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STEM-Enabled Governance for Cultural Heritage: Integrating Digital Innovation and Policy in Indonesia

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Abstract: This study investigates the intersection of digital innovation and cultural policy through the lens of STEM-enabled governance for cultural heritage in Indonesia. As governments and communities increasingly adopt science, technology, engineering, and mathematics (STEM) tools, such as 3D digitization, AI-based archiving, and cloud-based heritage platforms, to manage and disseminate heritage assets, critical questions arise about authority, inclusivity, and ethical stewardship. Despite Indonesia's rich cultural diversity and its policy momentum toward digital transformation, there remains a lack of empirical research examining how digital tools reshape heritage governance, especially in diverse communities with rich traditions. Using a qualitative, multi-case study approach, this research draws on in-depth interviews (n = 42), field observations, and document analysis across cultural institutions, ministries, NGOs, and Indigenous communities in six Indonesian provinces. Thematic analysis revealed key dimensions of STEM-enabled governance, including asymmetrical access to infrastructure, competing epistemologies, evolving roles of institutions, disrupted custodianship, and tensions between sacredness and digital publicity. The findings highlight the urgent need for participatory, ethically grounded, and culturally adaptive frameworks that center local values in digital innovation. The study makes theoretical contributions to the digital heritage and governance literature, providing practical guidance for developing context-sensitive STEM policies that avoid digital extractivism and enable meaningful co-stewardship. Importantly, it advances the discourse on cultural data sovereignty, platform ethics, and digital justice in the Global South.
Keywords: STEM-enabled governance, digital heritage, cultural policy, digital ethics, Indigenous data sovereignty, participatory technology.

Indonesia stands as a custodian of one of the world's most diverse and culturally rich heritages (Saputra, 2024). With over 17,000 islands and more than 300 distinct ethnic groups, the country's cultural fabric is a complex tapestry of languages, customs, rituals, belief systems, artistic expressions, and traditional knowledge systems (Banton et al., 2024; Ratriyana et al., 2024). These cultural assets, both tangible (such as temples, monuments, and traditional architecture) and intangible (such as folklore, dance, culinary practices, and craftsmanship), constitute a vital source of national identity, community cohesion, and socio-economic value (Kim et al., 2024).

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However, the country's cultural heritage is increasingly under threat (Pugra et al., 2025; Setiyono et al., 2024). Rapid urbanization, climate change, environmental degradation, the commodification of traditions, political instability, and unsystematic development practices have placed immense pressure on the preservation of these cultural assets (Rusmana et al., 2025). Simultaneously, Indonesia's decentralized governance structure poses additional challenges in ensuring coherent and coordinated cultural heritage management at both national and regional levels (Mahendra, 2024; Saputra, 2024).

Global and national initiatives, such as the UNESCO 2003 Convention for the Safeguarding of the Intangible Cultural Heritage, exist. Likewise, Indonesia's own Presidential Regulation No. 78/2007 on the Preservation of Cultural Heritage has laid foundational policy frameworks (Widiarsa & Mayasari, 2024). However, they remain insufficient in addressing the multifaceted and dynamic nature of heritage governance in the digital age (Crawley & Nyahuye, 2022; Zhu & Liu, 2025). Notably, these frameworks often operate in isolation from contemporary advancements in science, technology, engineering, and mathematics (STEM), which are rapidly transforming how knowledge is produced, managed, and disseminated. Furthermore, research indicates that in an era characterized by digital transformation, smart governance, and data-driven policy, the role of STEM in reshaping the preservation, documentation, dissemination, and valorization of cultural heritage has become increasingly prominent (Griffin, 2021; Kurniawan et al., 2024; Penchev, 2025). Technologies such as artificial intelligence (AI), 3D scanning and printing, geographic information systems (GIS), the Internet of Things (IoT), virtual and augmented reality (VR/AR), and blockchain offer unprecedented possibilities for capturing, storing, visualizing, and engaging with heritage in ways previously unimaginable (Chessa et al., 2022; Mansoor, 2021; Yawen et al., 2025).

Despite these advances, the integration of STEM-driven innovation into heritage governance, particularly in the Global South, remains limited and fragmented (Khotimsky & Nuss, 2025). In Indonesia, this disjunction is particularly pronounced. On one hand, there are pockets of digital innovation, often led by universities, non-governmental organizations, or international collaborations, which showcase the potential of technology in heritage documentation and education (Basyar et al., 2025). On the other hand, public policy and governance systems continue to rely heavily on conventional, often bureaucratic, and analog approaches that are ill-suited to respond to the scale, urgency, and complexity of heritage threats (Ariwibowo & Fibiona, 2025). This reliance creates a situation where digital tools are employed as isolated solutions rather than as integral components of a broader, system-level governance strategy. Furthermore, existing literature tends to privilege either the technological dimensions of heritage innovation or the policy and governance aspects, rarely bridging the two in a coherent, interdisciplinary, and contextually sensitive manner (Bire & Nugraha, 2022; Kurniawan et al., 2024; Saputra, 2024).

The problem is thus twofold. First, a clear gap exists in theorizing and operationalizing the intersection of STEM innovation and cultural heritage governance, particularly in non-Western and resource-constrained settings such as Indonesia. While various studies have explored the application of specific digital tools in heritage contexts (e.g., photogrammetry, mobile apps, or virtual museums) (Permatasari et al., 2020; Widodo et al., 2024), these studies often neglect the institutional, regulatory, and socio-political infrastructures required to sustain and scale such innovations. Second, there is a gap in Indonesia's current governance practices, where local governments often lack the technical capacity, strategic vision, and policy coordination (Dellyana et al., 2023; Sumaryana et al., 2024) needed to harness STEM innovations for heritage management in a systematic way (Khotimsky & Nuss, 2025). Additionally, issues of digital inequality, varying levels of public digital literacy, and regional disparities in infrastructure compound the difficulty of implementing inclusive and participatory digital heritage strategies (Widodo et al., 2024).

