

AR-Based Cultural Heritage Preservation: A Review of Technologies, Applications, and Research Challenges

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Abstract — Augmented Reality (AR) can make cultural heritage easier to explore by placing digital information and three-dimensional (3D) reconstructions into a user's view of the real world. It can support museum interpretation, tourism, education, and the documentation of historical objects. However, an engaging AR experience is not enough on its own to preserve heritage. A useful system also needs reliable historical information, access for people using different devices and network conditions, and a plan for keeping digital records available over time. This paper reviews four selected studies supplied for the review: an AR software adaptor for smart glasses, an interactive globe for tourism, an AR exhibition of traditional Chinese water measurement instruments, and the WebAR-based ARcheoTech platform for Indian heritage. Three wider review papers are also considered to place these examples in context. The studies show different ways to develop and deliver AR experiences, but they use different application settings and evaluation approaches, so their results cannot be compared as if they came from one experiment. Based on this focused review, the paper identifies research opportunities in source-linked historical narratives, community review of cultural information, lowbandwidth access, digital provenance, and long-term preservation. It proposes a conceptual framework called HeritageAR India that combines WebAR, structured heritage records, source and contributor information, optimized 3D assets, and preservation-oriented archiving. The framework is a proposal for future development; it has not been implemented or experimentally evaluated in this paper.

Keywords— Augmented Reality, Cultural Heritage Preservation, WebAR, Digital Reconstruction, Digital Archiving, Heritage Tourism.

I. INTRODUCTION

Culture is preserved through monuments, historical buildings, museum objects, traditional practices, oral histories, and the knowledge passed between generations. Physical objects and places can be damaged by weather, pollution, conflict, ageing, or limited maintenance. Digital technologies provide ways to document and explain this heritage, but a digital copy does not replace the original object or the people connected to it.

Augmented Reality (AR) overlays digital information, images, or 3D models on a view of the real environment.

For example, a visitor looking at a damaged building could view a reconstruction showing how part of the building may have looked in the past. A museum visitor could rotate a 3D model of an artifact, while a student could explore how a historical instrument was used. Such experiences can make information more interactive than a static label or photograph. Previous research shows that AR has been used for 3D reconstruction, digital heritage, virtual museums, education, tourism, and gamified learning [1]. Reviews also describe the importance of considering user experience, technical requirements, and the participation of visitors and communities

[2], [3]. These findings suggest that AR heritage systems should be assessed not only by their visual quality, but also by how well they communicate reliable information and work for different users.

This paper reviews selected studies on AR technologies and cultural heritage. Its objectives are to: (i) summarize the approaches used in the selected studies; (ii) compare their applications, technologies, and reported evidence; (iii) identify potential research gaps suggested by the reviewed material; and (iv) propose a framework for future research. The paper is a focused narrative review, not an exhaustive systematic review.

II. REVIEW METHODOLOGY AND LITERATURE SELECTION CRITERIA

This paper uses a focused narrative review. The four primary studies were supplied as PDFs for this work: ADA, AR Journeys, Digital Exhibition of Traditional Chinese Water Measurement Instruments, and ARcheoTech. Duplicate copies of ARcheoTech were treated as one study. Three broader review papers were added to provide context: Boboc et al. [1], Silva et al. [2], and Ramtohul and Khedo [3].

The primary papers were included because they cover different but related parts of AR heritage work: crossdevice development, tourism and exploration, digital reconstruction of historical objects, and browser-based heritage access. The contextual reviews were selected because they discuss trends, participation, technical requirements, and implementation challenges in cultural heritage AR.

For each paper, the review recorded its objective, application setting, technologies where stated, main contribution, evaluation approach, and limitations that could be identified from the paper. Findings are described as reported by the authors. Numbers reported by ARcheoTech, for example, are not treated as independently verified results. Where the papers do not provide enough evidence for a direct comparison, this limitation is stated rather than filling the gap with assumptions. This selection is limited and does not represent every publication in the field. No comprehensive database search, full screening process, or PRISMA flow was conducted for this draft. Therefore, the paper should not be described as a systematic review. A later version intended for publication should document database searches, search dates, exact search strings, screening decisions, and reasons for excluding papers.

III. LITERATURE REVIEW

1. ADA: cross-device AR Development

Jeong et al. present ADA, an Augmented-Reality Development Adaptor for supporting AR glasses [4]. The paper addresses the difficulty of developing AR content for different glasses, where device-specific data formats and capabilities can require separate work. The authors describe data profiles for four AR devices and an SDK developed within the Unity framework. The proposed adaptor converts device data into a standardized form and supports functions needed for AR content, such as tracking and interaction.

