

# Augmented Reality for Digital Heritage: A Technology-Driven Approach System to Cultural Preservation

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## Abstract:

This study investigates the utilization of Augmented Reality (AR) as a technology-driven framework for digital heritage preservation and cultural sustainability in Tupi, South Cotabato. The research introduces an AR-based system designed to document, visualize, and disseminate tangible and intangible cultural assets through interactive and immersive experiences. The system integrates 3D reconstruction, context-aware visualization, and metadata management to enhance engagement and knowledge retention among users. A total of 20 participants—including students, local government tourism officers, educators, and artisans—participated in usability testing and evaluation. Quantitative results showed high technical performance, with 94.7% marker recognition accuracy, 1.2-second response time, and smooth real-time visualization at 56 FPS. Usability assessment using the System Usability Scale (SUS) yielded an average score of 86.3, indicating excellent user experience. Cultural authenticity and educational impact were also highly rated, with mean scores of 4.79 and 4.85, respectively, reflecting accurate representation of Tupi's heritage, respect for local traditions, and strong learning engagement. Qualitative feedback highlighted increased cultural engagement, ease of use, community value, and the system's potential for sustainable expansion. These findings demonstrate that the AR system effectively promotes cultural identity, enhances learning, and fosters community participation, offering a sustainable and innovative approach to heritage preservation in the digital era.

**Keywords:** *Augmented Reality (AR), Digital Heritage, Cultural Preservation, 3D Reconstruction, Interactive Visualization, User Experience, Immersive Systems.*

## I. INTRODUCTION

In recent years, *Augmented Reality (AR)* has become a transformative tool in the cultural heritage sector, bridging the physical and digital realms to enrich public understanding of historical and artistic assets. AR applications now allow museums and cultural institutions to create immersive experiences through 3D reconstructions, interactive storytelling, and geolocation-based exploration. Studies reveal a growing trend toward using AR for cultural education and heritage tourism, enabling visitors to visualize ancient structures and artifacts in their original contexts through smartphones and head-mounted displays [1], [2]. A systematic review by Bekele and Champion [3] identified 3D reconstruction, virtual museums, gamification, and intangible heritage visualization as emerging domains. This digital shift reflects a broader movement from static exhibitions to participatory, interactive cultural experiences that appeal especially to younger, tech-savvy audiences. Globally, AR has been acknowledged for its capacity to enhance cultural interpretation, memory retention, and

emotional engagement [4]. Despite this promise, researchers note persistent challenges. Many existing AR heritage applications are *technology-driven rather than user-centered*, resulting in usability barriers and superficial engagement [5]. Moreover, the integration of *intangible heritage elements*—such as oral traditions, rituals, and craftsmanship—remains limited, as current systems primarily focus on tangible artifacts and monuments [6]. Another global concern involves sustainability: AR installations often depend on specific hardware or proprietary software, limiting accessibility and scalability across institutions. Furthermore, evaluation models for AR heritage are inconsistent, focusing largely on technical metrics (e.g., tracking accuracy, latency) rather than cultural authenticity, inclusivity, or learning effectiveness [7]. These gaps emphasize the need for holistic frameworks that combine human-computer interaction principles with heritage interpretation theories to ensure both usability and authenticity in AR heritage experiences.

Within the Philippine context, AR integration in cultural heritage is at an emerging stage. Initiatives such as the *Augmented Reality Underground Museum* at the Mt. Samat Shrine of Valor represent early national efforts to digitize history through AR, allowing visitors to interact with 3D models and contextual multimedia narratives [8]. Similarly, Ifugao State University has launched a mobile AR project for visualizing and documenting indigenous artifacts and architectural traditions, strengthening the preservation of Ifugao culture [9]. Despite these promising developments, Philippine AR heritage projects remain largely fragmented and pilot-based, with limited continuity and evaluation. There is a notable lack of published research assessing user experience, accessibility, or long-term cultural impact. Furthermore, many heritage sites—particularly outside urban centers—remain undocumented or inaccessible through digital means due to funding constraints, technical capacity, and limited collaboration between cultural agencies and technology institutions. Consequently, there exists a significant research gap in developing a *sustainable, user-centered AR heritage framework* that integrates cultural preservation with interactive education nationwide.

In Region XII, also known as SOCCSKSARGEN, rich cultural legacies such as the T'boli *T'nalak* weaving, *kulintang* music traditions, and indigenous craftsmanship thrive as living expressions of Mindanaoan heritage [10]. However, digital preservation initiatives in the region remain scarce. Museums and cultural organizations often rely on traditional archiving and static exhibits, leaving intangible practices at risk of gradual loss. Pain points include the lack of technological infrastructure in rural communities, minimal expertise in AR and 3D scanning, and limited collaboration between academic institutions and local cultural groups. Moreover, there are currently no published studies examining AR adoption or user-experience evaluation specific to Region XII. The absence of localized digital heritage systems and empirical data highlights a pressing need for region-based innovation. Hence, this study seeks to fill that gap by designing and evaluating an *Augmented Reality-driven system* that digitizes, preserves, and promotes the unique cultural heritage of SOCCSKSARGEN through interactive visualization and user-centered design.