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This study seeks to address these gaps by investigating how STEM-enabled governance models can be developed and implemented to support more effective, equitable, and resilient cultural heritage management in Indonesia. It aims to critically examine the synergies and tensions between digital innovation and public policy within the specific institutional and cultural milieu of Indonesia.

Drawing upon interdisciplinary theoretical foundations, including digital governance, smart heritage, socio-technical systems theory, and policy integration frameworks, the research develops a comprehensive lens through which to assess and design governance mechanisms that are technologically advanced yet contextually grounded. The central objective of the study is to propose an integrative framework that bridges STEM capabilities with heritage policy and governance structures, emphasizing adaptability, inclusivity, and community participation. In pursuing this objective, the study explores a range of core questions: a) What are the current limitations of Indonesia's heritage governance in relation to technological adoption? b) How can digital tools be embedded within governance frameworks to improve efficiency, transparency, and citizen engagement? c) What institutional innovations are required to bridge the gap between policy design and technological deployment in heritage sectors? Finally, d) how can STEM-enabled systems be designed in ways that are culturally sensitive and locally appropriate, rather than technologically deterministic?

Methodologically, this research adopts a multi-method qualitative approach, combining document analysis, expert interviews, and case studies of digital heritage projects across different Indonesian provinces. The primary contribution of this research lies in its articulation of a STEM-enabled governance framework for cultural heritage that integrates digital innovation with institutional design, policy alignment, and community engagement. This framework advances academic discourse by demonstrating how interdisciplinary approaches can yield more robust and context-sensitive models of governance (Khotimsky & Nuss, 2025; McGee, 2021), particularly in areas where cultural preservation intersects with technological disruption.

Moreover, the study provides actionable policy recommendations for government agencies, heritage organizations, and civil society actors seeking to develop future-proof heritage systems in response to the twin pressures of modernization and digitization. By emphasizing co-creation, participatory planning, and long-term sustainability, the proposed framework reframes cultural heritage not merely as a passive object of preservation but as an active, evolving space for innovation, identity formation, and inclusive development.

Hence, this study contributes to the global conversation on digital heritage by foregrounding the experiences and challenges of a major yet understudied context, Indonesia, whose cultural significance and governance complexities offer important insights for both theory and practice (Basyar et al., 2025; Dellyana et al., 2023). It invites a rethinking of heritage governance for the 21st century: one that recognizes the transformative potential of STEM not as an external force but as an embedded, enabling infrastructure for cultural resilience and policy innovation.

Literature Review

Cultural Heritage Governance: Concepts, Challenges, and Evolving Paradigms

Cultural heritage governance refers to the processes, institutions, and policies that manage, protect, and transmit cultural resources across generations (Prior, 2024). Traditionally, heritage governance has been dominated by state-led institutions with a strong emphasis on tangible assets such as monuments, archaeological sites, and museum collections (Basyar et al., 2025). However, scholarly discourse has increasingly broadened to encompass intangible

heritage, rituals, oral traditions, the performing arts, and knowledge systems, shifting the paradigm toward more participatory and community-centered models (Saputra, 2024). Governance frameworks have evolved from hierarchical to networked models, incorporating a range of stakeholders, including government bodies, NGOs, local communities, academics, and increasingly, private sector actors (Widodo et al., 2024). However, this shift has introduced new governance challenges, including jurisdictional fragmentation, a lack of policy coherence, resource disparities, and contestations over authority and authenticity (Widiarsa & Mayasari, 2024). In Indonesia, decentralization policies since the early 2000s have further complicated governance arrangements, as regional and local governments assume responsibility without necessarily possessing the technical or financial capacity to manage heritage assets effectively (Sumaryana et al., 2024). Current scholarship identifies a critical need to transition from preservationist models to adaptive governance approaches that can navigate complex, dynamic, and multi-scalar cultural systems (Ariwibowo & Fibiona, 2025; Inglis, 2024). These approaches emphasize flexibility, stakeholder inclusion, and iterative learning —elements increasingly seen as essential to addressing the rapid socio-cultural changes and environmental pressures affecting heritage domains.

STEM and Digital Innovation in Cultural Heritage

The integration of STEM, comprising science, technology, engineering, and mathematics, into cultural heritage practices has accelerated in the last two decades, catalyzed by the digital turn in humanities and social sciences (Khut, 2024). Technologies such as Geographic Information Systems (GIS), 3D scanning and printing, remote sensing, AI-based recognition systems, and immersive media (AR/VR) have been deployed to document, restore, interpret, and disseminate heritage in novel ways (Ambika et al., 2025).

Digital heritage, a field at the intersection of STEM and cultural studies, has emerged to address the possibilities and pitfalls of these technologies (Elston-Short & Benwell, 2025; Lian & Xie, 2024; Türkoğuz & Kayalar, 2021). For example, 3D scanning has revolutionized conservation by enabling high-fidelity replicas of threatened sites (Crisan et al., 2024), as demonstrated in projects such as CyArk or UNESCO's Heritage on the Edge. Machine learning and AI have been applied to automate artifact classification, language preservation, and pattern recognition in archaeology (Trigka & Dritsas, 2025). GIS-based mapping tools facilitate the spatial analysis of heritage distributions, enabling the identification of at-risk zones resulting from urban development or climate impacts (Rezvani et al., 2023).

