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DIGITAL TECHNOLOGY IN CULTURAL HERITAGE PRESERVATION: A SCOPING REVIEW OF OPPORTUNITIES AND IMPLEMENTATION CHALLENGES

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Abstract
Cultural heritage is at risk of damage, decay, and loss of authenticity. Tangible heritage (monuments, sites, artifacts) and intangible heritage (living practices, knowledge, skills) face different threats and need different preservation responses. However, evidence on how digital technologies serve each type is scattered across reviews that focus on a single technology. This scoping review maps the digital technologies used in cultural heritage preservation, their opportunities, and their implementation challenges, and it keeps tangible and intangible heritage separate in the analysis. The review followed Arksey and O'Malley (2005), Levac et al. (2010), and the JBI guidance. It is reported with PRISMA-ScR and a PRISMA 2020 flow diagram. Scopus was searched and reference lists were checked manually for English-language documents published in 2020–2026. From 433 records, 24 full texts were sought and 19 studies were included (4 reviews, 10 empirical studies, and 5 conceptual studies). The technologies were grouped into five categories by function: digital capture and documentation; integrated modelling and monitoring; computational analysis and generation; immersive presentation; and data governance, provenance, and access. Capture technologies for tangible heritage are the most mature. Digital twins with live sensors, generative AI, blockchain, and the metaverse are still at the pilot, prototype, or concept stage. Only three studies address intangible heritage alone, and no empirical study reports community-defined consent or data governance. Success depends on stable funding, technical skills, interoperability, long-term digital curation, and governance that gives communities authority over their heritage. The restrictive single-database search is a main limitation.

Keywords: Cultural Heritage, Digital Technology, Intangible Cultural Heritage, Data Governance, Scoping Review

INTRODUCTION

There are two primary types of cultural heritage. Archeological sites, structures, monuments, and relics are examples of tangible heritage. The customs, expressions, knowledge, and abilities that communities consider to be a part of their culture are included in intangible heritage (UNESCO, 2003). There are distinct threats to the two kinds. Disasters, urbanization,

armed conflict, and environmental deterioration all harm tangible heritage (Kovalchuk et al., 2025; Mahesh et al., 2026; Mazzetto, 2024). Intangible heritage is lost when knowledge is no longer passed between generations, when practitioners age or move away, and when local practices give way to global culture (Khamdamovna, 2025; Ruan et al., 2025; Wei et al., 2026).

These differences change what "preservation" means. For a building or an artifact, preservation mainly means keeping its material, shape, and condition. The main authenticity risk is that a digital copy or reconstruction misrepresents the original or comes to replace it (cf. Mazzetto, 2024). For a living practice, authenticity lies in the practice itself, its context, and the people who carry it. A recording does not guarantee that the practice continues, and digitization can remove a practice from its context or reinterpret it without the community's control (Khamdamovna, 2025; Wang & Zhou, 2025). This is why UNESCO (2003) speaks of "safeguarding" intangible heritage rather than conserving it. Technologies, authenticity risks, and forms of preservation therefore cannot be assumed to be the same for both types of heritage.

Conventional conservation relies on manual documentation, physical exhibitions, and paper archives. These methods are slow, costly, limited in coverage and precision, hard to apply at remote sites, and mostly reactive (Chandani, 2026; Ghasrah et al., 2025; Mazzetto, 2024; Oladokun et al., 2024; W. Li et al., 2025). Digital technologies have been proposed as an alternative, and research on them has grown steadily (Jiang et al., 2025; H. Wang & Yang, 2025).

Even so, most existing reviews focus on one technology or one type of heritage. Examples are digital twins for historic buildings (Mazzetto, 2024), 3D technologies in historic gardens (F. Li et al., 2025), artificial intelligence (B. Li et al., 2026; Colace et al., 2025), immersive technologies (Jiang et al., 2025), and digital technologies for intangible heritage only (Wei et al., 2026). Few studies compare technologies with each other, or ask whether findings about buildings and artifacts also hold for living practices. As a result, it is still unclear which technologies are mature, which conditions make implementation succeed, and what this means for the rights of the communities that own the heritage.

This scoping review addresses that gap. It contributes (1) a technology taxonomy with categories that do not overlap, (2) a synthesis of opportunities and challenges that keeps tangible and intangible heritage apart, and (3) a critical assessment of technology maturity, institutional conditions, and community rights. The objectives are to (1) map the categories of digital technology used in cultural heritage preservation in the 2020–2026 literature, by heritage type; (2) identify the reported opportunities and the technical, financial, institutional, and ethical challenges; (3) assess which technologies are mature and which are still experimental, and which conditions shape implementation; and (4) identify research gaps and propose a future research agenda.