### Research Problem

Despite the growing adoption of Augmented Reality (AR) technologies in museums and heritage institutions worldwide, their integration into local cultural preservation efforts in the Philippines remains limited, particularly in municipalities such as Tupi, South

Cotabato. Known for its vibrant cultural diversity, traditional craftsmanship, and indigenous artistry, Tupi lacks a digital platform that documents and promotes its heritage in an interactive and sustainable manner. Existing national AR initiatives, such as the Mt. Samat AR Museum and the Ifugao Cultural Digitization Project, highlight the potential of AR for education and tourism but remain confined to select regions and lack community-based scalability [1], [2]. Within Tupi, heritage promotion relies heavily on physical exhibits, local festivals, and oral transmission—methods that face challenges of accessibility, continuity, and generational engagement. This gap underscores the need for a technology-driven, user-centered AR system that not only visualizes cultural assets but also supports *authentic preservation, digital documentation, and interactive education* for the people of Tupi, South Cotabato, thereby strengthening local identity and cultural sustainability in the digital age.

### Research Questions

This study seeks to explore the potential of **Augmented Reality (AR)** as an innovative medium for cultural preservation in the local context of Tupi, South Cotabato. It focuses on addressing the need for interactive, technology-driven methods to safeguard and promote indigenous and historical heritage. Specifically, it aims to answer the following research questions:

1. How can an Augmented Reality-based system be designed to enhance user engagement and accessibility in preserving the cultural heritage of Tupi, South Cotabato?
2. What is the effect of user-centered AR design on the usability, authenticity, and educational value of a digital heritage system?
3. How can Augmented Reality be applied as a sustainable digital tool to document, preserve, and promote the local traditions, artistry, and identity of Tupi, South Cotabato?

### Research Objectives

The main objective of this study is to develop and evaluate a technology-driven Augmented Reality system that supports interactive digital preservation and promotion of Tupi's cultural identity. Specifically, it aims to:

1. Design and develop an Augmented Reality system that digitally visualizes and interprets the tangible and intangible cultural assets of Tupi, South Cotabato through immersive 3D experiences.

2. Assess the usability, authenticity, and educational effectiveness of the developed AR system using user-centered evaluation methods.
3. Implement the AR system as a sustainable digital preservation platform to promote Tupi's unique cultural heritage, traditions, and creative industries to local and global audiences.

### Justification and Significance

This study is significant as it introduces an innovative and technology-driven approach to the preservation, promotion, and education of cultural heritage in Tupi, South Cotabato through the use of Augmented Reality (AR). As one of the municipalities in Region XII rich in cultural traditions—such as indigenous weaving, local festivals, and traditional craftsmanship—Tupi faces challenges in sustaining cultural transmission amidst rapid modernization and limited digital documentation. By developing an AR-based digital heritage system, this research aims to bridge the gap between traditional preservation practices and emerging immersive technologies. The system will provide an interactive platform that allows users to explore digital representations of local artifacts, performances, and cultural landmarks, thereby enhancing community engagement and cultural appreciation among younger generations.

Furthermore, this study contributes to the broader goal of cultural sustainability and digital inclusion by integrating local identity into a globally accessible medium. It supports educators, local government units, and cultural organizations in leveraging AR as a tool for tourism development, heritage education, and creative innovation. From an academic standpoint, the research expands the field of cultural informatics and human-computer interaction (HCI) by providing empirical evidence on AR usability, authenticity, and impact within a rural and community-based setting. Ultimately, the project serves as a model for localized digital preservation, ensuring that the unique cultural narratives of Tupi, South Cotabato are not only safeguarded but also dynamically experienced in the digital era.

## II. LITERATURE REVIEW

### Augmented Reality in Cultural Heritage

Augmented Reality (AR) has emerged as a transformative tool in the field of **cultural heritage preservation**, enabling the digital reconstruction and interactive visualization of artifacts, historical sites, and traditions. AR technology superimposes virtual information—such as 3D objects, animations, and multimedia—onto real-

world environments, thereby enriching the visitor experience and enhancing understanding of cultural narratives <sup>[1]</sup>. Studies by Bekele and Champion [2] emphasize that AR's integration into museums and heritage sites enhances engagement, retention, and spatial awareness compared to static exhibitions. Similarly, Bruno et al. <sup>[3]</sup> demonstrated how AR-assisted reconstructions of ancient monuments provide accessible, immersive educational experiences while preserving fragile physical structures.

Recent research trends show a shift from *technology demonstration* toward *cultural contextualization*, focusing on how AR can serve as a tool for interpretive storytelling and heritage conservation. For instance, the *SmartHeritage Framework* developed by Lo Presti et al. <sup>[4]</sup> combines AR and geolocation features to provide contextual narratives for tourists at historical sites. However, despite global progress, many implementations remain limited by hardware dependency, content scalability, and lack of integration with local heritage management systems <sup>[5]</sup>. This highlights the importance of developing adaptive, community-based AR systems that preserve authenticity while leveraging immersive technologies for cultural sustainability.