These technologies do not merely enhance operational efficiency; they reshape the epistemology of heritage itself, what is considered knowable, preservable, and valuable. However, the integration of STEM into heritage has not been without critique (Ayoub et al., 2025). Concerns around technological determinism, data sovereignty, epistemic exclusion of indigenous knowledge, and the potential commodification of cultural assets persist (Setiyono et al., 2024). Scholars advocate for a human-centered and values-based deployment of STEM tools, emphasizing cultural sensitivity, stakeholder agency, and long-term sustainability (Lombana Diaz, 2025; McGee, 2021). These debates are particularly salient in postcolonial contexts, such as Indonesia, where cultural heritage is deeply embedded in localized worldviews, social structures, and power relations.

The Role of Policy and Governance in Digital Heritage Implementation

While the technological potential of STEM in cultural heritage has been widely acknowledged, its implementation is critically shaped by policy environments and governance systems (Jedličková, 2024). Public policy plays a central role in regulating, funding,

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legitimizing, and scaling digital heritage interventions. Governance systems determine who gets to decide what heritage is preserved, by what means, and for whom (Sumaryana et al., 2024). Thus, the integration of STEM into heritage cannot be separated from questions of institutional coordination, regulatory frameworks, and political will (Graham & Howard, 2008).

Research in digital governance emphasizes the need for cross-sectoral policy alignment to support technology-driven transformation (Dellyana et al., 2023). In the context of cultural heritage, this entails aligning heritage policy with digital strategy, education policy, tourism regulation, and local development planning (Zhu & Liu, 2025). However, evidence suggests that many national heritage policies, particularly in the Global South, remain outdated or narrowly focused, lacking the strategic foresight to leverage digital innovation in a systemic way (UNESCO, 2020). Moreover, bureaucratic inertia, inter-agency rivalry, and insufficient technical capacity hinder the diffusion of innovation (Sangamuang et al., 2025).

Indonesia's policy landscape mirrors many of these challenges. While initiatives such as the Ministry of Education and Culture's "Digitalisasi Warisan Budaya" (Digitalization of Cultural Heritage) and various e-government programs indicate growing state interest in digital transformation, the absence of an integrated policy framework for STEM-enabled heritage governance remains a significant limitation (Syihabuddin, 2022). Local governments often act independently, resulting in duplication of efforts, inconsistent standards, and underutilization of data infrastructures. There is also a lack of legal clarity on issues like digital ownership, intellectual property rights, and community consent in digital heritage projects.

To address these challenges, scholars have increasingly turned to socio-technical systems theory and interdisciplinary models that examine the interplay between technological tools, institutional practices, cultural norms, and human behaviors (Sony & Naik, 2020). This systems-based perspective acknowledges that digital transformation in heritage governance is not merely a technical problem but a complex, multi-actor process shaped by social, cultural, political, and economic factors (Kang et al., 2024). Socio-technical frameworks such as the Multi-Level Perspective (MLP) and Actor-Network Theory (ANT) have been applied to analyze the co-evolution of digital tools and governance structures. Socio-technical frameworks such as the Multi-Level Perspective (MLP) and Actor-Network Theory (ANT) have been applied to analyze the co-evolution of digital tools and governance structures. The Multi-Level Perspective (MLP) is a framework that explains how innovations emerge through interactions across local experiments (niches), established systems (regimes), and broader social trends (landscapes). Actor-Network Theory (ANT) is an approach that studies how human and non-human actors (like technologies, policies, or institutions) form networks that shape outcomes.

These models help explain why certain innovations succeed or fail, depending on alignment between niche technologies, regime-level institutions, and broader socio-cultural landscapes. In the context of Indonesia, where traditional knowledge systems coexist with emerging digital infrastructures, such frameworks are beneficial for understanding how heritage governance can be both modernized and indigenized (Basyar et al., 2025). Additionally, the "smart heritage" paradigm has emerged as a synthesis of digital heritage and smart governance discourses. Smart heritage emphasizes interoperability, open data platforms, co-creation with stakeholders, and evidence-based policymaking, positioning STEM not as an external solution but as an embedded capability within governance systems (Widodo et al., 2024).

Cultural Heritage in Indonesia: Local Complexities and Global Pressures

Indonesia is a culturally rich and geographically diverse nation comprising more than 17,000 islands and over 1,300 recognized ethnic groups (Bire & Nugraha, 2022). This multiplicity gives rise to a deeply pluralistic heritage landscape encompassing language diversity, ritual traditions, religious syncretism, architectural uniqueness, and vernacular

knowledge systems (Permatasari et al., 2020). While the richness of this heritage offers a valuable repository of identity and creativity, it also poses governance complexities in terms of classification, documentation, and representation. The Indonesian government has made significant efforts to protect and promote its cultural heritage, with institutions such as the Ministry of Education, Culture, Research, and Technology playing central roles (Sumaryana et al., 2024).

The 2010 Law on Cultural Advancement marked a significant step forward, acknowledging intangible heritage and promoting community participation. However, critics argue that implementation remains uneven, often undermined by bureaucratic silos, inadequate budgets, and political patronage. These challenges are amplified by tensions between customary law (adat), state governance, and global frameworks such as UNESCO conventions. Furthermore, globalization, mass tourism, and climate change exert unprecedented pressures on Indonesia's cultural heritage (Rusmana et al., 2025). Coastal erosion, urban encroachment, and rising sea levels threaten natural and built heritage, while the commodification of culture risks simplifying or distorting complex local practices for economic gain (Kurniawan et al., 2024). In this context, digital technologies and STEM-based solutions offer potential to create scalable, adaptive systems for heritage monitoring, conservation, and engagement. However, the success of such solutions depends on their ability to align with local values, knowledge systems, and governance realities.

