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Technical Assessment of Neuro-Symbolic AI for Cultural and Fractal Analysis of Batik Motifs

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ABSTRACT

This study presents a structured literature review of Neuro-Symbolic Artificial Intelligence (NSAI) approaches for extracting cultural semantics and fractal features from Batik motifs. A structured multi-database screening (2015–2025) yielded 69 peer-reviewed studies, which were synthesized thematically. The review identifies three key findings: existing vision-based models generally lack explicit mechanisms for encoding intangible cultural rules; hybrid neural–symbolic approaches demonstrate improved interpretability and compositional reasoning; and fractal-based descriptors show promise for representing culturally grounded motif structures. Based on these findings, this study proposes a conceptual NSAI framework that combines symbolic knowledge representations with fractal feature modeling, without empirical validation at this stage. The synthesis highlights potential applications in motif recognition, generative motif modeling, and computer-assisted cultural heritage preservation. Overall, NSAI offers a feasible and explainable conceptual framework for modeling Batik's intangible cultural knowledge.

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1. INTRODUCTION

Batik, recognized by UNESCO in 2009 as an Intangible Cultural Heritage of Humanity, constitutes a cultural knowledge system in which visual motifs encode philosophical values, social norms, and historical narratives rather than serving merely decorative purposes [1], [2]. Recent advances in computer vision and deep learning, particularly Convolutional Neural Networks (CNNs), have enabled high-accuracy classification of Batik motifs across various regional styles. However, these models largely function as black boxes [3], [4], providing limited insight into how visual features relate to the symbolic meanings and cultural rules embedded within Batik motifs.

This limitation highlights a representational gap between quantitative visual descriptors and symbolic cultural reasoning. Semiotic studies have extensively explored Batik motifs using qualitative frameworks, such as Peircean semiotics [5], to interpret philosophical and cultural meanings, yet these interpretations are rarely formalized into computational representations suitable for AI integration [6]. Conversely, studies in computer vision and fractal analysis successfully capture geometric characteristics—such as texture, self-similarity, and fractal dimension—but treat Batik motifs primarily as visual objects, detached from their cultural semantics and contextual constraints.

To address this gap, Neuro-Symbolic Artificial Intelligence (NSAI), which integrates neural perception with symbolic reasoning, offers a promising conceptual approach for developing explainable and culturally grounded AI systems. Accordingly, this study conducts a Systematic Literature Review (SLR) following the PRISMA 2020 protocol to map existing symbolic and quantitative research on Batik motifs, identify integrative gaps, and propose a conceptual NSAI framework that combines fractal-based visual descriptors with formalized symbolic knowledge [7]. This work contributes a theoretically grounded roadmap for future research toward interpretable AI models aligned with Batik's intangible cultural heritage.

2. RESEARCH METHOD

2.1 Systematic Review Protocol and Research Questions

This study employs a Systematic Literature Review (SLR) to synthesize research across heterogeneous domains, including semiotics, computer vision, fractal geometry, and neuro-symbolic artificial intelligence. The review follows the PRISMA 2020 protocol to ensure transparency, reproducibility, and methodological rigor in study identification, screening, and reporting [8]. The SLR approach is particularly suitable for addressing the representational gap between symbolic cultural knowledge and quantitative visual modeling identified in the introduction.

The review is guided by three research questions: (RQ1) how Batik's symbolic meanings are extracted and represented using computationally relevant approaches; (RQ2) what quantitative descriptors—particularly fractal and visual features—are used to analyze Batik motifs; and (RQ3) how neuro-symbolic AI models can conceptually integrate symbolic and quantitative representations within a cultural heritage context.

2.2 Data Sources, Search Strategy, and Selection Criteria

The literature search was conducted across five major academic databases—Scopus, Web of Science, ScienceDirect, IEEE Xplore, and Dimensions—covering publications from January 2015 to December 2025. Domain-specific Boolean queries were adapted to each database to capture studies related to Batik, traditional textile analysis, computer vision, fractal descriptors, symbolic modeling, and neuro-symbolic AI. To mitigate regional bias, supplementary searches using Google Scholar and citation chaining were performed to identify relevant local cultural studies, although formal inclusion was restricted to peer-reviewed sources.

Inclusion criteria comprised peer-reviewed articles written in English, published within the defined timeframe, and demonstrating methodological relevance to symbolic, fractal, computer-vision, or integrative AI approaches. Exclusion criteria eliminated duplicates, non-technical commentaries, and studies lacking methodological transparency. From an initial set of 1,582 records, the screening process resulted in 69 studies included in the final synthesis.