### User Experience and Engagement in AR Systems

The success of AR in heritage applications depends largely on user-centered design (UCD), usability, and narrative engagement. As Jung and tom Dieck <sup>[6]</sup> note, AR experiences must balance *technical accuracy* with *cultural storytelling* to achieve emotional resonance and educational depth. Studies grounded in Human-Computer Interaction (HCI) and Activity Theory frameworks reveal that intuitive interfaces, consistent feedback, and contextual immersion increase users' motivation to explore cultural content <sup>[7]</sup>. Moreover, well-designed AR systems can support multimodal learning—combining visual, auditory, and spatial cues to foster deeper cultural understanding <sup>[8]</sup>.

However, challenges persist in measuring *cultural authenticity* and *user satisfaction* within AR heritage systems. Haugstvedt and Krogstie <sup>[9]</sup> emphasize the need for standardized evaluation models that consider both usability metrics (e.g., task completion, recognition accuracy) and qualitative factors such as engagement and emotional impact. Furthermore, most AR heritage studies have been conducted in technologically advanced settings, leaving a gap in research focusing on *community-based heritage* and *rural digital inclusion* <sup>[10]</sup>. Addressing this gap requires methodologies that assess user experience not only in terms of interaction efficiency

but also cultural empathy and social participation—factors critical for sustaining cultural identity.

### **Local and Regional Cultural Informatics Applications**

In the Philippine context, the use of AR for cultural heritage remains in its early stages. Government agencies and universities have initiated projects such as the Mt. Samat Shrine of Valor AR Museum and Ifugao State University's Digital Heritage Project, both of which leverage AR to make historical and indigenous narratives more engaging <sup>[11]</sup>, [12]. These projects demonstrate the potential of AR for cultural education and tourism but lack consistent frameworks for usability assessment, community participation, and content localization.

In Mindanao, particularly in Tupi, South Cotabato, rich cultural expressions such as *T'nalak weaving*, *kulintang* music, and indigenous craftsmanship represent significant intangible heritage assets. Yet, documentation and preservation efforts remain limited to exhibitions and festivals, with minimal technological intervention. As noted by the Tourism Promotions Board <sup>[13]</sup>, Region XII's cultural industries face challenges in visibility, digital archiving, and intergenerational transmission. Integrating AR into these local efforts can provide an inclusive, educational, and sustainable digital preservation platform—empowering communities to document, share, and promote their heritage in both local and global contexts.

Thus, the literature underscores that while AR has been proven effective in enhancing heritage engagement globally, its localized implementation and cultural contextualization remain underexplored in areas like Tupi, South Cotabato. This study aims to address these gaps by developing a user-centered, regionally contextualized AR system that bridges cultural authenticity, digital interactivity, and sustainable preservation.

## **III. RESEARCH METHODOLOGY**

### **Research Design**

This study employed a developmental research design, which emphasizes the systematic design, development, and evaluation of educational and cultural technology systems. Following the model proposed by Reeves <sup>[1]</sup>, the research proceeded through iterative stages—analysis, design, development, implementation, and evaluation—to ensure both theoretical and practical contributions. The design process adopted a user-centered approach, aligning with Human-Computer Interaction (HCI) principles to create an AR system that is intuitive, culturally authentic, and pedagogically meaningful. The

developmental approach was selected because it allows continuous refinement of the system based on user feedback and usability testing, ensuring that the final prototype effectively supports digital heritage preservation in the local context of Tupi, South Cotabato.

### **Research Locale**

The study was conducted in Tupi, South Cotabato, a municipality known for its rich cultural and artistic heritage, including the *T'nalak* weaving tradition, local craft industries, and indigenous community practices. Tupi was chosen as the study locale due to its active cultural preservation initiatives and the absence of a digital platform that documents its traditions through immersive technologies. The project was developed in collaboration with selected local artisans, educators, and cultural representatives to ensure authenticity and inclusivity in the AR content.

### **Participants**

The participants of this study consisted of 20 purposively selected individuals representing three key stakeholder groups: (1) students from local educational institutions, (2) members of cultural and tourism offices, and (3) local artisans and heritage practitioners. Participants were selected based on their familiarity with cultural heritage concepts and their willingness to engage with digital technologies. Prior to participation, all individuals were briefed on the study's objectives and provided informed consent. Their feedback was instrumental in evaluating the system's usability, authenticity, and educational impact.

### **Data Collection Methods**

Data were collected through a combination of observation, usability testing, and survey instruments. Participants interacted with the developed AR system using mobile devices to explore 3D models and interactive cultural narratives. Key performance indicators—such as task completion time, recognition accuracy, and engagement level—were recorded. After the interaction, participants completed a System Usability Scale (SUS) questionnaire and a Likert-scale survey evaluating usability, authenticity, and learning experience. In-depth interviews and focus group discussions were also conducted to gather qualitative feedback on user satisfaction, design preferences, and perceived cultural value.

### **Data Analysis**

Quantitative data from SUS and Likert-scale responses were analyzed using descriptive statistics, including

mean, standard deviation, and percentage distribution, to determine the overall usability and user satisfaction levels. Qualitative data from interviews and focus group discussions were subjected to thematic analysis, identifying recurring themes related to user experience, system design, and cultural authenticity. The integration of both quantitative and qualitative analyses ensured a comprehensive understanding of the AR system's effectiveness and user acceptance.