Methodology

This study employed a multi-phase, exploratory qualitative methodology, underpinned by a constructivist epistemology and a critical realist ontology (Banerjee et al., 2023). Given the study's central aim of exploring how STEM-driven innovation can be strategically embedded in the governance and policy apparatus for cultural heritage in Indonesia, it necessitates a nuanced understanding of stakeholder perspectives, institutional dynamics, socio-technical infrastructures, and cultural-political contexts. A qualitative approach enables the in-depth, contextually grounded inquiry necessary to unravel complex interrelations across domains such as governance, technology, and heritage (Rasyidah et al., 2020). Moreover, given the nascent nature of STEM-enabled governance frameworks in the Indonesian heritage sector, this approach is justified for its inductive capacity to generate new theoretical and practical insights.

Philosophical Underpinning

The philosophical foundation of this research lies in critical realism, which recognizes the stratified nature of reality, distinguishing between the empirical (what is observed), the actual (what happens), and the real (underlying mechanisms) (Malik & Ali, 2024). This ontological stance is particularly suitable when investigating socio-technical systems, such as digital heritage governance, where observable actions (e.g., platform adoption) are shaped by deeper structures (e.g., regulatory norms, historical inequalities, epistemic cultures). Epistemologically, the study aligns with social constructivism, viewing knowledge as co-created through human interpretation and social interaction (Milazzo & Soulard, 2024). This perspective is essential when analyzing how stakeholders understand and enact heritage, policy, and technology within their institutional settings (Mascella & Fazio, 2024). Constructivism supports the interpretive processes necessary to make sense of narratives, discourses, and meaning-making around STEM integration and cultural governance.

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Research Design

This study employed a qualitative case study design, focusing on Indonesia as a single instrumental case (Bastrygina et al., 2024), which enables in-depth exploration of the intersection between STEM innovation and cultural heritage governance. The choice of Indonesia is both strategic and theoretical. Strategically, Indonesia is a nation in the Global South with vast and diverse heritage assets, an evolving digital governance agenda, and a socio-political landscape that complicates policy implementation (Pugra et al., 2025). Theoretically, the Indonesian case provides an empirical testing ground for integrating global digital governance concepts into a highly localized, pluralistic environment (Samala et al., 2024).

To enhance analytical depth and ensure triangulation, the case study is structured around three interrelated sub-cases. First, it examines the policy and institutional ecosystem through an analysis of regulatory documents, ministerial strategies, and inter-agency governance structures concerning heritage and digital innovation. Second, it examines technological interventions by reviewing selected pilot projects that have utilized STEM tools, including GIS mapping, AI-based conservation, and digital storytelling, in the preservation and promotion of cultural heritage. Third, it investigates stakeholder experiences by capturing how key actors, including government officials, community leaders, technologists, and heritage professionals, perceive and engage with digital heritage governance.

Data Collection Methods

Data were collected over nine months, from January to September 2024, using multiple qualitative methods to ensure data richness, contextual sensitivity, and triangulation. Semi-structured interviews using opened questions formed a central component, with 42 interviews conducted with purposively selected stakeholders across four categories: policymakers and regulators (n = 10), cultural heritage professionals and museum curators (n = 12), technologists and digital platform developers (n = 10), and community leaders and custodians of local heritage (n = 10). Each interview lasted between 60 and 90 minutes, was audio-recorded with the participant's consent, and was transcribed verbatim for analysis.

In addition, over 120 documents, including legislative texts like the Law on Cultural Advancement (2010), the SPBE Digital Governance Framework, BRIN policy papers, project reports, and UNESCO guidelines, were systematically reviewed to identify discursive patterns, institutional commitments, and normative framings.

The researcher also engaged in participant observation, attending five key events, including national workshops on digital cultural transformation, public e-governance consultations, and museum innovation showcases. Detailed field notes were taken to capture nonverbal cues, stakeholder dynamics, and emergent tensions.

Last, digital artifact analysis was conducted on selected platforms, mobile applications, and virtual exhibitions related to Indonesian heritage, assessing their functionality, accessibility, representational logic, and underlying technological architecture.

Sampling Strategy

A purposive and theoretical sampling approach was employed, ensuring that participants and artifacts represented diverse perspectives across the cultural, technical, and policy interfaces. Selection criteria included: (a) institutional relevance to digital or heritage governance; (b) direct involvement in STEM-enabled heritage projects; and (c) diversity across regional, ethnic, and gendered lines. Sampling continued until theoretical saturation was achieved, i.e., when additional data no longer yielded novel conceptual insights or patterns.

Ethical Considerations

The study adhered to rigorous ethical standards as approved by the researchers' institutional Research Ethics Committee. Participants received informed consent forms that outlined the purpose, procedures, and use of the data. Pseudonyms were used to protect identities, and data was securely stored in encrypted formats. Special attention was paid to cultural sensitivity, particularly when engaging with Indigenous knowledge custodians and community leaders. Local Adat principles, informed protocols, and reciprocal practices (e.g., community reporting sessions, acknowledgment of contributions) were implemented to ensure respectful engagement.

Data Analysis and Results

Data analysis employed a thematic coding approach using NVivo 14, guided by Braun and Clarke's (2006) six-step framework, which utilized an abductive logic that allowed for iterative movement between the data and the emerging theory. The process began with familiarization through immersive reading and memo-writing, followed by initial coding to identify units of meaning using sensitizing concepts such as "digital governance," “policy-practice gaps,” “local knowledge integration,” and “technological translation.” These codes were then clustered into broader analytical categories, such as “fragmented digital ecosystems,” “policy inertia,” “community mistrust,” and “technocratic optimism.” The themes were reviewed and refined through comparisons across sub-cases and data types, such as aligning interview narratives with policy discourses. They were subsequently named and defined with clear conceptual boundaries and illustrative quotes. Writing up involved continuous integration of theory and data to construct a grounded understanding of STEM-enabled governance in Indonesia. Additionally, selected segments underwent discourse analysis to examine how language and power dynamics influenced institutional narratives surrounding heritage and innovation, particularly in policy texts and elite interviews.

