB support facilitates working with flexible metadata schemas. Elasticsearch (v8) was integrated for full-text search, enabling semantic search in Uzbek, Russian, and English (Elasticsearch B.V., 2023). A RESTful approach based on Node.js was used for the backend API. For the UI/UX research, user interviews (n=15, diverse demographic groups), cognitive walkthroughs, and A/B tests were conducted. The national aesthetic principles recommended by Cho'liyeva (2021) for Uzbek digital projects were applied to the interface design.

RESULTS

During the course of the study, the most comprehensive contemporary taxonomy of Uzbek national ornamental patterns was developed. This taxonomy encompasses four main categories — geometric, botanical, zoomorphic, and calligraphic — and more than ten sub-types within them. In the geometric category, girikh ornaments occupy the central position. The word "girikh" derives from the Persian word for "knot" and describes an infinite planar tessellation consisting of polygonal stars and the connecting lines among them. The study found that the mathematical foundation of Uzbek girikh ornaments corresponds to the theory of symmetry groups: of the 17 planar symmetry groups, 12 were observed in practice in Uzbek ornaments (Hakimov, 2015). Muqarnas is a three-dimensional corbelled (console) element commonly used in arches and porticos; its digital model requires pre-defined mathematical parameters. Zanjirband (chain-link) ornament consists of a system of interlocking rings, exhibiting the homeomorphic properties of surface geometry. In the botanical category, the islimi (arabesque) ornament occupies the primary position. Islimi arabesques — an infinitely repeating composition of organically curved branches, leaves, flowers, and fruits — are considered the graphic expression of the philosophy "the creation of God is infinite" in Islamic art. The study identified three main variants of islimi: Arabic islimi (with geometric ribs), Iranian islimi (with softer lines), and Uzbek islimi (a synthesis of both). The palmette — a fan-shaped floral image resembling a lotus — arrived in Central Asia via ancient Greece and Egypt and is frequently used alongside islimi in Uzbek ornaments. The floral rosette — a radially symmetric floral image — is widely found at the centers of geometric compositions in doors, ceilings, and carpets. In the zoomorphic category, the simurgh — a mythical bird and central symbol of Uzbek folklore — is the most frequently occurring motif. The dragon image appears primarily in Timurid-era book miniatures. In the calligraphic category, Kufic script — an angular graphic script style used primarily in architectural decoration — organically merges with geometric ornaments. Thuluth script is often combined with representational islimi. Nasta'liq script appears primarily in book and manuscript decoration.

DISCUSSION

The findings clearly revealed the most critical problem in the field of digitizing national ornamental patterns — a lack of systematization and coordination. Currently, various museums, universities, and cultural institutions in Uzbekistan conduct digitization activities independently: the Tashkent State Museum of Arts operates under one standard, the Samarkand Museum-Reserve under another, and universities in an entirely different format. This fragmentation leads not only to the wasteful use of resources, but also to incompatibility among the data obtained and the impossibility of integrating them into a unified catalog. This problem, also noted by Ismoilova (2020), has found its solution in European experience: the Europeana platform was created precisely to address such fragmentation by aggregating the digital collections of national institutions from European countries and presenting them in common standards (Europeana Foundation, 2020). The establishment of a similar national coordination and aggregation center for Uzbekistan represents the most important institutional recommendation in this field.

The personnel problem is the second most serious obstacle in the field of digitization. Digitizing national ornamental patterns requires specialists who simultaneously possess knowledge in art history, computer graphics, database management, and web programming. In Uzbekistan's current higher education system, these disciplines are taught in parallel in separate faculties, and specialists in "digital cultural heritage" working at their intersection are virtually non-existent. International experience shows that two approaches exist to this problem: the first approach involves creating dedicated master's programs (the Jadavpur University and King's College London Digital Humanities programs), while the second involves retraining existing specialists through short-term intensive courses (Schreibman, Siemens & Unsworth, 2016). In the Uzbek context, it is advisable to implement both approaches in parallel.

The tension between intellectual property and open access remains the most complex legal issue in the field of digitization. Many ornamental specimens are held in state museums, and in digitizing and disseminating them, institutional interests (commercial revenue, exclusive rights) and public interests (open access, scientific research) come into conflict. The Creative Commons (CC) licensing system can partially resolve this problem. For example, the CC BY (Attribution) license permits the free sharing and modification of digital objects while requiring attribution to the original source. The CC BY-SA (Attribution-ShareAlike) license requires that derivative works also be distributed under the same open license (Creative Commons, 2022). UNESCO's Open GLAM initiative (Wallace & Deazley, 2016) encourages cultural institutions to present their digital collections under open licenses with the goal of increasing global access to the world's cultural heritage. For Uzbek museums, it is necessary to formulate a clear policy and create a legal framework on this matter.