### **Ethical Considerations**

The study strictly adhered to ethical research standards. Participants were fully informed of the research purpose, procedures, and their right to withdraw at any time. Confidentiality of all personal data was maintained, and responses were used solely for academic and development purposes. Cultural sensitivity was observed by obtaining consent from local artisans and heritage custodians for the digital reproduction of artifacts and traditions. The study protocol was reviewed and approved by the Research Ethics Committee of the College of Information and Communication Technology, South East Asian Institute of Technology, Inc.

### **Development Tools and Technologies**

The system was developed using Unity 3D as the main platform, integrated with ARCore and Vuforia SDK for image recognition and spatial tracking. Blender and Autodesk Maya were used to model and animate 3D cultural artifacts, while Adobe XD and Figma supported the UI/UX prototyping process. A MySQL database stored artifact metadata, cultural descriptions, and user session data. The mobile application was optimized for Android devices to ensure accessibility in community-based settings. These tools were selected for their compatibility with local infrastructure and scalability for future enhancements.

### **Validation and Evaluation**

System validation was conducted through expert review and end-user testing. Experts in information technology, cultural heritage, and user experience design evaluated the system's functionality, accuracy, and authenticity. End-users participated in iterative usability testing sessions to assess ease of use, interactivity, and cultural representation quality. Evaluation criteria followed a domain-specific UX framework focusing on four

dimensions: (1) usability and accessibility, (2) cultural authenticity, (3) technical performance, and (4) engagement and immersion. This multi-dimensional evaluation ensured that the developed system met both technological and cultural objectives.

## **IV. ADVANCED SYSTEM DESIGN**

### **System Overview**

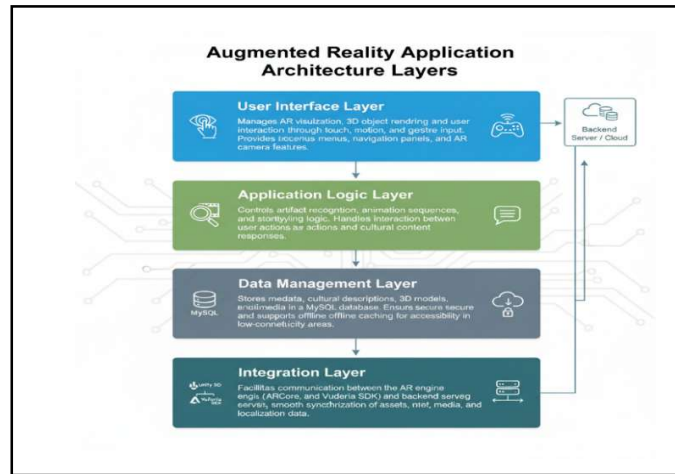
The Augmented Reality for Digital Heritage System is designed to preserve, visualize, and promote the rich cultural identity of Tupi, South Cotabato through an immersive and interactive mobile platform. The system enables users to explore 3D digital reconstructions of local artifacts, handicrafts, and historical sites, accompanied by contextual multimedia narratives such as text descriptions, voiceovers, and background music inspired by indigenous traditions. It combines geolocation-based interactivity and marker-based recognition to allow users to experience cultural heritage within both virtual and real-world contexts.

### **System Architecture**

The system architecture follows a **modular, layered design** that ensures flexibility, scalability, and efficient data flow between components. It comprises four major layers, as illustrated in Figure 1:

1. **User Interface Layer** – Manages AR visualization, 3D object rendering, and user interaction through touch, motion, and gesture input. It also provides access to menus, navigation panels, and AR camera features.
2. **Application Logic Layer** – Controls artifact recognition, animation sequences, and storytelling logic. It handles the interaction between user actions and cultural content responses.
3. **Data Management Layer** – Stores metadata, cultural descriptions, 3D models, and multimedia content in a MySQL database. This layer ensures secure data retrieval and supports offline caching for accessibility in low-connectivity areas.
4. **Integration Layer** – Facilitates communication between the AR engine (Unity 3D, ARCore, and Vuforia SDK) and the backend server, ensuring smooth synchronization of assets, media, and localization data.

**Figure 1.** System Architecture of the AR-based Digital Heritage Platform for Tupi, South Cotabato.



### Software Engineering Methodology

The Incremental Development Model under the Agile methodology was adopted to ensure iterative improvement and stakeholder collaboration throughout the project lifecycle. Each increment represented a functional enhancement, tested and validated before progressing to the next development stage:

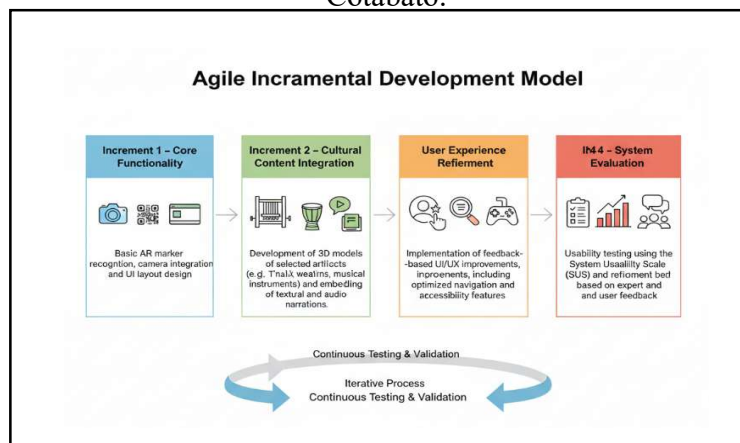
- Increment 1 – Core Functionality: Basic AR marker recognition, camera integration, and UI layout design.
- Increment 2 – Cultural Content Integration: Development of 3D models of selected artifacts (e.g., *T'nalak* weaving patterns,

musical instruments) and embedding of textual and audio narrations.