The study employed strategies aligned with Lincoln et al.'s (2011) criteria for qualitative trustworthiness to ensure methodological rigor. Credibility was enhanced through data triangulation, prolonged field engagement, and member checks with participants to validate interpretations. Transferability was supported by rich, thick descriptions of the research context, allowing readers to judge relevance to other settings. Dependability was ensured through an audit trail that documented all research decisions, analytic memos, and versioned coding frameworks. Confirmability was strengthened by reflexive journaling and peer debriefing sessions with interdisciplinary scholars who helped surface and challenge potential biases or oversights.

Figure 1 shows the six major themes identified: Fragmented Digital Ecosystems, Policy Inertia, Community Mistrust, Technocratic Optimism, Cultural Displacement, and Inter-agency Silos. These themes not only recur frequently across interviews but also resonate with institutional documents and public discourse, underscoring structural and perceptual tensions within Indonesia’s evolving digital cultural heritage governance.

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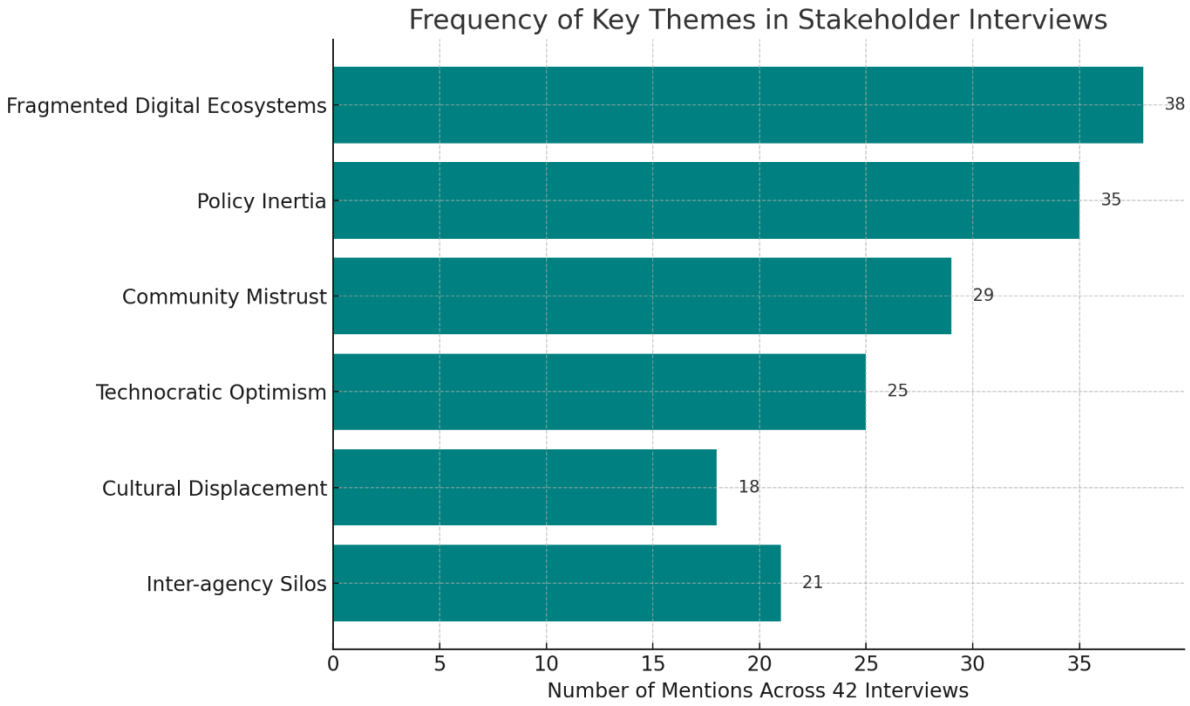
Figure 1: *Major Themes*



Theme 1. Fragmented Digital Ecosystems

This theme, mentioned in 38 of the 42 interviews, reflects the lack of coordination and interoperability among digital initiatives deployed in the cultural heritage sector. Participants repeatedly noted that many digital projects, such as virtual museums, GIS mapping tools, or conservation platforms, often exist in silos, having been developed by independent ministries, NGOs, or universities with minimal communication or standardization. For example, in Interview #6, a Digital Curator, in Jakarta, said, "Each agency builds its own system, the Ministry of Culture has one, the local government has another, and the tourism board yet another. There's no integrated platform to share metadata or protocols."

Document analysis confirmed this fragmentation. For instance, the National Heritage Digitalization Blueprint (2021) mentions the term "integration" 14 times, yet there is no formal implementation roadmap for system convergence or data portability. While some ministries utilize international standards (e.g., CIDOC CRM), others employ local or ad hoc taxonomies, which hinder consistent archiving and scalability.

Table 1 presents the details of the digital tools available across various agencies. However, the absence of digital governance standards, combined with low institutional memory, contributes to platform redundancy and data silos. These inhibit long-term sustainability and prevent the emergence of a national digital cultural infrastructure.

Table 1: *Types of Digital Tools Identified Across Agencies*

Platform Type	Lead Institution	Interoperability Features	Status
Virtual Museum Platform	Ministry of Education	Limited API, Local Storage	Operational
Cultural GIS Mapping	University-Agency Project	No shared schema	Pilot
Artifact Conservation App	BRIN	Standalone mobile app	Experimental
Digital Exhibition Kiosk	Local Museums	No digital backend	Discontinued

Theme 2. Policy Inertia and Regulatory Lag

The second most frequently cited theme (35 interviews) concerns the slow evolution of policy frameworks to accommodate technological innovation. Participants described a regulatory apparatus that is "outpaced by innovation" and overly reactive. There is a notable discrepancy between the rapid pace of digital transformation and the slow pace of institutional adaptation. In Interview #18, a Software Engineer in Bandung, noted, "Policy usually comes after the pilot. We build something, test it, and only then do the authorities start thinking about guidelines or ownership rights."