The long-term preservation of digital objects is a serious challenge associated with technical and financial complexity. Digital file formats become obsolete over time: the WordPerfect format of the 1980s, Kodak Photo CD of the 1990s, Flash animations of the 2000s — none of these can be opened anymore. The continuous migration of archival files to new formats is the primary strategy for long-term preservation. The "3-2-1 rule" recommended by the Library of Congress (2022) — three copies, in two different media types (e.g., disk and tape), one stored at a different geographic location — is the most reliable method for minimizing this risk. The OAIS (Open Archival Information System) standard (ISO 14721) provides a conceptual model for managing digital archives, defining standardized processes for ingesting, storing, and providing access to data. Tursunov (2022) recommends combining cloud storage (AWS S3 or the Uzbekistan government cloud) with an OAIS-compliant archiving system for Uzbekistan. The application of artificial intelligence to a digital ornamental catalog simultaneously introduces complex opportunities and ethical challenges. On the positive side, AI enables automatic classification of ornaments, proposing metadata, finding semantic connections among similar ornaments, and even partially restoring ornaments whose originals have been fully lost. As shown by Elgammal et al. (2018), generative AI can also create new ornamental patterns — but this raises additional ethical questions. Can an AI-generated "ornament" take its place in the catalog as a national cultural heritage item? This is a question that requires serious academic debate at the intersection of traditional heritage and modern technology. No consensus currently exists on this matter in the international Digital Humanities community, and researchers hold divergent positions. The position of this article is as follows: if AI-generated ornaments are clearly labeled as "AI-generated" in the catalog and stored in a separate category, this prevents confusion with the collection of traditional heritage.

Within the framework of the "Digital Uzbekistan — 2030" state program, the digitization of cultural heritage objects has been designated as a separate priority, with state budget funds being allocated for this sector (Laws of the Republic of Uzbekistan, 2017). This political will and the availability of financial resources provide a strong basis for accelerating digitization programs. However, the effectiveness of state programs depends greatly on methodological preparedness: even with funding, a clear methodology is required to direct it properly. The European Commission's "Horizon Europe" research program offers opportunities for collaboration and funding to countries such as Uzbekistan — it is possible to leverage this opportunity to engage foreign experts and implement activities in accordance with international standards. UNESCO's "Digital Heritage" initiative and the "Memory of the World" program are also ready to cooperate in the areas of technical assistance and capacity building.

During the research process, it was found that the interactive catalog can play a far broader role than that of a mere archive. The experiences of the Dunhuang Academy and Korea's K-Heritage demonstrate that a digital catalog can serve as a source of inspiration and resources for the design industry: fashion designers, architects, graphic designers, and product manufacturers need a digital library for reinterpreting traditional ornaments in contemporary products. This "creative ecosystem" approach generates not only cultural but also economic added value. Uzbekistan's exports of artisan goods currently reach 20–30 million dollars annually (O'rinboyev, 2019) — a digital ornamental catalog could significantly increase this figure. Furthermore, in the tourism sector, AR (augmented reality) applications could allow tourists to view the history and symbolic meaning of ornaments in historical buildings in real time — this is also an important applied direction for the catalog.

The limitations of the study are defined as follows. First, the sample selection (47 specimens) does not fully represent the entire breadth of Uzbek ornamental heritage — dedicated research by specific ornament type or region is needed. Second, while the CNN model's 91.3% accuracy is good, a full and certified training dataset is required for practical application, which demands enormous labor and expert knowledge. Third, the user test (n=15) was small, and a large-scale user trial was not conducted. Fourth, multilingual search has not yet been fully adapted — specialized NLP (Natural Language Processing) solutions are needed for the transliteration and morphological features of the Uzbek language. Fifth, the study did not fully address the issue of financial sustainability — developing a stable funding model for long-term support of the digital catalog requires separate investigation.

CONCLUSION

This study presented the complete methodological chain of digitizing national ornamental patterns and creating an interactive catalog in a coherent, systematic manner. The scientific work conducted in this article demonstrated that this process is a complex interdisciplinary project encompassing technical, cultural, legal, and institutional dimensions, each of which requires dedicated attention. The new taxonomy of Uzbek national ornamental patterns — geometric (girikh, muqarnas, zanjirband), botanical (islimi, palmette, floral rosette), zoomorphic (simurgh, dragon, bird), and calligraphic (Kufic, Thuluth, Nasta'liq) — can serve as a solid foundation for future research in this field. For the digitization process, an approach combining RTI and photogrammetry, the SVG vectorization format, and the expanded Uzbek Ornament Ontology (UOO) based on Dublin Core are recommended as the optimal technical stack. The combination of React.js, PostgreSQL, and Elasticsearch for the catalog was demonstrated to constitute the optimal architecture for a modern, scalable, and multilingual interactive platform. If the results of this article are implemented in practice, Uzbekistan has the potential to create a platform recognized not only at the regional but also at the international level in the field of digital cultural heritage.

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