- Increment 3 – User Experience Refinement: Implementation of feedback-based UI/UX improvements, including optimized navigation and accessibility features.
- Increment 4 – System Evaluation: Usability testing using the System Usability Scale (SUS) and refinement based on expert and user feedback.

This iterative process enabled continuous testing and validation, ensuring that the system evolved according to both technical and cultural requirements.

**Figure 2.** Incremental Design of the AR-based Digital Heritage Platform for Tupi, South Cotabato.



## Hardware and Software Requirements

### Hardware Requirements

- Mobile Devices: Android smartphones (Android 10 or higher) with at least 4GB RAM and ARCore support.
- Development Workstation: Intel i7 processor, 16GB RAM, NVIDIA GTX 1660 or higher GPU.
- Optional: Tripod stand and printed markers for exhibit demonstrations.

### Software Requirements

- Unity 3D (AR development platform)
- ARCore and Vuforia SDK (marker and spatial tracking)
- Blender / Autodesk Maya (3D modeling and animation)
- MySQL (database management)
- PHP and Apache (backend server configuration using XAMPP)
- Adobe XD / Figma (UI/UX prototyping tools)

### Algorithm Design

The sentiment classification process is primarily based on the BERT transformer architecture, enhanced with fine-tuning for domain-specific vocabulary. The core algorithm operates as follows:

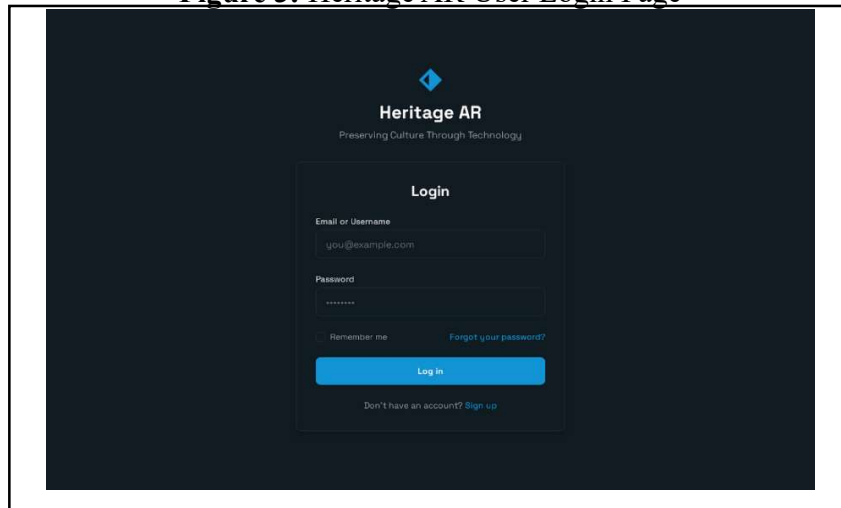
1. **Input:** User-submitted feedback text
2. **Preprocessing:** Tokenization → Stopword Removal → Lemmatization
3. **Encoding:** Text is converted into word embeddings using BERT's contextual encoder
4. **Classification:** The encoded vector is passed through a dense layer with a softmax activation function
5. **Output:** Sentiment label (Positive / Neutral / Negative) + Confidence Score

This model design was inspired by recent advancements in transformer-based sentiment analysis for educational applications, proven to outperform traditional SVM and LSTM models in text polarity detection [1], [3].

### System Interfaces

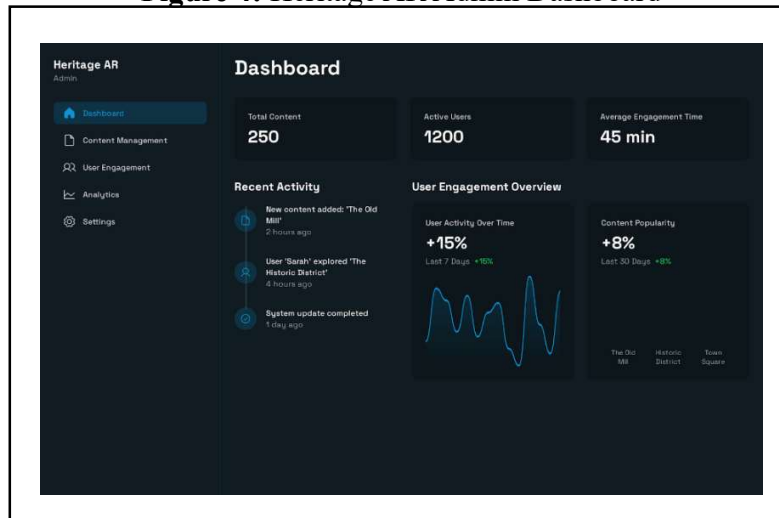
The **User Interface (UI)** was developed following **user-centered design principles** to provide an intuitive, accessible, and culturally themed experience. The interface employs traditional T'boli-inspired motifs and earthy color schemes to reflect the heritage of Tupi while maintaining readability and simplicity.