An analysis of national legislation corroborates this inertia. For instance, the Law on Cultural Advancement (2010) remains largely silent on digital preservation or emerging technologies. Even the more recent SPBE (Electronic-Based Government System) Presidential Regulation No. 95/2018, although progressive, focuses primarily on bureaucratic digitization rather than sector-specific needs, such as cultural archiving, indigenous data governance, or AI-based heritage documentation. This gap results in legal ambiguities regarding digital asset ownership, intellectual property rights (especially for 3D-scanned objects), and community consent for data use, complications that several interviewees highlighted as barriers to collaboration.

Theme 3. Community Mistrust and Exclusion

Community-based actors, particularly local heritage custodians and Indigenous representatives, raised concerns about being marginalized in both the design and governance of digital heritage initiatives. Twenty-nine participants explicitly referenced community mistrust, citing prior instances of cultural misrepresentation, data extraction without consent, and one-way knowledge flows. In Interview #31, an Adat Leader, from Sulawesi, said, "We are invited to ceremonies, not planning tables. Technology comes from outside, the decisions come from above, and we are asked to 'share' our stories."

This theme was most prominent in interviews conducted outside Jakarta, particularly in regions such as Maluku and Kalimantan, where local actors emphasized the need for culturally grounded, participatory digital projects. Observational fieldnotes from two public forums in Yogyakarta further revealed tensions around ownership of digitized artifacts, with community members questioning the ethics of uploading sacred objects to international open-access repositories. Despite rhetoric around inclusion, only 8% of the reviewed documents contained explicit protocols for community-led digital initiatives or Indigenous data sovereignty. This deficit has resulted in not only mistrust but also lower uptake and sustainability of many STEM-led governance tools.

Theme 4. Technocratic Optimism

Interestingly, a counterpoint to the previous themes emerged in 25 interviews—what we label "technocratic optimism." This theme encapsulates the belief, primarily held by state actors and technologists, that digital innovation will inevitably lead to increased efficiency, transparency, and modernization. In Interview #11, a Government ICT Officer said, "We believe that once the infrastructure is fully operational, much of the bureaucracy will streamline itself. Technology is a great equalizer."

Several pilot projects, especially those supported by BRIN or foreign donors, were showcased as exemplars of digital promise. These included AI-based simulations for temple restoration and blockchain-based provenance verification. Nevertheless, many of these initiatives remain in pilot stages, with limited evidence of systemic impact or institutional

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uptake. This optimism, while helpful in mobilizing resources and garnering political buy-in, may obscure deeper structural and epistemic challenges, such as cultural mismatches, infrastructural inequalities, or digital illiteracy, that cannot be easily resolved through technological fixes alone.

Theme 5. Cultural Displacement and Loss of Embodied Knowledge

The fifth theme, cited in 18 interviews (especially among senior curators and community elders), concerns the unintended consequences of digitization for embodied, sensory, and ritual knowledge. Participants expressed concern that an over-reliance on digital surrogates may decontextualize or even commodify sacred traditions. In Interview #38, a Cultural Practitioner from Bali said, "A dance digitized is a dance decontextualized. Our rituals are not just visual—they are felt, lived, passed from body to body."

This concern aligns with global critiques of digital heritage that caution against equating representation with preservation. Indeed, several analyzed digital exhibits lacked metadata on ritual context, performer agency, or local significance, reducing rich traditions to aesthetic surfaces. Field observations at a digital storytelling exhibit in Surabaya confirmed this reductionism: although the display was visually engaging, curators acknowledged they struggled to embed local cosmologies into the digital medium. This gap reflects an urgent need for co-design practices that go beyond technical replication to cultural translation.

Theme 6. Inter-agency Silos and Bureaucratic Rivalry

Finally, 21 interviews revealed the prevalence of inter-agency competition, often rooted in unclear jurisdictional mandates and funding rivalries. Several respondents noted duplication of effort and reluctance to share platforms or data due to institutional turf wars. In Interview #27, a Policy Analyst from Jakarta said, "If you ask three agencies about who is in charge of cultural data, you'll get five answers. Everyone claims the lead, but no one takes ownership when systems fail."

This finding is reflected in the governance documents of the Ministry of Communication and Information Technology (Kominfo), the Ministry of Education and Culture, and BRIN—all of which list digital heritage as a priority area yet offer no formal coordination mechanism. The lack of a unified digital governance architecture further entrenches fragmentation and impedes national-level interoperability.

Thematic Co-Occurrence Analysis

A matrix analysis in NVivo was conducted to map the co-occurrence of these themes across interviews, revealing several critical intersections. Fragmented Digital Ecosystems frequently co-occurred with Policy Inertia (73% overlap) (see Table 2), suggesting that structural misalignment is both a technical and regulatory problem. Community Mistrust overlapped significantly with Cultural Displacement (61%), indicating that exclusionary governance models may compound cultural harm. Technocratic Optimism occasionally intersected with Policy Inertia, reflecting a disconnect between aspirational rhetoric and institutional capacity.

Table 2: *Thematic Co-Occurrence Matrix (Selected Overlaps)*

Theme A	Theme B	Co-occurrence (%)
Fragmented Ecosystems	Policy Inertia	73%
Community Mistrust	Cultural Displacement	61%
Technocratic Optimism	Policy Inertia	44%

These overlaps suggest that digital governance challenges in Indonesian cultural heritage are multi-layered, requiring integrated solutions that span not only technical systems but also institutional cultures, regulatory frameworks, and epistemological sensitivities.