This work is relevant to heritage projects because a museum or heritage organization may want its content to run on more than one device. A common development layer may reduce duplicated work. However, the study is primarily about device compatibility and software development, not the historical accuracy or long-term preservation of heritage content. Its contribution should therefore be understood as a technical building block rather than a complete heritage preservation solution.

2. AR Journeys: Interactive Globe for Tourism

Vashisht and Sharma introduce AR Journeys, an interactive globe concept intended to support travel and cultural

exploration [5]. The work connects immersive technology with tourism and presents an approach for exploring destinations through an interactive globe. The paper describes a toolchain involving 3D and visualdesign software and an AR development platform. Its main relevance is the way a geographic interface can help users discover locations and cultural information.

An interactive globe could be useful for connecting heritage sites across regions and showing relationships between locations. However, tourism discovery and preservation are not identical goals. A tourism interface may encourage exploration, while preservation also requires documented sources, careful handling of uncertainty, and reliable long-term storage. These aspects need to be considered when adapting such an approach to a preservation platform.

3. Digital Exhibition of Traditional Chinese Watermeasurement Instruments

Liu, Fan, Yin, and Wu examine the digital preservation and presentation of traditional Chinese watermeasurement instruments [6]. Their work uses historical records and museum artifacts to study the instruments' form and function, digitally reconstructs them, and uses Unity to integrate the reconstructed objects into an AR display. This example shows how AR can communicate the shape and possible use of an object that may be difficult to understand from a photograph alone.

The paper is directly relevant to the interpretation of technical and historical artifacts. The use of historical records and museum objects is important because a 3D model should be based on evidence rather than appearance alone. At the same time, the available paper focuses on a specific class of Chinese instruments. Its approach may inform other projects, but it does not by itself establish how the same process would work for every type of heritage or community.

4. ARcheoTech: Browser-Based AR for Indian Heritage

Babu et al. describe ARcheoTech, a WebAR platform for the preservation and wider access of Indian cultural heritage [7]. The paper reports a browser-based implementation using AR.js, Three.js, React.js, and Firebase, along with Progressive Web App features, interactive 3D artifacts, multilingual support, and gamified learning activities. A browser-based approach can lower the barrier to entry because users may not need to install a separate native application.

The authors report performance figures across low-end, mid-range, and high-end devices, including frame rates of 25–60 frames per second, cached asset loading below 0.8 seconds, and

an average learning gain of 38.1%. They also report higher quiz completion for a gamified condition than a non-gamified condition. These are figures stated in the paper and should be quoted with that qualification; this review has not independently reproduced the tests. Direct comparison with the other selected studies is not possible because the studies use different systems, tasks, and evaluation measures.

ARcheoTech is the closest selected example to a broad access platform for Indian heritage. Its focus on browser access, offline support, language options, and learning is useful for future design. Further work can investigate how heritage sources are checked, how local communities participate in reviewing content, and how digital records remain understandable and usable over many years.

IV. COMPARATIVE ANALYSIS OF EXISTING STUDIES

The selected studies approach AR from different directions. ADA focuses on device compatibility; AR Journeys focuses on tourism discovery; Liu et al. focus on the reconstruction and interpretation of historical instruments; and ARcheoTech combines browser-based access with heritage learning features. These are complementary contributions, but their results are not directly interchangeable.

Study	Main focus	Reported approach / contribution	Boundary for this review
Jeong et al. (2023) [4]	AR glasses compatibility	Unity SDK and profiles for four AR devices; standardized data handling.	Mainly a development adaptor; not a heritage-content evaluation.
Vashisht & Sharma (2024) [5]	Tourism and cultural discovery	Interactive globe concept for exploring travel and cultural destinations.	Tourism focus; preservation governance is not the central question.
Liu et al. (2024) [6]	Historical instruments	Historical records and museum artifacts inform digital reconstruction; Unity-based AR display.	Specific artifact context; findings should not be generalized to all heritage types.
Babu et al. (2026) [7]	Indian heritage access	WebAR/PWA approach, 3D artifacts, language support, gamified learning; authors report performance and learning measures.	Reported figures have not been independently reproduced in this review.

V. RESEARCH CHALLENGES AND IDENTIFIED GAPS

The gaps below are potential research opportunities suggested by this limited set of papers and the broader reviews. They should not be read as proof that no other research has addressed them.

1. Historical Accuracy and Source Transparency

A realistic-looking 3D model can still be historically incorrect. A platform should record the source of each important claim, image, reconstruction, date, and interpretation. Where evidence is incomplete, it should indicate that a reconstruction is uncertain or based on a particular interpretation. This would help users distinguish documented facts from an artist's or researcher's reconstruction.