RESEARCH METHOD

This study is a scoping review. This design suits the aim, which is to map a broad, fast-growing, and multidisciplinary field rather than to measure the effect of one intervention. The review followed the framework of Arksey and O'Malley (2005), as refined by Levac et al. (2010). The Joanna Briggs Institute (JBI) guidance (Peters et al., 2020) was used to define the eligibility criteria (Population–Concept–Context) and to plan data charting. This review was guided by the following research question: "What technologies exist for cultural heritage preservation, and what opportunities and challenges are associated with their implementation?"

The search had three steps. First, a limited search in Scopus was used to refine the keywords. Second, the following search string was applied in Scopus: ("cultural heritage" OR "heritage" OR "cultural preservation" OR "cultural conservation") AND ("technology" OR "technologies" OR "innovation" OR "digital tools") AND ("preservation" OR "conservation" OR "restoration" OR "maintenance") AND ("documentation" OR "archiving" OR "recording" OR "monitoring") AND ("3D modeling" OR "virtual reality" OR "augmented reality" OR "digital imaging") AND ("materials" OR "techniques" OR "methods" OR "approaches"). This search returned 419 documents. Third, the reference lists of the included articles and of relevant review articles were checked manually, which added 14 records.

The eligibility criteria are shown in Table 1. They cover document type, the definition of cultural heritage, the type of technology, and the implementation context. Reviews and conceptual papers were kept together with empirical studies for two reasons. First, some technologies (blockchain, the metaverse, generative AI, and digital twins) are discussed mostly in conceptual or review form. Leaving these papers out would hide how limited the evidence for them is. Second, reviews bring together evidence on ethics and implementation barriers that single studies rarely cover. To keep the three evidence types distinct, every source was coded as review [R], empirical [E], or conceptual [C], and this code is used in all tables.

Table 1. Eligibility criteria (Population–Concept–Context)

Domain	Included	Excluded
Document type	Peer-reviewed journal articles, conference papers, and book chapters that report empirical or technical work (case studies, field comparisons, prototypes, user or interview studies), literature reviews, or conceptual, position, or narrative analysis	Records with no analysis of a technology or its implementation (e.g., news items, editorials, abstract-only records)
Cultural heritage (population)	Tangible heritage: monuments, buildings, sites, museum objects. Intangible heritage: practices, representations, expressions, knowledge, skills, with associated objects and spaces. Digital or digitalized heritage when the authors frame it as cultural heritage	Natural heritage only; "heritage" in the sense of legacy software or systems with no cultural framing
Technology (concept)	Digital technologies applied for preservation purposes (documentation, conservation, monitoring, restoration, safeguarding, access) that fit at least one category of the taxonomy in Table 2	Non-digital conservation methods; digital work with no preservation purpose
Implementation context	Any setting (sites, museums, archives, institutions, communities, platforms) and any region; reports of opportunities, challenges, or enabling conditions	Purely algorithmic work with no heritage use case or discussion of implementation
Time, language, access	Published 2020–2026; English; full text retrievable	Other periods or languages; full text not retrievable (reported as "not retrieved")

The selection process is shown in Figure 1. A total of 433 records were identified (419 from Scopus and 14 from manual searching). Before screening, 142 records were removed: 9 duplicates, 122 published outside 2020–2026, and 11 not in English. The year and language limits were applied after the search, which is why they appear as removals. The remaining 291 records were screened by title and abstract, and 267 were excluded because they were not

relevant to the topic. Twenty-four reports were sought for full-text retrieval. Five could not be retrieved, even through institutional subscriptions, open-access repositories, and requests to the authors. The other 19 reports were read in full and checked against Table 1. None was excluded at this stage (reports excluded, n = 0), so 19 studies were included