A complete summary of database-specific query strings, timeframes, and hit counts is provided in Table 1.

Table 1: Literature Search Strategy and Initial Screening Summary

Database	Example Search Query (Representative)	Timeframe	Initial Hits
Scopus	TITLE-ABS-KEY ("batik" AND "computer vision" AND "pattern recognition") AND PUBYEAR > 2014 AND PUBYEAR < 2026	2015–2025	247
ScienceDirect	("batik" AND "computer vision")	2015–2025	300
IEEE Xplore	("neuro-symbolic AI" AND "cultural heritage") OR ("fractal dimension" AND "traditional textiles")	2015–2025	235
Web of Science	TS=("batik" AND "fractal dimension" AND "traditional textiles")	2015–2025	400
Dimensions	"batik" AND ("neuro-symbolic" OR "fractal dimension" OR "computer vision")	2015–2025	400
Total			**1,582**

The search strings presented in Table 1 represent simplified examples of the actual queries used. Minor adaptations were applied across databases to accommodate differences in indexing syntax and search interfaces.

2.3 Data Extraction, Categorization, and Quality Assessment

Data extraction focused on capturing methodological characteristics, representational strategies, and analytical contributions of the selected studies [9]. A three-layer analytical framework—Symbolic (S), Fractal/Vision (F), and Integration (I)—was employed to organize the literature and support cross-domain thematic synthesis [10], [11]. Within each layer, open coding was applied to identify recurring concepts, techniques, and representational patterns rather than imposing rigid a priori categories.

Study quality was assessed using the Mixed Methods Appraisal Tool (MMAT) 2018 to accommodate the multidisciplinary nature of the corpus, which includes qualitative semiotic analyses, quantitative computer-vision studies, and mixed-method research [12]. To enhance reliability, the screening and coding processes were conducted independently by two reviewers. Inter-rater agreement was evaluated using Cohen's kappa ($\kappa = 0.78$), indicating substantial consistency [13]. MMAT scores were used descriptively to inform interpretation rather than as exclusion thresholds.

2.4 Data Synthesis and Analytical Approach

A narrative thematic synthesis was adopted to integrate findings across symbolic, quantitative, and integrative research streams. Given the heterogeneity of data types, statistical meta-analysis was not feasible. Instead, the synthesis focused on identifying representational disconnections between symbolic cultural interpretations and quantitative visual descriptors, as well as mapping integration opportunities highlighted in neuro-symbolic and multimodal studies [14].

The analytical emphasis was placed on distinguishing evidence-based findings from conceptual proposals, thereby maintaining the integrity of the systematic review while supporting the development of a theoretically grounded neuro-symbolic framework for Batik motif analysis.

3. RESULT AND ANALYSIS

3.1 Study Selection and Bibliometric Overview

The PRISMA-guided screening process identified 1,582 records retrieved from major academic databases, including Scopus, Web of Science, IEEE Xplore, ScienceDirect, Dimensions, and supplementary sources. After duplicate removal (N = 947) and title–abstract screening, 126 articles were assessed for full-text eligibility. Following methodological quality appraisal and relevance assessment, 69 peer-reviewed studies were included in the final synthesis. Inter-rater reliability analysis yielded a Cohen's kappa value of $\kappa = 0.78$, indicating substantial agreement between reviewers and reinforcing the robustness of the screening process.

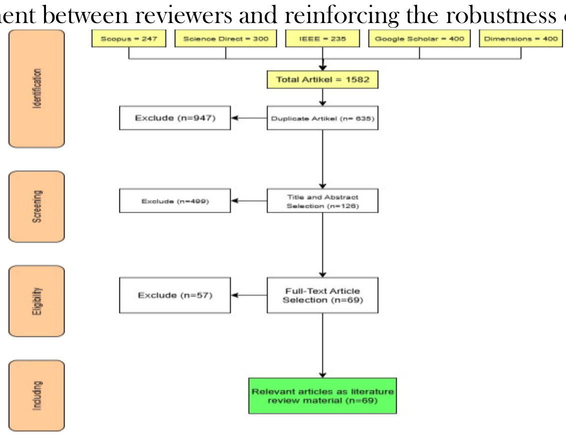
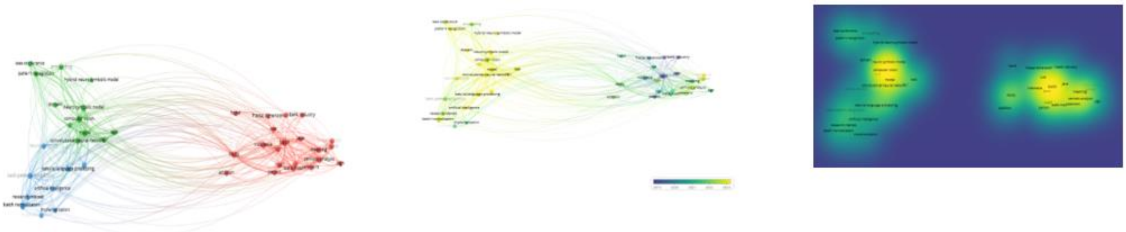