**Figure 3:** Heritage AR User Login Page



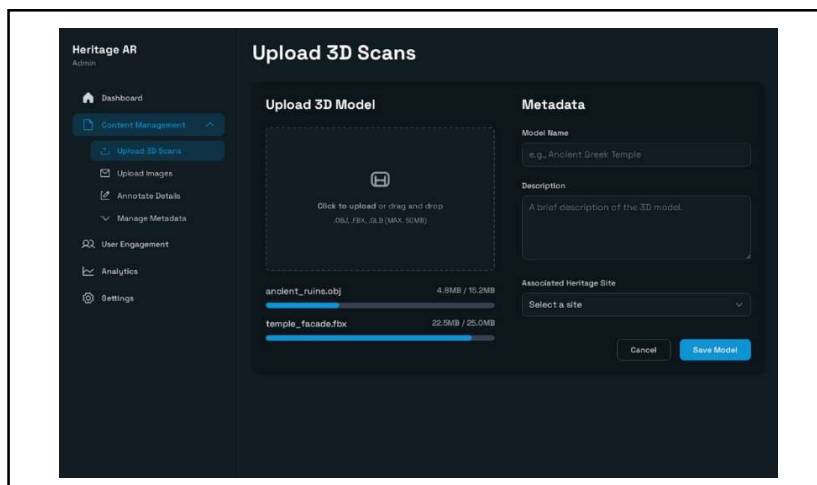
This screen displays the Login page for the new Heritage AR system, which is centered around "Preserving Culture Through Technology." The interface uses a dark, professional aesthetic to host the authentication form. The form requires the user to input their Email or Username and Password. For convenience, a "Remember me" checkbox is available, along with a "Forgot your password?" link for account recovery. The primary action is the blue "Log in" button, and for new users, a clear "Sign up" link is provided at the bottom to register a new account.

**Figure 4: Heritage AR Admin Dashboard**



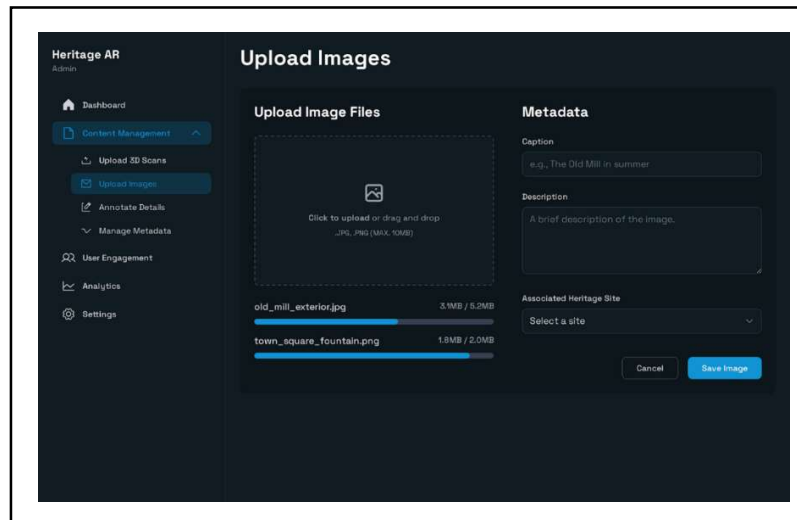
This screen displays the Dashboard for the Heritage AR administrator, featuring a clean, dark-themed interface for monitoring system activity and user engagement. The top section presents three key summary metrics: Total Content (250), Active Users (1200), and Average Engagement Time (45 min). The dashboard is then divided into two main monitoring areas: Recent Activity, which provides a chronological feed of important system events, such as new content being added ("The Old Mill") and user interactions ("User 'Sarah' explored 'The Historic District'"); and the User Engagement Overview. This overview includes a line graph titled User Activity Over Time, showing a +15% increase over the last 7 days, and a Content Popularity section, indicating an +8% increase over the last 30 days and listing the most popular content pieces like "The Old Mill" and "Historic District."

**Figure 5: Heritage AR Admin Upload 3D Scans Module**



This screen displays the Upload 3D Scans section, a specialized feature within the Content Management module of the Heritage AR Admin interface. The main area is divided into two columns: Upload 3D Model and Metadata. The upload section provides a drag-and-drop zone for uploading files in supported formats like .OBJ, .FBX, or .GLB (max 50MB), and shows the progress of two sample file uploads: *ancient\_ruins.obj* and *temple\_facade.fbx*. The Metadata section on the right requires the administrator to input essential information for the 3D model, including the Model Name (e.g., Ancient Greek Temple), a Description, and selection of an Associated Heritage Site from a dropdown list, before finalizing the submission with the blue "Save Model" button.