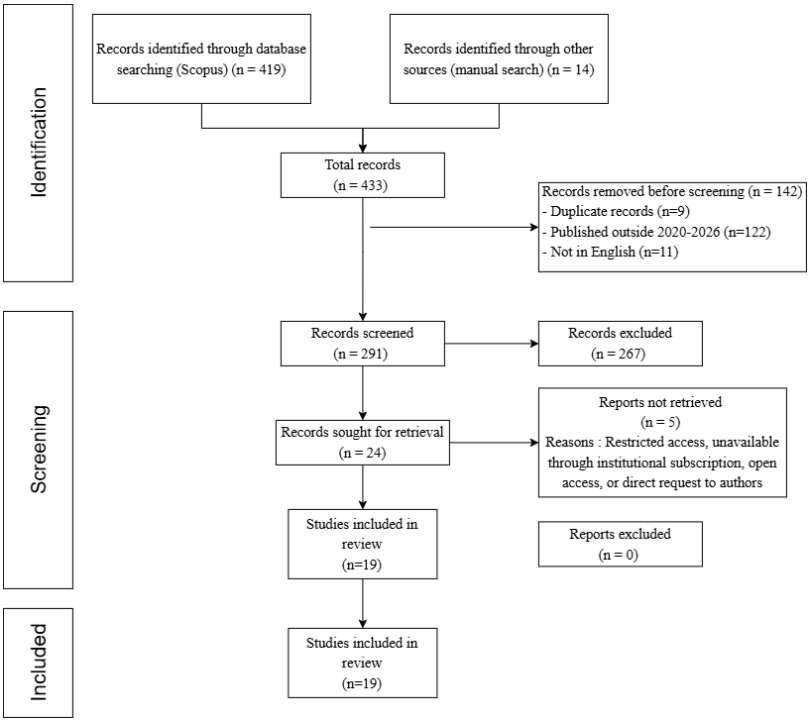


Figure 1. PRISMA diagram

Data from the 19 studies were charted in a form that was refined during the process (Levac et al., 2010). The form recorded author, year, and country (of the first author's affiliation); evidence type; heritage type (tangible, intangible, both or general, or digital); technology category; implementation context; aim; key findings; and limitations. Technologies were classified by the function they perform in a preservation workflow, not by hardware or platform, so each technology belongs to only one category. Each study received one primary category and, where relevant, secondary categories. Broad reviews that cover several categories were marked as spanning categories.

The charted findings were analyzed thematically and inductively. They were grouped into five themes (Table 4) and compared by heritage type within each theme. To limit double counting when reviews and other studies are analyzed together, four steps were taken. (1) The reference lists of the four reviews (Mahesh et al., 2026; Mazzetto, 2024; Mendoza et al., 2023; Suaidi et al., 2026) were checked for the 15 other included studies, and no overlap was identified. This check is limited to cited references, so it cannot detect studies that a review screened but did not cite. (2) Findings from reviews were reported separately from findings of the other studies and marked [R], and the number of studies that a review itself covers was not added to any count. (3) All counts use the 19 included sources as the unit of analysis. (4) When a review and another study support the same point, it is treated as one finding supported by two types of evidence, not as two independent confirmations. Publications cited only in the Introduction were not charted and contribute no findings.

RESULT AND DISCUSSION

Selection and characteristics of the evidence

Nineteen studies published between 2021 and 2026 were included (Figure 1), and 13 of them were published in 2025–2026. The corpus has four reviews [R] (Mahesh et al., 2026; Mazzetto, 2024; Mendoza et al., 2023; Suaidi et al., 2026), ten empirical studies [E] (field comparisons, case studies, tested prototypes, and interview or mixed-methods studies), and five conceptual, position, or narrative studies [C] (Grzeszczuk et al., 2026; Khamdamovna, 2025; Oladokun et al., 2024; Pasupuleti, 2025; Xiong et al., 2025). Xiong et al. (2025) is coded as conceptual because its framework is illustrated with practice cases but not tested in a replicable design.

By heritage type, eight studies address tangible heritage only, three address intangible heritage only, seven address both types or heritage in general, and one addresses digital or digitalized heritage. The first authors are based in 15 countries. Table 3 gives the main characteristics.

Table 3. Condensed characteristics of included studies

Author (year)	Country	Evidence	Heritage type	Category (primary; secondary)
Aldweesh (2023)	Saudi Arabia	E (prototype)	Both (sites, artifacts, TCE)	C5
Daineko et al. (2025)	Kazakhstan	E (prototype, tested)	Tangible (museum)	C4; C3
Ghasrah et al. (2025)	Bahrain	E (comparative case)	Tangible (fort, archaeological site)	C1
Grzeszczuk et al. (2026)	Poland	C (panel)	Digital/digitalized	C5; C4
Khamdamovna (2025)	Uzbekistan	C (document analysis)	Intangible (practices, values)	C5; C1, C4
Kovalchuk et al. (2025)	Ukraine	E (case study)	Tangible (building)	C1; C2
Kudela et al. (2025)	Slovakia	E (comparative)	Tangible	C1
Mahesh et al. (2026)	India	R (systematic)	Both	Spans C3, C4, C5
Mazzetto (2024)	Saudi Arabia	R (review + expert survey)	Tangible (heritage buildings)	C2; C1, C3
Mendoza et al. (2023)	Colombia	R (systematic)	Both	Spans C1, C3, C4
Oladokun et al. (2024)	Nigeria	C (conceptual)	Both	C4
Pasupuleti (2025)	India*	C (narrative)	Tangible	C2; C1, C3
Ruan et al. (2025)	China	E (system + usability)	Intangible	C4; C1
Sandriester et al. (2025)	Austria	E (mixed methods)	Both (small institutions)	C5
Suaidi et al. (2026)	Malaysia	R (systematic)	Both	Spans C1, C3, C4, C5
Todorova-Ekmekci et al. (2021)	Bulgaria	E (interviews)	Tangible (museum objects)	C5; C1, C4
Ulvi (2021)	Turkey	E (field case)	Tangible (archaeological site)	C1
Wang & Zhou (2025)	China	E (development)	Intangible (dyeing motifs)	C3
Xiong et al. (2025)	China	C (framework + cases)	Both	C3; C2, C4