Figure 1: PRISMA Diagram of the Article Selection Flow

Beyond documenting the screening process, bibliometric mapping was conducted to examine the intellectual structure and research trends within the selected literature.

Bibliometric mapping using VOSviewer provides a high-level overview of the intellectual structure of Batik-related research (Figure 2). The keyword co-occurrence network reveals two dominant and weakly connected clusters. The first cluster is centered on symbolic and cultural interpretations, characterized by terms such as batik, meaning, semiotic analysis, and Java. The second cluster is dominated by computational approaches, including computer vision, CNN, model, and image processing. Overlay visualization by publication year indicates a recent surge (2022–2024) in deep learning–based Batik studies, while density visualization confirms the absence of integrative terms linking symbolic interpretation with quantitative visual modeling. Notably, no Batik-specific neuro-symbolic AI implementation was identified (N = 0), substantiating the core research gap addressed in this review.



(a) Batik Research Clusters (b) VOSviewer Co-occurrence by Year (c) Density Visualization

Figure 2: Bibliometric Visualization (a–c)

Figure 2 summarizes the bibliometric landscape of Batik-related research based on keyword co-occurrence analysis. The network visualization (Figure 2a) reveals two dominant and weakly connected clusters, representing symbolic–cultural studies and computational computer-vision approaches. The overlay visualization by publication year (Figure 2b) indicates a recent shift toward deep learning–based Batik research since 2022, while symbolic studies remain relatively stable. The density visualization (Figure 2c) further confirms the absence of integrative terms linking symbolic interpretation with quantitative modeling. Notably, neuro-symbolic AI–related keywords do not appear in close proximity to Batik-related terms, supporting the finding that Batik-specific NSAI implementations remain absent (N = 0).

3.2 Cross-Domain Thematic Findings

a. Symbolic and Semiotic Studies

Semiotic research consistently treats Batik motifs as symbolic systems that encode philosophical values, social norms, and cultural identity. The majority of the 29 symbolic studies adopt Peircean or related semiotic frameworks, interpreting motifs through sign relations such as icon, index, and symbol. These studies provide rich cultural insights—ranging from expressions of morality, religiosity, and social hierarchy to representations of regional identity—but remain predominantly qualitative [15]. Symbolic meanings are articulated narratively and are rarely formalized into computationally actionable structures such as logical predicates, ontologies, or knowledge graphs. Consequently, while semiotic studies establish semantic depth, they offer limited direct interoperability with AI-based reasoning systems [16], [17]. The complete list of symbolic studies is provided in Appendix A.

b. Computer Vision and Fractal-Based Approaches

In contrast, quantitative studies focus on the automated recognition and classification of Batik motifs using computer vision and fractal geometry[18]. Convolutional Neural Networks (CNNs), often enhanced through transfer learning with architectures such as VGG, ResNet, MobileNet, and Vision Transformers, dominate this research stream [19], [20]. These models achieve high classification accuracy across diverse regional Batik datasets. Complementary studies employ feature engineering techniques—such as GLCM texture descriptors, SIFT/AKAZE local features, and fractal dimension estimation—to capture geometric complexity and self-similarity in motifs. While these approaches demonstrate strong numerical performance and robustness, they treat Batik motifs primarily as visual objects. Cultural meaning, symbolic constraints, and philosophical interpretations remain external to the computational pipeline. Detailed listings of computer vision and feature-engineering studies are provided in Appendices B and C.

c. Natural Language Processing and Knowledge Representation

Only a limited subset of studies explores the use of Natural Language Processing (NLP) or knowledge representation for cultural meaning extraction. Existing work primarily focuses on keyword-based analysis, document categorization, or general cultural knowledge graph construction rather than motif-specific semantic relation extraction [9]. Advanced NLP techniques—such as named entity recognition, relation extraction, or Large Language Model (LLM)–assisted symbolic reasoning—are largely absent in Batik-focused research [21]. As a result, the potential to transform narrative cultural descriptions into structured symbolic knowledge remains underexplored. The complete list of NLP - and knowledge-graph–related studies is presented in Appendix D.