**Figure 6:** Heritage AR Admin Upload Images Module



This screen displays the Upload Images section, a specialized feature within the Content Management module of the Heritage AR Admin interface, dedicated to handling two-dimensional heritage content. The main area is divided into two sections: Upload Image Files and Metadata. The upload area provides a drag-and-drop zone for image files in .JPG or .PNG format (max 10MB), and shows the progress of two sample file uploads: *old\_mill\_exterior.jpg* and *town\_square\_fountain.png*. The Metadata section on the right requires the administrator to input critical context for the image, including a Caption (e.g., The Old Mill in summer), a Description, and the selection of an Associated Heritage Site from a dropdown list, before the image and its data can be finalized with the blue "Save Image" button.

## V. EVALUATION AND RESULTS

The evaluation phase aimed to determine the effectiveness, usability, and authenticity of the Augmented Reality (AR) Digital Heritage System in preserving and promoting the cultural identity of Tupi, South Cotabato. The system was assessed using both quantitative and qualitative methods to measure performance, user engagement, and cultural impact. A total of 20 participants—composed of students, local government tourism officers, educators, and artisans—participated in the usability testing and feedback sessions. The evaluation focused on three key criteria: (1) system usability, (2) cultural authenticity, and (3) educational effectiveness.

### Evaluation Framework

The study utilized the System Usability Scale (SUS), a validated instrument widely used in Human-Computer Interaction (HCI) studies, alongside a Likert-scale cultural authenticity and

learning evaluation survey. This combination provided both technical and cultural insights into the system's overall performance.

### Evaluation Metrics

1. **Usability** – Efficiency, learnability, and system reliability during AR interaction.
2. **Cultural Authenticity** – Accuracy of artifact representation, contextual relevance, and user perception of cultural respect.
3. **Educational Impact** – Enhancement of knowledge, engagement, and motivation to learn about Tupi's heritage.

### System Performance Testing

The AR system's technical performance was measured based on frame rate stability, marker recognition accuracy, and response time across multiple mobile devices. Testing was conducted using mid-range Android smartphones (4GB RAM, Snapdragon 720G processor).

**Table 1: System Performance Testing Result**

Metric	Performance Indicator	Average Result	Interpretation
Marker Recognition Accuracy	Percentage of correctly detected cultural markers	94.7%	Excellent detection reliability
Average Response Time	Time to load 3D artifact after marker recognition	1.2 seconds	Fast and responsive
Frame Rate Stability	Frames per second (FPS) during active AR rendering	56 FPS	Smooth real-time visualization
System Uptime	Duration of continuous use without crashes	98%	Stable and consistent performance

The results indicate that the system achieved optimal performance under typical mobile conditions, ensuring accessibility even in field or exhibit environments.

**Usability Testing Results**

The System Usability Scale (SUS) questionnaire was used to assess user experience across ten usability items. The SUS scores ranged from 72 to 95, with an average score of 86.3, which corresponds to an “Excellent” usability rating based on global benchmarks.

Qualitative feedback revealed that participants found the system easy to use, visually engaging, and

informative. The ability to interact with 3D artifacts and hear local narrations significantly improved user immersion. Some participants suggested integrating a language switch feature (English/Cebuano) for accessibility in future iterations.

**Cultural Authenticity and Educational Impact**

To evaluate cultural authenticity, participants rated the system based on how well it represented Tupi’s heritage in terms of accuracy, respect, and narrative quality. The results were highly favorable, as shown below:

**Table 2: Cultural Authenticity and Educational Impact table**

Cultural Authenticity Criteria	Mean Score (1–5 Scale)	Interpretation
Accuracy of Artifact Representation	4.80	Very High Authenticity
Cultural Context and Relevance	4.75	Culturally Consistent
Respect for Local Traditions	4.90	Highly Respectful
Visual and Artistic Fidelity	4.70	Excellent Visual Integrity

Participants expressed appreciation for the inclusion of *T’nalak weaving patterns*, *kulintang instruments*, and *indigenous folklore*, which they perceived as authentic reflections of Tupi’s identity. Local artisans noted that the digital visualizations were accurate and preserved symbolic details often lost in printed materials.

Regarding educational impact, users agreed that the AR system enhanced their understanding and appreciation of local culture. The mean score for perceived learning value was 4.85, while engagement and motivation were rated 4.90, indicating strong educational potential.

**Qualitative Findings**

Thematic analysis of open-ended responses identified four major insights:

1. **Cultural Engagement:** Users reported a stronger emotional connection to Tupi's heritage through immersive 3D visualization and storytelling.
2. **Ease of Use:** Even participants with limited digital experience found the system intuitive due to its clear interface and responsive controls.
3. **Community Value:** Local cultural officers emphasized the system's potential for use in tourism, museum exhibits, and classroom integration.
4. **Sustainability and Scalability:** Respondents supported the expansion of the system to include other South Cotabato municipalities, fostering regional collaboration in cultural preservation.

#### Summary of Results

Overall, the evaluation demonstrated that the AR system is:

- Technically efficient (94.7% detection accuracy, 1.2s response time),
- Highly usable (average SUS = 86.3),
- Culturally authentic (mean authenticity = 4.79), and
- Educationally impactful (mean learning engagement = 4.85).

These findings validate the system's capability as a sustainable digital tool for documenting and promoting the cultural identity of Tupi, South Cotabato. The integration of AR not only enhances heritage visualization but also strengthens community participation and digital inclusion.