E = empirical, R = review, C = conceptual, TCE = traditional cultural expressions.

C1, digital capture and documentation. Terrestrial laser scanning (TLS) and photogrammetry record shape and appearance as point clouds and textured models (Kovalchuk et al., 2025; Kudela et al., 2025; Ulvi, 2021). Field comparisons agree that TLS gives higher point

density and accuracy on complex surfaces. UAV photogrammetry is cheaper and faster and can reach places that are hard to access (Ghasrah et al., 2025; Kudela et al., 2025; Ulvi, 2021).

C2, integrated modelling and monitoring. BIM models built from scan data, and digital twins that link such models to IoT sensor data, organize information and follow the condition of a structure over time (Kovalchuk et al., 2025; Mazzetto, 2024; Pasupuleti, 2025). Mazzetto (2024) describes a move toward preventive and predictive conservation, but also notes problems of integration and standardization.

C3, computational analysis and generation. Machine learning supports cataloging and damage detection (Mahesh et al., 2026). Big data and CAD support digital repair and early warning (Xiong et al., 2025). A generative model fine-tuned with LoRA creates new designs from digitized traditional motifs (Wang & Zhou, 2025).

C4, immersive presentation and interaction. The studies include an AR museum application with machine-learning object recognition (Daineko et al., 2025), a VR platform for intangible heritage built with Unity3D, 3D scanning, and motion capture (Ruan et al., 2025), and a conceptual account of the metaverse (Oladokun et al., 2024).

C5, data governance, provenance, and access. This category includes blockchain smart contracts for provenance and rights management (Aldweesh, 2023); websites, virtual tours, and open repositories (Sandriester et al., 2025; Todorova-Ekmekci et al., 2021); and analyses of the cultural effects of digital platforms and of digital-format obsolescence (Grzeszczuk et al., 2026; Khamdamovna, 2025).

The distribution is uneven by heritage type. By primary category, C1 has four studies, C2 has two, C3 has two, C4 has three, and C5 has five. Three reviews span several categories. All six studies with a primary code of C1 or C2 concern tangible heritage. The three studies on intangible heritage alone fall under C3 (Wang & Zhou, 2025), C4 (Ruan et al., 2025), and C5 (Khamdamovna, 2025).

Thematic synthesis

Table 4 is the main frame for the rest of the Results. Within each theme, findings are reported by evidence type and, where the studies allow, by heritage type.

Table 4. Thematic map of opportunities and challenges (evidence type in brackets)

Theme	Sub-theme	Focus	Sources [evidence type]
1. Technology categories and heritage focus	C1 capture and documentation	T	Ghasrah et al. (2025) [E]; Kovalchuk et al. (2025) [E]; Kudela et al. (2025) [E]; Ulvi (2021) [E]; Mendoza et al. (2023) [R]
	C2 modelling and monitoring	T	Mazzetto (2024) [R]; Pasupuleti (2025) [C]; Xiong et al. (2025) [C]; Kovalchuk et al. (2025) [E]
	C3 analysis and generation	I / B	Wang & Zhou (2025) [E]; Xiong et al. (2025) [C]; Mahesh et al. (2026) [R]; Mendoza et al. (2023) [R]
	C4 immersive presentation	T / I	Daineko et al. (2025) [E]; Ruan et al. (2025) [E]; Oladokun et al. (2024) [C]; Mahesh et al. (2026) [R]; Suaidi et al. (2026) [R]
	C5 governance, provenance, access	B	Aldweesh (2023) [E]; Sandriester et al. (2025) [E]; Todorova-Ekmekci et al. (2021) [E]; Khamdamovna (2025) [C]; Grzeszczuk et al. (2026) [C]; Mahesh et al. (2026) [R]
2. Opportunities: accuracy,	Geometric precision and point density	T	Ulvi (2021) [E]; Kovalchuk et al. (2025) [E]; Kudela et al. (2025) [E]