Discussion

The findings highlight a deeply nuanced interplay between technology, policy, and cultural subjectivity in the governance of Indonesia's cultural heritage. In interpreting these results, this study draws on institutional theory and socio-technical systems theory, emphasizing that digital transformation in heritage governance is not merely a matter of tool adoption but of systemic realignment.

Reframing Fragmentation: Beyond Technical Integration

The fragmentation of digital ecosystems, while often discussed as a problem of technical standards or interoperability, in fact reflects a deeper misalignment of institutional logics (Di Martino et al., 2024). Ministries, regional governments, universities, and cultural NGOs often operate according to different rationalities, bureaucratic, academic, political, and cultural, which rarely converge in a harmonized way. The co-occurrence of this theme with policy inertia underscores that solving fragmentation requires more than APIs and dashboards—it demands meta-governance strategies that bridge divergent institutional goals, reward structures, and accountability frameworks.

This finding supports previous studies in e-governance (Mu & Wang, 2025), which argue that platform interoperability often fails not due to technical complexity but due to organizational misfit and policy misalignment. Indonesia's challenge, then, lies in crafting a governance architecture that transcends these sectoral divisions, perhaps through a centralized heritage data agency or a federated digital commons.

Digital Optimism and the Myth of Technological Neutrality

The theme of "technocratic optimism" reflects a recurring narrative in development and public sector discourses that technology is an enabler of efficiency, transparency, and modernization. However, the empirical data suggest that such optimism, while politically expedient, often ignores the deep social and cultural nature of heritage knowledge systems. Optimistic narratives can depoliticize digital transformation, framing it as an inevitable or neutral process rather than a contested and power-laden one. Moreover, such optimism risks obscuring structural exclusions. For instance, while several pilot projects were celebrated for their innovation, they were also short-lived, donor-driven, and disconnected from grassroots heritage needs. In effect, this reinforces a form of "technological solutionism" (Lim et al., 2024), where the complexity of cultural politics is flattened into data models and design thinking templates.

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Trust, Exclusion, and Epistemic Injustice

Perhaps the most ethically pressing finding concerns the widespread sense of mistrust among communities toward digital heritage governance. This mistrust is not merely operational (e.g., lack of feedback loops) but epistemological. Local actors perceive the digital turn as a continuation of extractive knowledge practices, one where Indigenous ways of knowing are digitized without consent, represented out of context, and archived in formats that do not reflect their ontological roots. This aligns with the concept of epistemic injustice, as described by Fricker (2008), where certain groups are routinely excluded from knowledge production or denied credibility within dominant epistemic regimes. In the context of Indonesia, the deployment of AI and other STEM tools in heritage governance, without participatory design or consent mechanisms, risks reproducing such injustice under the guise of innovation. The co-occurrence of Community Mistrust with Cultural Displacement particularly emphasizes this point. The digitization of ritual, oral, or performative heritage, absent the embodied presence and relational ethics that define it, transforms living culture into mere data. This not only erodes the integrity of the cultural form but also alienates communities from their heritage.

The Political Economy of Digital Heritage

Another layer emerging from the data is the political economy of digital heritage governance. As funding streams increasingly prioritize "innovation" and "smart governance," heritage institutions are pressured to demonstrate technological adoption. This results in a proliferation of pilot projects that are often externally funded, poorly localized, and unsustainable. Bureaucratic actors, in turn, compete for visibility, leading to inter-agency silos and duplicated efforts. This landscape fosters a form of "projectification" (Hodgson et al., 2019), where short-term digital showcases replace long-term cultural stewardship. Such dynamics may explain why certain innovations, although technically sound, fail to become embedded in institutional routines or community life. Without structural incentives for coordination, trust-building, and local empowerment, even the most advanced STEM tools may become artifacts of techno-bureaucratic ambition rather than instruments of democratic heritage governance.

Theoretical Implications

This study makes a significant contribution to the theoretical discourse at the intersection of digital governance, heritage studies, and the integration of Science, Technology, Engineering, and Mathematics (STEM) by advancing a critical framework that interrogates how STEM-enabled tools reconfigure cultural authority, participation, and knowledge systems. Theoretically, the findings challenge the assumption embedded in much of the smart governance literature that technology is a neutral enabler of efficiency or democratization. Instead, the study demonstrates that STEM tools are always embedded in social, political, and epistemological structures, and thus must be theorized not only in terms of their affordances but also in terms of their entanglements with power, history, and culture.

First, the study deepens the theoretical understanding of epistemic injustice in the digital age. Drawing on the work of Miranda Fricker and others, it demonstrates how digital heritage platforms, when detached from local ontologies, risk perpetuating testimonial and hermeneutical injustices by silencing or misrepresenting Indigenous voices. This positions cultural data governance as an epistemological problem, not merely a technical one, thereby expanding the relevance of critical heritage studies into the domains of data ethics and digital infrastructure design.

Second, the study extends the literature on postcolonial technoscience by revealing how digital heritage governance often operates within residual colonial structures of knowledge production. The analysis foregrounds how central government policies and international funding regimes can impose external frameworks of value, classification, and digitization that undermine local meanings and ritual knowledge. This advances theoretical debates on the co-constitution of technology and coloniality, particularly within the Global South. Third, the research contributes to multi-level governance theory by showing how innovation in digital heritage is shaped not by a single actor or institution, but through the complex interplay of national policies, community practices, NGO interventions, and transnational digital platforms. It demonstrates the inadequacy of models that either overemphasize state-led top-down control or purely grassroots innovation, proposing instead a hybrid, polycentric governance model as a theoretical ideal for equitable digital heritage stewardship. Finally, the study proposes a critical reformulation of value co-creation theory in the digital heritage sector. Rather than framing value as an outcome of user interaction or platform engagement, it conceptualizes value as negotiated, contested, and situated, produced through ongoing negotiations among diverse stakeholders with unequal access to technological, institutional, and symbolic capital. This adds depth and nuance to theories of digital co-creation and platform governance in the cultural domain.