2. Community Participation and Review

Heritage includes local knowledge, oral histories, traditional skills, and community practices. Experts and community members may hold information that is not present in formal publications. A platform could provide a controlled process for contributors to submit information, cite sources, suggest corrections, and request review. Contributions should not become public as verified facts until an appropriate review process has been completed.

3. Access Across Devices and Network Conditions

AR experiences can be difficult to use on older phones or in locations with weak connectivity. WebAR and offline-capable design can help, but performance depends on model size, device capability, tracking method, and browser support. A system should measure performance across representative devices and network conditions rather than claiming universal compatibility.

4. Long-Term Digital Preservation

Displaying an artifact in AR is not the same as preserving the digital record. The original photographs, 3D models, metadata, licenses, source records, and different versions should be stored in formats that can be exported and checked. Backups, file integrity checks, clear ownership, and migration plans are needed to reduce dependence on a single website or software library.

5. Evaluation Beyond Engagement

User engagement and quiz results can help evaluate an educational application, but they do not prove historical accuracy or long-term preservation. Evaluation should also examine usability, accessibility, content reliability, loading time, frame rate, network use, learning retention, and whether community reviewers consider the presentation appropriate. Research should clearly report participant numbers, tasks, test devices, measures, and limitations.

6. Comparability and Reproducibility

The selected studies use different applications and evaluation methods. Future work should report test conditions and metrics in a consistent way. A shared evaluation checklist would make it easier to understand whether an apparent improvement comes from the technology, the content, the interface, or differences in the user study.

VI. PROPOSED RESEARCH DIRECTIONS

This paper proposes HeritageAR India as a conceptual framework for future investigation. It is not a completed or tested system. Its purpose is to connect accessible AR delivery with reliable cultural information and preservation practices.

1. Proposed Components

- Heritage record repository: stores an artifact or site identifier, name, location where appropriate, description, date or period, media, rights information, and related records.
- Source-linked narratives: connects important historical statements and reconstruction decisions to references, archival records, museum catalogues, or approved oralhistory sources. Uncertain claims should be labelled clearly.
- 3D asset preparation: stores a high-quality master model and prepares compressed or lower-detail versions for devices with limited processing power. Original files should remain preserved separately from optimized display versions.

- WebAR viewer: provides access through a browser where supported. The viewer can offer a non-AR 3D or image-based fallback when AR tracking is unavailable.
- Community contribution and review: allows approved contributors to submit corrections, stories, translations, and additional evidence. A moderator or qualified heritage partner reviews proposed changes before publication.
- Preservation and version history: records content versions, source changes, contributor roles, timestamps, licenses, backups, and file integrity information. This supports traceability and future migration.
- Evaluation dashboard: records technical performance and user-study results separately from claims about preservation success.

2. Proposed Workflow

The proposed workflow begins with selecting a heritage item and collecting available documentation. A curator or research team checks the sources and identifies uncertainties. The team creates or obtains a 3D model, records how it was produced, and prepares optimized versions. The record and model are published through the web platform. Visitors explore the item in AR or through a fallback viewer. Users can submit feedback, but factual changes are reviewed before they become part of the official record. Finally, the platform backs up the source files and metadata and tracks versions over time.

3. Proposed Evaluation Plan

A future prototype could be evaluated using four groups of measures. Technical measures could include initial load time, cached load time, frame rate, memory use, and failure rate on a stated set of devices and network conditions. Usability measures could include task completion, errors, and a standard usability questionnaire. Learning measures could compare pre- and post-activity understanding and, if possible, retention after a delay. Heritage-governance measures could examine source completeness, the number of claims with traceable evidence, review time, correction handling, and feedback from qualified heritage stakeholders.

No performance or learning values are predicted here because the framework has not been implemented or tested. The measures above are a plan for future research, not results.

VII. CONCLUSION AND FUTURE SCOPE

This review considered four selected studies covering cross-device AR development, tourism exploration, digital reconstruction of historical instruments, and browserbased access to Indian cultural heritage. The studies show that AR can

support different heritage activities, but they address different problems and cannot be compared through a single performance number. Wider reviews also show that cultural heritage AR includes technical, educational, experiential, and participatory concerns [1]– [3].

The main conclusion is that a useful heritage platform should do more than display a 3D model. It should make the sources behind historical information visible, provide access across a range of devices, support responsible community contributions, and preserve the digital records needed to maintain the experience in the future. HeritageAR India has been proposed as a framework that brings these needs together. It remains a conceptual proposal and requires implementation, consultation with heritage professionals and communities, and systematic evaluation.

Future work should first define the collection and governance rules for a small group of heritage objects, then build a prototype and test it with real users and relevant experts. The study should report its methods and results transparently, including negative findings and limitations. A broader literature search would also be required before claiming that any proposed feature is novel.

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