efficiency, preventive conservation	Time, cost, and safety gains over conventional methods	T	Ghasrah et al. (2025) [E]; Ulvi (2021) [E]; Kudela et al. (2025) [E]
	Real-time monitoring and predictive conservation	T	Mazzetto (2024) [R]; Pasupuleti (2025) [C]; Xiong et al. (2025) [C]
	AI-assisted cataloging and damage detection	B	Mahesh et al. (2026) [R]; Xiong et al. (2025) [C]
3. Opportunities: engagement, access, revitalization	Visitor engagement and learning	T / I	Daineko et al. (2025) [E]; Ruan et al. (2025) [E]; Grzeszczuk et al. (2026) [C]
	Wider access (virtual tours, online exhibitions, repositories)	T	Todorova-Ekmekci et al. (2021) [E]; Pasupuleti (2025) [C]; Xiong et al. (2025) [C]
	Tourism and regional development	T / B	Sandriester et al. (2025) [E]; Todorova-Ekmekci et al. (2021) [E]
	Revitalization of living practices	I	Wang & Zhou (2025) [E]; Ruan et al. (2025) [E]; Oladokun et al. (2024) [C]
	Provenance and rights management	B	Aldweesh (2023) [E]; Mahesh et al. (2026) [R]
4. Challenges: technical, operational, institutional	Cost, infrastructure, hardware	B	Ghasrah et al. (2025) [E]; Ruan et al. (2025) [E]; Sandriester et al. (2025) [E]; Mazzetto (2024) [R]; Xiong et al. (2025) [C]
	Expertise and human resources	B	Kudela et al. (2025) [E]; Sandriester et al. (2025) [E]; Mazzetto (2024) [R]
	Interoperability and standardization	B	Mahesh et al. (2026) [R]; Mazzetto (2024) [R]; Xiong et al. (2025) [C]
	Format obsolescence and long-term storage	B	Grzeszczuk et al. (2026) [C]
	Regulatory and site constraints (flight rules, weather, conflict)	T	Ghasrah et al. (2025) [E]; Ulvi (2021) [E]; Kovalchuk et al. (2025) [E]
5. Challenges: ethical, social, policy	Authenticity and cultural representation	B	Wang & Zhou (2025) [E]; Daineko et al. (2025) [E]; Oladokun et al. (2024) [C]; Khamdamovna (2025) [C]; Mahesh et al. (2026) [R]
	Data ownership, digital colonialism, community rights	B	Pasupuleti (2025) [C]; Oladokun et al. (2024) [C]; Mahesh et al. (2026) [R]
	Privacy and data security	B	Aldweesh (2023) [E]; Oladokun et al. (2024) [C]
	Homogenization and loss of local narratives	I	Khamdamovna (2025) [C]

Focus: T = tangible, I = intangible, B = both or general. Evidence: [E] empirical, [R] review, [C] conceptual. Reviews and the primary studies they could in principle cover were checked for overlap.

Opportunities: accuracy, efficiency, and preventive conservation.

The strongest empirical evidence is here, and it concerns tangible heritage almost entirely [E]. Ulvi (2021) and Kudela et al. (2025) report higher point density and accuracy from TLS, and Ulvi (2021) found that combining UAV and TLS data gave more complete models. Ghasrah et al. (2025) report that drones are safer, faster, and cheaper than conventional methods for structures that are hard to reach. Kovalchuk et al. (2025) show that non-invasive scanning can document a building at risk during war, although the roofs could not be modelled. Claims about real-time monitoring and predictive conservation rest on a review [R] (Mazzetto, 2024) and on conceptual work [C] (Pasupuleti, 2025; Xiong et al., 2025). Xiong et al. (2025) report 95% accuracy for an early-warning system, but this comes from an illustrative case, not a repeated field trial. For intangible heritage, documentation means capturing skilled movement and knowledge. Ruan et al. (2025) combined 3D scanning and motion capture to place 300 cultural elements on a VR platform.

Opportunities: engagement, access, and revitalization.