3.3 Synthesis of Gaps and Integration Opportunities

The thematic synthesis reveals a persistent representational divide between symbolic cultural knowledge and quantitative visual modeling. Semiotic studies generate discrete, meaning-rich interpretations that lack formal computational structure, while computer vision and fractal approaches produce continuous numerical representations devoid of cultural semantics. These two research trajectories progress in parallel with minimal methodological interaction, resulting in limited explainability and cultural grounding in existing AI-based Batik systems.

This disconnection highlights the absence of integrative models capable of reasoning jointly over geometric form and symbolic meaning. Neuro-Symbolic Artificial Intelligence (NSAI) emerges as a theoretically suitable paradigm to bridge this gap by combining neural perception with symbolic reasoning. The bibliometric and thematic evidence confirms that such integration has not yet been realized in Batik research (N = 0). Consequently, the findings of this review directly motivate the proposed conceptual NSAI framework, which positions fractal and visual descriptors as neural inputs and symbolic cultural rules—extracted via computational semiotics and NLP—as logical constraints within a unified reasoning architecture [22].

3.4 Discussion

3.4.1 Findings from the Literature

The cross-cluster synthesis of symbolic, computer-vision, fractal, and NLP/KG studies reveals a structural gap between discrete cultural knowledge and continuous visual descriptors. Semiotic and symbolic studies (Cluster S) contribute rich qualitative interpretations of Batik motifs as sign systems, yet rarely translate these insights into formal computational representations such as logic rules, ontologies, or queryable knowledge graphs. Conversely, computer-vision and fractal/feature-extraction studies (Cluster F) achieve strong performance in motif classification and pattern discrimination but typically treat motifs as purely visual objects without encoding their cultural constraints or meanings.

Quantitatively, the review shows that 11 of 15 CV-oriented studies rely on CNN-based architectures, confirming the predominance of deep neural models in Batik recognition tasks, while 7 of 16 feature-extraction studies employ fractal descriptors and 6 emphasize texture statistics. At the same time, none of the 69 included studies implements a Batik-specific Neuro-Symbolic AI model (N = 0), and only a small subset of NLP/KG works goes beyond representation to support reasoning. This pattern indicates that symbolic and computational contributions remain parallel and loosely coupled rather than integrated into coherent, interpretable AI systems for Batik.

3.4.2 Proposed NSAI Framework (Conceptual)

Building on these findings, this subsection outlines a conceptual NSAI framework designed to bridge symbolic and metric representations for Batik motifs. The framework is not yet implemented or empirically validated in Batik contexts; instead, it is proposed as a roadmap grounded in the identified methodological gaps and informed by existing neuro-symbolic architectures in other domains.

The core idea is to combine a visual feature extractor with a symbolic knowledge base and a logic-based reasoning component. On the visual side, a CNN or related computer-vision model produces feature vectors that include fractal descriptors (e.g., FD estimates obtained via DBC) and texture statistics (e.g., GLCM features) characterizing motif complexity and structure [23]. On the symbolic side, a cultural knowledge base encodes motif categories, associated meanings, usage rules, and contextual constraints using predicates, relations, and logical axioms derived from semiotic and ethnographic studies [24], [25].

An illustrative example involves the Kawung motif, traditionally associated with concepts such as balance, justice, and social restraint. Visual features capture the radial symmetry, repetitive circular shapes, and fractal-like scaling patterns, while the symbolic layer encodes rules such as “Kawung is associated with self-control” or “Kawung historically appears in courtly attire”. A neuro-symbolic model can then reason over both the feature-based evidence and symbolic constraints to generate explanations like: “This motif is classified as Kawung because it exhibits circular repetition with FD in a given range and matches symbolic rules associated with balance and restraint.” The example is intended as a conceptual illustration of how NSAI could operate rather than as a direct empirical result from the reviewed corpus.