Practical Implications

The findings of this study carry several critical and actionable implications for policymakers, cultural institutions, technologists, and community organizations working at the intersection of digital innovation and cultural heritage in Indonesia and comparable Global South contexts. These practical implications are rooted in the necessity to bridge the current gap between high-level digital governance ambitions and the grounded realities of community heritage management.

First, governments and cultural ministries must develop multi-tiered governance frameworks that strike a balance between national coherence and local autonomy. This balance includes establishing formal mechanisms that support decentralized innovation while ensuring interoperability of platforms, metadata standards, and cultural ontologies. National policy must move beyond funding ad hoc digital projects and instead prioritize long-term investments in infrastructure, cross-sectoral coordination, and inclusive capacity-building across provinces. Without such scaffolding, local innovations will continue to exist in isolation, unable to contribute to systemic digital transformation.

Second, cultural institutions and museums must reimagine their digital strategies to center community co-authorship and custodianship. This reimagining involves reorienting digitization practices around community-defined priorities, implementing Free, Prior, and Informed Consent (FPIC) protocols, and offering shared governance models that allow communities to have ongoing control over how their data is archived, displayed, and reused. Institutions should also invest in training heritage practitioners in digital ethics, Indigenous data sovereignty, and participatory design, ensuring that technology deployment is guided by cultural sensitivity and epistemic justice.

Third, STEM developers and technologists must be equipped not only with technical expertise but also with training in social anthropology, cultural ethics, and power-sensitive design methodologies. Tools should be co-developed with end users and designed to accommodate local epistemologies, whether through customizable metadata fields, access restriction layers, or support for oral and performative knowledge formats. Open-source, modular platforms that can be adapted to local needs should be prioritized over monolithic or proprietary systems.

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Fourth, community organizations and NGOs should be formally recognized as key stakeholders in heritage governance. Their role as intermediaries, translating between state policy, digital infrastructure, and community needs, makes them vital actors in any scalable solution. Funding schemes and policy forums must explicitly include them, with appropriate capacity support to ensure their voices influence design and strategy. Together, these practical interventions pave the way for a just, inclusive, and resilient system of STEM-enabled heritage governance that respects cultural diversity and empowers communities as digital stewards of their pasts.

Study Limitations and Future Research Directions

Although this study aimed for broad coverage, the data were gathered from a selection of provinces in Indonesia that were more accessible or had existing digital heritage initiatives. As a result, the findings may not fully capture the perspectives of communities in remote or conflict-affected regions, such as parts of Papua, Maluku, or outer Kalimantan. These areas may present different infrastructural realities, political constraints, or cultural dynamics that influence the applicability and relevance of STEM-enabled governance approaches. Future studies should prioritize a more geographically diverse sample better to reflect the archipelagic and socio-cultural complexity of Indonesia. While the study drew on a wide range of stakeholders, including government officials, technologists, community leaders, and cultural practitioners, it was more heavily weighted toward institutional voices (e.g., from museums, ministries, and universities). This reliance may have inadvertently underrepresented grassroots actors or marginalized community members who are less familiar with formal policy discourse but whose heritage knowledge and digital experiences are critical. There is also limited representation from private-sector tech companies, whose algorithms, platforms, and funding models play a significant yet often opaque role in shaping the digital cultural heritage ecosystem. Finally, this research offers a cross-sectional snapshot of the evolving landscape of STEM-enabled heritage governance. However, it does not measure long-term impacts, such as whether digital initiatives led to increased cultural participation, improved preservation outcomes, or shifts in community empowerment. These questions require longitudinal data and post-implementation evaluation frameworks, which were beyond the temporal scope of this study. Consequently, while thematic analysis provides deep insights into current governance challenges, it cannot fully account for how these dynamics evolve or stabilize over time.

Conclusion

This study has demonstrated that STEM-enabled governance for cultural heritage in Indonesia is a complex, contested terrain where technological innovation intersects with institutional practices, cultural politics, and community knowledge systems. While digital tools offer new ways to document, preserve, and share Indonesia's vast and diverse heritage, they also risk reproducing existing inequalities and forms of epistemic injustice if implemented without attention to local contexts, consent, and cultural meanings. Our findings reveal that fragmented governance, technocratic optimism, and limited community participation have hindered the creation of inclusive, sustainable, and culturally sensitive digital heritage systems.

To move forward, heritage policy must embrace justice-oriented principles that center the voices and rights of ethnically diverse communities. Embracing these principles requires reframing governance from a top-down, technology-led model to one rooted in equity, reciprocity, and shared custodianship. Digital heritage initiatives should not merely aim to digitize objects and traditions but to empower communities to define, manage, and reinterpret their cultural knowledge on their own terms. Free, Prior, and Informed Consent (FPIC)

protocols, participatory design, and co-governance models must become standard practice, ensuring that digitization respects local ontologies and strengthens, rather than erodes, cultural sovereignty.

Ultimately, the findings of this study underscore the need for intercultural dialogue that bridges state agencies, technologists, and local communities, fostering mutual understanding and co-creation of heritage futures. Justice-oriented heritage policy should promote transparency, accountability, and cultural pluralism, resisting the tendency to impose uniform narratives or extractive data practices. By embedding these values in both policy frameworks and technological design, Indonesia can build a more equitable, resilient, and inclusive system of cultural heritage governance, one that not only preserves its extraordinary cultural diversity but also empowers communities as active stewards of their histories and identities in the digital age.

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