Daineko et al. (2025) report that an AR application increased engagement in a partner museum. In a usability study with 120 participants, Ruan et al. (2025) reported 98.7% immersion satisfaction and 38% higher learning retention than conventional video. Grzeszczuk et al. (2026) argue [C] that VR supports well-being and social identity. Digital platforms are linked to tourism, education, and regional development, especially for small institutions in peripheral regions [E] (Sandriester et al., 2025; Todorova-Ekmekci et al., 2021). For intangible heritage, the opportunity is described as revitalization. Wang and Zhou (2025) found that a generative model improved design efficiency and opened a new store of creative resources. Two cautions apply. The outcomes in this theme are satisfaction, engagement, and learning, which are not preservation outcomes. The user studies were also done at a single site or in a single region.

Challenges: technical, operational, and institutional.

The cost of equipment such as drones, scanners, and head-mounted displays, and of the infrastructure to support them, is a barrier for small institutions in resource-limited settings (Ghasrah et al., 2025; Sandriester et al., 2025). Processing 3D data and building digital twins need skills from several fields, which are often missing (Kudela et al., 2025; Mazzetto, 2024). Weak standards and poor interoperability make it hard to connect platforms (Mahesh et al., 2026; Mazzetto, 2024; Xiong et al., 2025). Digital-format obsolescence threatens long-term access to digital heritage itself (Grzeszczuk et al., 2026). Conditions at the site, such as flight rules, weather, and wartime access, also limited data collection (Ghasrah et al., 2025; Kovalchuk et al., 2025; Ulvi, 2021).

Challenges: ethical, social, and policy.

Studies on immersive technology and generative AI raise questions about authenticity and the distortion of cultural meaning (Oladokun et al., 2024; Wang & Zhou, 2025). Questions of data ownership and “digital colonialism” arise when community heritage is digitized and managed by outside parties (Oladokun et al., 2024; Pasupuleti, 2025). Digital platforms may make cultures more alike and erase local stories (Khamdamovna, 2025), and they raise privacy and security concerns (Aldweesh, 2023). Among the empirical studies, none reports community-defined consent or governance rules. These issues are discussed mainly in the conceptual and review literature, and they are analyzed further in the Discussion.

DISCUSSION

Tangible and intangible heritage: different problems, different technology fit.

The evidence is unbalanced. Eight studies address tangible heritage only and three address intangible heritage only. Every primary study on capture or monitoring concerns tangible heritage. Capture technologies fit tangible heritage because the thing to be preserved is a material form that can be measured, and success can be judged with technical criteria such as accuracy, completeness, and cost. For living practices, what must be preserved is not a form but a process of passing knowledge from person to person. A VR platform or a generative model can record or re-present a craft, but neither shows that the craft will continue to be practiced. The authenticity risks differ as well. For buildings and artifacts, the risk is confusing the copy with

the original or losing material information. For living practices, the risk is losing context, freezing the practice, and reinterpreting it without its bearers (Khamdamovna, 2025; Wang & Zhou, 2025). Findings from the tangible side, such as the accuracy comparisons of TLS and UAV photogrammetry, should therefore not be generalized to intangible heritage. Studies of intangible heritage also need outcome measures that include transmission, benefit to practitioners, and community acceptance, not only user satisfaction.

Technology maturity and institutional conditions.

Table 5 groups the technologies by the level of maturity that the evidence supports. Capture technologies are the most mature. They are backed by repeated field comparisons with measurable results, and their remaining problems are mostly institutional: cost, skills, flight rules, and capacity to process data (Ghasrah et al., 2025; Kudela et al., 2025; Ulvi, 2021). At the other end, blockchain, generative AI, and the metaverse rest on one prototype, one development case, and conceptual argument. A pattern follows from this. As maturity falls, the main barrier changes from resources and skills to governance, because questions of rights, consent, and authenticity must be settled before wider use. Four institutional conditions appear across the studies: stable funding instead of one-off project money (Khamdamovna, 2025; Sandriester et al., 2025); interdisciplinary teams that link technologists, conservators, and communities (Mazzetto, 2024; Oladokun et al., 2024); interoperability standards and long-term digital curation (Grzeszczuk et al., 2026; Mahesh et al., 2026); and policy and governance frameworks that include owner communities (Mahesh et al., 2026; Suaidi et al., 2026). These conditions come mostly from the limitations sections of the studies and from reviews. They are therefore likely success factors, not tested ones.