3.4.3 Mathematical and Technical Implications

Formally, $(X \subset R^d)$ denote the feature space obtained from Batik images, where each $vector\ (x \in X)$ concatenates fractal descriptors (e.g., FD estimates) and texture features (e.g., GLCM statistics) extracted from a given motif [26], [27]. $Let\ (V)$ be a symbolic vocabulary of predicate symbols (e.g., Motif(x), Sacred(x), Represents(x, Justice), Region(x, Java)), and $let(\mathcal{I}(V))$ denote the set of possible interpretations of these predicates over a domain of Batik objects. A neuro-symbolic model defines a mapping

$$(I: X \to \mathcal{I}(V))$$

that associates each feature $vector\ (x)$ with truth values for the predicates in (V), subject to a set of logical constraints (Φ) encoding cultural rules (e.g., Sacred(x) → NotForCasualUse(x)).[34]

- $X \subset R^d$: the feature space containing FD, GLCM, and related descriptors.
- V: the symbolic vocabulary (the set of predicate symbols).
- I(V): the set of interpretations of the vocabulary V.
- I: X → I(V): the mapping from feature vectors to interpretations, constrained by a set of rules Φ.

In practice, architectures such as Logic Tensor Networks implement (I) by jointly learning feature representations and predicate truth assignments so that both the empirical data (images, FD/GLCM vectors) and the logical constraints (Φ) are approximately satisfied [28]. This provides a mathematically grounded mechanism for linking continuous fractal/texture spaces to discrete symbolic reasoning about Batik motifs. From an applied mathematics perspective, understanding the stability and bias properties of FD estimators, as well as the geometry of the induced feature space (X), is crucial for designing robust thresholds, similarity measures, and logical predicates that remain meaningful under variations in resolution, noise, and motif deformations, [29].

By clearly separating evidence-based findings (Section 3.4.1) from the conceptual NSAI proposal and its technical implications (Sections 3.4.2–3.4.3), the discussion maintains the integrity of a systematic review while outlining a grounded roadmap for future neuro-symbolic Batik research.

4. CONCLUSION

This Systematic Literature Review synthesized 69 studies across semiotics, fractal geometry, computer vision, and emerging neuro-symbolic technologies to evaluate how Batik's symbolic meanings and geometric structures can be computationally represented. The findings address each research question (RQ) as follows.

4.1 Key Findings and Contributions

To align the conclusions with the objectives of this review, the synthesized findings are organized according to the three research questions (RQ1–RQ3):

a. **Regarding RQ1 (symbolic and cultural modeling):**
Symbolic knowledge derived from Semiotics and NLP studies—such as cultural meanings, philosophical interpretations, and narrative rules—remains predominantly qualitative and text-based. These representations lack formalization into logical predicates or structured ontologies, limiting their integration into current Batik-related AI systems.

b. **Regarding RQ2 (fractal and quantitative modeling):**
Batik motifs exhibit measurable geometric and fractal characteristics captured through GLCM, HOG, FD, and related descriptors. While these quantitative representations support high classification performance, they lack cultural interpretability and cannot articulate reasoning that aligns with Batik's symbolic semantics.

c. **Regarding RQ3 (integration opportunities):**
The literature reveals a clear multimodal disconnection between symbolic cultural rules and fractal/metric visual descriptors. This integrative gap motivates the conceptual development of a Neuro-Symbolic AI (NSAI) framework as proposed in this review. The framework remains theoretical and untested, and thus requires empirical validation through future experimentation.
Overall, this review contributes by:
   a. Reframing Batik AI research toward explainable and culturally grounded reasoning, and
   b. Offering a conceptual roadmap for unifying symbolic/logical rules and fractal/metric inputs within NSAI architectures. The primary contribution of this paper is to frame and structure the problem space for NSAI in Batik, rather than to present an implemented or empirically validated system.

4.2 Theoretical and Practical Implications

a. Theoretical Implications

This review highlights the need for cognitive performance evaluation in cultural-AI systems: not only predictive accuracy but also interpretability, cultural trustworthiness, and alignment with symbolic meaning. Conceptually, the NSAI perspective suggests that fractal descriptors—typically treated as statistical features—can be reconceptualized as elements of a feature space that support symbolic reasoning when linked to logical predicates and constraints. This reframing provides a theoretical foundation for future NSAI experimentation, though such transformations have not yet been empirically realized in Batik contexts.

b. Practical Implications

a) **Explainable Authentication and Education:**
A future NSAI-based Batik classification system could provide human-understandable reasoning paths explaining why a motif is authentic, rare, or culturally significant. This capability may enhance the credibility of AI tools used by educators, curators, or heritage practitioners. Realizing this potential will require domain-specific pilot testing and careful evaluation of both accuracy and interpretability [30].

b) **Structured Knowledge Base Development:**
This review identifies the need to construct a Heritage Logic Base formalizing Batik's compositional and semantic rules [31]. Such a resource would support NSAI reasoning and may extend to broader digital heritage preservation domains, including textile traditions, ornamental art, and symbolic iconography across Southeast Asia.