Table 5. Technology maturity and institutional conditions (interpretive assessment)

Maturity	Technologies	Evidence in this corpus	Institutional conditions for success
Established	TLS and photogrammetry (ground and UAV); scan-to-BIM; websites and repositories (unevenly adopted)	Repeated field comparisons with quantitative accuracy and cost results [E]; museum-level adoption reported, with large differences between institutions [E]	Funding for equipment and staff; technical expertise for data processing; permits for flights; data standards and long-term storage plans
Pilot-stage	AR/VR for engagement; AI cataloging and damage detection; IoT-linked digital twins	Single-site prototypes and usability studies [E]; a review noting minimal large-scale field implementation [R]; digital-twin evidence mainly from reviews and conceptual work [R, C]	Interdisciplinary teams; interoperability across platforms; lightweight and edge-based computing where resources are limited; evaluation designs that measure preservation outcomes
Experimental	Generative AI for intangible heritage; blockchain provenance and rights; the metaverse	One development case [E] (generative AI); one testnet prototype without field validation [E] (blockchain); conceptual accounts [C] (metaverse)	Community consent and governance frameworks before deployment; rules on provenance labelling of AI output; legal clarity on rights; validation in real institutions

Geographic and authorship patterns.

First authors are based in 15 countries, but the distribution is concentrated. China (3 studies), Saudi Arabia (2), and India (2) account for seven of the 19 studies. By region, eight

studies come from Asia, four from the Middle East and Turkey, five from Europe, and one each from Africa and Latin America. None comes from North America or Oceania, and Southeast Asia appears once (Malaysia). The type of evidence also varies by region. Field studies of capture technologies come from Turkey, Slovakia, Ukraine, and Bahrain. Work on AI and VR for intangible heritage comes from China. The studies from Nigeria, Colombia, India, and Uzbekistan are reviews or conceptual papers. Evidence on implementation in low-resource settings is therefore thin and mostly conceptual, even though resource-limited institutions are those that Sandriester et al. (2025) and Mahesh et al. (2026) describe as most constrained. Three cautions apply. The corpus is small, so the patterns are only indicative. Several countries with large heritage-technology literatures, such as Italy, Spain, and the United Kingdom, are absent. This is more likely a result of the restrictive single-database search than a finding about research activity. Finally, country refers to the first author's affiliation, which may differ from where the heritage is located.

Community rights, data governance, consent, and AI reinterpretation.

Digitization creates new data, such as 3D models, motion-capture records, recordings, and training sets for AI. Questions of who owns and controls these data follow. Pasupuleti (2025) warns that many artifacts and sites belong to communities or nations that may not control their digital representations. Oladokun et al. (2024) point to open questions about intellectual property and cultural sovereignty over virtual reproductions. Mahesh et al. (2026) go furthest. They propose combining the FAIR principles with the CARE Principles for Indigenous Data Governance (Collective benefit, Authority to control, Responsibility, and Ethics; Carroll et al., 2020), and they cite community-governed repositories such as Mukurtu, where access and metadata follow community cultural protocols. These positions are consistent with the right of Indigenous peoples to maintain, control, and develop their cultural heritage and traditional knowledge (United Nations, 2007, Art. 31).

Four points follow for implementation. First, consent must be collective, specific, and continuing. Research-ethics consent covers individual participants. It does not decide who may copy, sell, or reuse a community's heritage, including as AI training data. In the corpus, informed-consent statements concern research participants (Sandriester et al., 2025) or are marked "not applicable" (Wang & Zhou, 2025), so they say nothing about cultural rights over the content. Second, access should follow community protocols. Some knowledge is not meant for public sharing, so repositories that are open by default can cause harm. Third, technical tools for rights need careful fit. Aldweesh (2023) proposes smart contracts to manage rights and royalties for traditional cultural expressions, which is a useful idea. However, a ledger that cannot be changed sits uneasily with a community's right to restrict or withdraw access to sensitive material, and it enforces the rules that designers wrote, not the rules that the community holds. Permissioned designs, which Mahesh et al. (2026) suggest for pilot projects, give more control over who takes part, and keeping sensitive content outside the ledger would reduce the problem further. Fourth, authority over data comes before the other three points: who sets the rules matters more than which tool enforces them.

AI-generated reinterpretation is a separate risk. Wang and Zhou (2025) show that a generative model trained on digitized motifs can produce new designs quickly, and they note limits in authenticity and reliability. The concern is that such models can mix motifs without their symbolic and social meaning, can fill circulation with convincing but inauthentic versions, and can move authorship and benefit away from the practitioners whose work trained them.

Mazzetto (2024) also stresses that AI used to alter or reconstruct images must respect integrity and authenticity. Mahesh et al. (2026) call for AI processes that respect symbolic and Indigenous value, with informed consent. Drawing these points together, minimum safeguards for generative AI on living heritage would include: community review of training data and outputs; no training on restricted or sacred material; clear labels that separate documented heritage from machine-generated content; credit and benefit sharing with practitioners; and a way for the community to withdraw its material. These safeguards are our own synthesis, not tested practice. No empirical study in this corpus puts community-defined consent or governance into practice, and this absence is itself a main finding.

Research gaps and future agenda.

Table 6 summarizes the gaps that this synthesis reveals and the research they call for. The gaps share one theme. The field has become good at capturing and displaying heritage, but it has shown much less that digital preservation keeps heritage alive, especially living heritage, in the hands of the people who own it.

Table 6. Research gaps and future research agenda

Gap	Evidence in this review	Research direction
Intangible heritage is under-evidenced	3 of 19 studies address intangible heritage only; none concerns monitoring or provenance	Studies that test whether digital tools support transmission to new practitioners, with outcome measures for continuity and community benefit, not only satisfaction
Experimental technologies lack field validation	Blockchain, generative AI, and the metaverse rest on one prototype, one development case, and conceptual work	Pilot trials in real institutions with shared evaluation protocols; longitudinal studies of IoT-linked digital twins and AI damage detection
Community governance is not operationalized	No primary study reports community-defined consent or data governance	Participatory action research and co-design with owner communities; CARE- and FAIR-aligned protocols tested in practice; rules for AI use on living heritage
Geographic and resource imbalance	Concentration in a few countries; lower-resource settings appear mainly as conceptual or review evidence	Comparative implementation studies in underrepresented regions (Africa, Latin America, Southeast Asia, the Pacific); lightweight and edge-based tools
Long-term sustainability is rarely studied	Obsolescence, interoperability, and recurring cost are raised mostly as limitations	Longitudinal cost and sustainability studies, including the environmental footprint of digital preservation and preservation of the digital records themselves
Evidence is hard to compare and combine	Mixed designs and outcome measures; reviews and primary studies overlap in principle	Common reporting of heritage type and outcomes; transparent handling of overlap in future syntheses

CONCLUSION

This scoping review mapped the use of digital technology in cultural heritage preservation using 19 studies published between 2021 and 2026. A taxonomy of five categories that do not overlap (capture and documentation; modelling and monitoring; analysis and generation; immersive presentation; and governance, provenance, and access) replaces the overlapping categories used in earlier mapping. The evidence is strongest and most mature for capturing tangible heritage. IoT-linked digital twins, AI, blockchain, generative AI, and the metaverse are still at the pilot, prototype, or concept stage. Only three studies address intangible heritage alone, and the two types of heritage differ in what preservation requires and in their authenticity risks. Success depends on stable funding, technical skills, interoperability and long-

term digital curation, and governance that gives owner communities authority over consent, access, and reuse of their heritage, including by AI. Future research should test whether digital tools help living practices continue, validate experimental technologies in real institutions, put community data governance into practice, and widen the geographic base of the evidence

SUGGESTION

This review has several limitations. (1) The search was restrictive. Only Scopus was searched, and all six concept groups were joined with AND, including specific technology terms ("3D modeling", "virtual reality", "augmented reality", "digital imaging") and words such as "preservation" and "documentation". Studies that use other terms, such as "safeguarding" for intangible heritage, or that focus on AI, blockchain, digital twins, or drones, may have been missed. The corpus may therefore over-represent 3D, AR, and VR documentation and under-represent other technologies and intangible heritage. (2) No report was excluded at the full-text stage on eligibility grounds, but five reports could not be retrieved, and their effect on the findings is unknown. (3) The corpus mixes reviews, empirical studies, and conceptual papers, and no quality appraisal was done. The overlap check used reference lists only, so it cannot detect studies that a review screened but did not cite. (4) The maturity assessment (Table 5) and the geographic patterns are interpretive and based on a small corpus, and country refers to the first author's affiliation. (5) None of the empirical studies charted here reports community-defined consent or governance, so the discussion of community rights relies on conceptual papers, a review (Mahesh et al., 2026), and external frameworks. (6) The review is based mainly on Scopus, covers only English-language documents from 2020–2026, and excludes grey literature such as reports from UNESCO, ICOMOS, and ICCROM.

Future reviews should search several databases (for example, Scopus, Web of Science, and IEEE Xplore), combine technology terms with OR, and run separate searches for each technology family and for intangible heritage. They should also include grey literature, regional databases, and non-English publications, as Suaidi et al. (2026) recommend, record the reasons for every full-text exclusion, and consider appraising study quality. In practice, the findings suggest that interdisciplinary frameworks involving communities from the start, interoperability protocols, ethical governance guidelines, and low-cost solutions for resource-limited institutions could help share the benefits of digital technology more fairly.

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