4.3 Limitations

Several limitations should be acknowledged:

a. **Humanities–Technical Divide:**
Semiotic studies prioritize cultural meaning, while AI studies emphasize statistical patterns. These epistemic differences constrain direct integration of semantic and computational perspectives and limit the availability of multimodal datasets that combine both [32], [33].

b. **Absence of Batik-Specific NSAI Implementations:**
Although related LLM–KG integration research is emerging, no direct NSAI implementations for Batik were found [21]. The NSAI framework proposed in this paper is therefore conceptual rather than empirically validated, and its feasibility must be tested in future work [34].

c. **Lack of Standardized Symbolic Representations:**
Semiotic interpretations remain narrative and non-formalized, preventing seamless integration into NSAI architectures. Establishing standardized symbolic structures—such as ontologies, rule sets, and predicate vocabularies—is a prerequisite for future system development [21].

These limitations highlight that effective NSAI integration—particularly at the symbolic level—remains an emerging research frontier.

4.4 Recommendations for Future Research (Novelty)

This review highlights several conceptual opportunities for advancing the integration of symbolic cultural knowledge and quantitative fractal descriptors within Batik-related AI research. As no Batik-specific NSAI implementations currently exist, future investigations should focus on empirically operationalizing the theoretical directions identified in this study. Three primary avenues of exploration are proposed:

a. **Architectural Focus (Technical Novelty):**
Future research should develop and experimentally evaluate prototype NSAI models—such as Logic Tensor Networks or LLM–KG augmented systems—to test bimodal integration of fractal/metric features with symbolic/logical rules. Small-scale pilot projects and benchmark experiments on Batik datasets will be necessary to validate feasibility and to study how logical constraints interact with continuous feature representations.

b. **Formalization Focus (Methodological Novelty):**
Dedicated efforts are required to formalize Batik's compositional and semantic rules into ontologies or logical predicate structures. This Heritage Logic Base will serve as the symbolic backbone for NSAI reasoning and may generalize to other cultural heritage domains. From an applied mathematics perspective, this also raises questions about how to encode such rules in differentiable logic formalisms and how to measure consistency between symbolic constraints and data-driven predictions.

c. **Feature Focus (Domain Novelty):**
Future work should explore fractal-sensitive feature extraction methods—such as FD, L-systems, or geometric decomposition—as neural inputs within NSAI frameworks. This opens mathematically interesting problems, including the design of loss functions that couple logical constraint satisfaction with deviations in fractal or texture measures, and the stability analysis of NSAI models when trained on fractal descriptors that are sensitive to resolution, quantization, and noise.

Collectively, these recommendations guide the transformation of the NSAI conceptual roadmap into practical, tested models, standardized symbolic resources, and culturally grounded computational tools. At the same time, they point to a class of applied mathematics problems at the interface of logic, fractal analysis, and learning theory, with potential impact beyond Batik and into the broader field of digital heritage preservation.

5. REFERENCE

[1] A. Akbar, M. Perdana, M. Fajar, and A. Muis Mappalotteng, "Enhancing Batik Classification Leveraging CNN Models and Transfer Learning," *International Journal On Informatics Visualization*, vol. 9, no. 3, pp. 1033–1040, 2025.

[2] I. B. K. Manuaba and V. J. Basiroen, "Comparison Study Of Image Augmentation On Modified CNN Architecture For Indonesian Lasem-Batik's Motifs," *ICIC Express Letters*, vol. 17, no. 4, pp. 409–417, Apr. 2023, doi: https://doi.org/10.24507/icicel.17.04.409.

[3] S. P. Nan Quddus, A. Cahyana, A. M. Falah, and M. R. Nagara, "Transformasi Visual dan Makna Simbolik Motif Batik Parang Rusak dalam Konteks Budaya Modern," *Serat Rupa: Journal of Design*, vol. 9, no. 2, pp. 205–216, Jul. 2025, doi: 10.28932/srjd.v9i2.11994.

[4] M. A. El Youssr, M. El Hamlaoui, and Y. Laghouaouta, "From Black Box to Glass Box: A Model-Driven Engineering Approach for Explainable AI," in *Lecture Notes in Networks and Systems*, vol. 1313 LNNS, Springer Science and Business Media Deutschland GmbH, 2025, pp. 472–483. doi: https://doi.org/10.1007/978-3-031-94623-3_41.

[5] A. Z. Khoirunisa and Muhajirin, "Semiotika Batik Motif Weton Indonesia Karya Omah Kreatif Dongaji dengan Pendekatan Charles S.Peirce," *Sungging : Jurnal Seni Rupa, Kriya, Desain dan Pembelajarannya*, vol. 1, no. 2, pp. 147–158, 2022.

[6] O. Ida Ayu Made Wedasuwari and I. Wayan Rasna, "Analisis Semiotika Puisi Pesona Batik Karya Uswatun Khasanah sebagai Pendekatan Pemahaman Makna," *Media Bina Ilmiah*, vol. 15, no. 3, pp. 4163–4168, Oct. 2020, [Online]. Available: http://ejurnal.binawakya.or.id/index.php/MBI

[7] T. Chandrasekaran, S. Ramisetty, and M. R. Pulicharla, "Neurosymbolic AI: Bridging neural networks and symbolic reasoning," *World Journal of Advanced Research and Reviews*, vol. 25, no. 1, pp. 2351–2373, Jan. 2025, doi: 10.30574/wjarr.2025.25.1.0287.

[8] P. Tugwell and D. Tovey, "PRISMA 2020," Jun. 01, 2021, *Elsevier Inc.* doi: 10.1016/j.jclinepi.2021.04.008.

[9] R. Azhar, D. Tuwohingide, D. Kamudi, Sarimuddin, and N. Suciati, "Batik Image Classification Using SIFT Feature Extraction, Bag of Features and Support Vector Machine," in *Procedia Computer Science*, Elsevier, 2015, pp. 24–30. doi: 10.1016/j.procs.2015.12.101.

[10] D. Wijaya and A. R. Widiarti, "Batik classification using KNN algorithm and GLCM features extraction," in *E3S Web of Conferences*, EDP Sciences, Jan. 2024. doi: 10.1051/e3sconf/202447502012.

[11] A. A. Kasim, R. Wardoyo, and A. Harjoko, "Feature extraction methods for batik pattern recognition: A review," in *AIP Conference Proceedings*, American Institute of Physics Inc., Jul. 2016. doi: 10.1063/1.4958503.

[12] Q. N. Hong *et al.*, "Improving the content validity of the mixed methods appraisal tool: a modified e-Delphi study," *J Clin Epidemiol*, vol. 111, pp. 49-59.e1, Jul. 2019, doi: 10.1016/j.jclinepi.2019.03.008.

[13] S. Sun, "Meta-analysis of Cohen's kappa," *Health Serv Outcomes Res Methodol*, vol. 11, no. 3–4, pp. 145–163, Dec. 2011, doi: 10.1007/s10742-011-0077-3.

[14] A. Gomaa and M. Feld, "Towards Adaptive User-centered Neuro-symbolic Learning for Multimodal Interaction with Autonomous Systems," in *ACM International Conference Proceeding Series*, Association for Computing Machinery, Oct. 2023, pp. 689–694. doi: 10.1145/3577190.3616121.

[15] S. Maziyah, Mahirta, and S. Atmosudiro, "Makna Simbolis Batik pada Masyarakat Jawa Kuna," *Paramita*, vol. 26, no. 1, pp. 23–32, 2016.

[16] M. H. S. Ar-Rasyid and P. M. Lestari, "Motif Batik Ambarawa (Kajian Semiotika)," *Kawruh: Journal of Language Education, Literature and Local Culture*, vol. 6, no. 1, pp. 1–10, Apr. 2024, doi: 10.32585/kawruh.v6i1.5046.

[17] F. Abdullah, S. B. Basar, A. M. Adnan, J. Awang, R. Mat Nashir, and B. T. Wardoyo, "Exploring semiotic visual of batik stamp motif in Malaysia and Indonesia," *International and Interdisciplinary Conference on Arts Creation and Studies*, vol. 9, pp. 1–9, 2024, doi: 10.33153/iicacs.v9i1.247.

[18] G. Tian, Q. Yuan, T. Hu, and Y. Shi, "Auto-generation system based on fractal geometry for batik pattern design," *Applied Sciences (Switzerland)*, vol. 9, no. 11, Jun. 2019, doi: 10.3390/app9112383.

[19] S. S. F. Ardyani and C. A. Sari, "A Web-Based for Demak Batik Classification Using VGG16 Convolutional Neural Network," *Advance Sustainable Science, Engineering and Technology*, vol. 6, no. 4, pp. 0240406-01-0240406–09, Aug. 2024, doi: 10.26877/asset.v6i4.771.

[20] A. Chusnyriani Sani Zulkarnaen *et al.*, "Application of Convolutional Neural Network Method with MobileNet V1 and ResNet-152 V2 Architecture in Batik Motif Classification," in *International Conference on Broadband and Wireless Computing, Communication and Applications*, Springer Nature Switzerland., 2024, pp. 57–68.

[21] M. Maree, "Quantifying Relational Exploration in Cultural Heritage Knowledge Graphs with LLMs: A Neuro-Symbolic Approach for Enhanced Knowledge Discovery," *Data (Basel)*, vol. 10, no. 4, Apr. 2025, doi: 10.3390/data10040052.

[22] P. Ardhianto, Y. P. Santosa, and G. Anandhita, "Enhancing the Traditional Batik Design Practices: An Approach to Batik Motif Design Using Artificial Intelligence," vol. 52, no. 2, pp. 317–324, Feb. 2025.

[23] Ş. Öztürk and B. Akdemir, "Application of Feature Extraction and Classification Methods for Histopathological Image using GLCM, LBP, LBGLCM, GLRLM and SFTA," in *Procedia Computer Science*, Elsevier B.V., 2018, pp. 40–46. doi: 10.1016/j.procs.2018.05.057.

[24] Husnia and Nur Wiji Sholikin, "Etnomatematika pada Batik Manggur Kota Probolinggo," *Kognitif: Jurnal Riset HOTS Pendidikan Matematika*, vol. 5, no. 1, Mar. 2025, doi: 10.51574/kognitif.v5i1.2693.

[25] A. W. Bustan, M. Salmin, and T. Talib, "Eksplorasi Etnomatematika terhadap Transformasi Geometri pada Batik Maléfo," *Jurnal Pendidikan Matematika (Jupitek)*, vol. 4, no. 2, pp. 87–94, Jan. 2022, doi: 10.30598/jupitekvol4iss2pp87-94.

[26] Ş. Öztürk and B. Akdemir, "Application of Feature Extraction and Classification Methods for Histopathological Image using GLCM, LBP, LBGLCM, GLRLM and SFTA," *Procedia Comput Sci*, vol. 132, pp. 40–46, 2018, doi: 10.1016/j.procs.2018.05.057.

[27] D. Wijaya and A. R. Widiarti, "Batik classification using KNN algorithm and GLCM features extraction," *E3S Web of Conferences*, vol. 475, p. 02012, Jan. 2024, doi: 10.1051/e3sconf/202447502012.

[28] I. Donadello, L. Serafini, and A. d'Avila Garcez, "Logic Tensor Networks for Semantic Image Interpretation," *ArXiv*, May 2017, [Online]. Available: http://arxiv.org/abs/1705.08968

[29] A. Halnaut, R. Giot, R. Bourqui, and D. Auber, "Samples Classification Analysis Across DNN Layers with Fractal Curves," in *in ICPR 2020's Workshop Explainable Deep Learning for AI*, ICPR, 2021. [Online]. Available: https://hal.science/hal-03111634v1

[30] S. Shivadekar, *Artificial Intelligence for Cognitive Systems: Deep Learning, Neuro- symbolic Integration, and Human-Centric Intelligence*. Deep Science Publishing, 2025. doi: 10.70593/978-93-7185-611-9.

[31] M. Maree, "Quantifying Relational Exploration in Cultural Heritage Knowledge Graphs with LLMs: A Neuro-Symbolic Approach for Enhanced Knowledge Discovery," *Data (Basel)*, vol. 10, no. 4, p. 52, Apr. 2025, doi: 10.3390/data10040052.

[32] D. Amalia, A. Rosdiana, N. Al Azizi, A. Wulandari, and U. Islam Nahdlatul Ulama Jepara, "Semiotika Batik Jepara sebagai Bentuk Identitas Budaya Lokal Masyarakat Jepara," *ENTITA: Jurnal Pendidikan Ilmu Pengetahuan Sosial dan Ilmu-Ilmu Sosial*, vol. 6, no. 1, 2024, doi: 10.19105/ejpis.v5i2.12169.

[33] M. H. S. Ar-Rasyid and P. M. Lestari, "Motif Batik Ambarawa: Kajian Semiotika," *Kawruh: Journal of Language Education, Literature and Local Culture*, vol. 6, no. 1, pp. 1–10, Apr. 2024, doi: 10.32585/kawruh.v6i1.5046.

[34] S. Gondi, D. Aggarwal, and S. Bansal, "Comparative Analysis of NSAI," *Universal Threats in Expert Applications and Solutions: Proceedings of 4th UNI-TEAS 2025, Volume 1*, vol. 1, p. 25, 2025.