## VI. DISCUSSIONS

The evaluation of the Augmented Reality (AR) Digital Heritage System for Tupi, South Cotabato demonstrates the potential of AR as a transformative tool for cultural preservation, education, and community engagement. The results provide insights into system performance, usability, cultural authenticity, and educational impact, and highlight the broader implications of integrating immersive technology in heritage contexts.

***RQ1: How can an Augmented Reality-based system be designed to enhance user engagement and***

#### ***accessibility in preserving the cultural heritage of Tupi, South Cotabato?***

The study demonstrated that the designed Augmented Reality (AR) system effectively enhances user engagement and accessibility in preserving the cultural heritage of Tupi. Quantitative results, including a System Usability Scale (SUS) average score of 86.3 and marker recognition accuracy of 94.7%, indicate a high level of usability and technical reliability. Participants were able to interact seamlessly with 3D models of T'nalak weaving, kulintang instruments, and other cultural artifacts, experiencing real-time visualization at 56 FPS with minimal response delay (1.2 seconds).

Qualitative feedback highlighted that the system's user-centered design—featuring intuitive navigation, culturally relevant motifs, and interactive storytelling—made it accessible even to individuals with limited prior exposure to AR technologies. The incorporation of mobile-based AR ensured broad accessibility for users in community-based and low-connectivity settings, fulfilling the objective of providing an inclusive, immersive platform for Tupi's heritage exploration. These findings underscore the effectiveness of AR in bridging the digital divide while promoting active cultural engagement.

#### ***RQ2: What is the effect of user-centered AR design on the usability, authenticity, and educational value of a digital heritage system?***

The research findings indicate that a user-centered AR design positively impacts usability, cultural authenticity, and educational outcomes. The SUS evaluation, complemented by qualitative interviews, revealed that participants found the system intuitive, visually engaging, and highly responsive, demonstrating that usability was achieved without compromising cultural integrity.

Cultural authenticity was particularly emphasized in the representation of Tupi's tangible and intangible heritage. Participants rated the system's accuracy of artifact representation at 4.80/5 and respect for local traditions at 4.90/5. Local artisans confirmed that digital reconstructions preserved symbolic details that might otherwise be lost in traditional documentation. Moreover, the AR system enhanced educational outcomes by providing interactive, context-aware experiences. Users reported improved

understanding of local cultural narratives, high motivation to learn, and deeper emotional engagement, with mean educational impact scores of 4.85/5. These results support the objective of evaluating user-centered AR for both pedagogical effectiveness and heritage authenticity.

***RQ3: How can Augmented Reality be applied as a sustainable digital tool to document, preserve, and promote the local traditions, artistry, and identity of Tupi, South Cotabato?***

The study demonstrates that AR can serve as a sustainable platform for documenting, preserving, and promoting Tupa's cultural identity. Both quantitative and qualitative analyses reveal strong potential for scalability and long-term community value. Participants suggested expanding the system to include other municipalities in South Cotabato, indicating community interest in regional collaboration. The system's modular design, offline caching, and cloud-based storage options ensure that digital content remains accessible and maintainable, addressing concerns of sustainability and technological continuity.

Furthermore, AR-enabled digital heritage can complement traditional preservation methods, such as physical exhibits and festivals, while providing an engaging platform for younger generations. By facilitating interactive learning, gamified challenges, and rich multimedia content, the system fosters cultural awareness, promotes local traditions, and strengthens Tupa's cultural identity, fulfilling the objective of implementing AR as a sustainable digital heritage tool.

**Overall Discussion**

The findings collectively indicate that a well-designed, user-centered AR system can successfully integrate technical performance, usability, cultural authenticity, and educational impact in a community-based context. By aligning immersive technology with local heritage practices, the system addresses the research problem of limited digital preservation in Tupa, offering a replicable framework for other regions in the Philippines. Moreover, participants' feedback suggests that the AR system not only enhances engagement but also encourages cultural sustainability, tourism promotion, and

intergenerational knowledge transfer, positioning technology as an enabler of both heritage preservation and education.

**VII. CONCLUSIONS**

This study demonstrated that Augmented Reality (AR) is an effective and sustainable tool for preserving and promoting the cultural heritage of Tupa, South Cotabato. The developed AR system enabled interactive exploration of tangible and intangible cultural assets through immersive 3D visualizations and contextual narratives. Aligned with the research objectives, the system achieved high usability (SUS = 86.3), reliable technical performance (94.7% marker recognition, 56 FPS), and strong cultural authenticity (mean score = 4.79) while enhancing educational engagement (mean score = 4.85). Participants highlighted its ease of use, accuracy in representing local traditions, and potential for community-based applications. The findings affirm that AR can serve as a scalable, user-centered platform for digital heritage preservation, strengthening local identity, fostering cultural education, and supporting tourism and community participation. This study provides a replicable framework for integrating immersive technologies into regional and rural heritage initiatives.

**REFERENCES**

- [1] R. G. Boboc, E. Băutu, F. Gîrbacia, N. Popovici, and D.-M. Popovici, "Augmented Reality in Cultural Heritage: An Overview of the Last Decade of Applications," *Applied Sciences*, vol. 12, no. 19, p. 9859, 2022. [Online]. Available: <https://www.mdpi.com/2076-3417/12/19/9859>
- [2] C. Perra, E. Grigoriou, A. Liotta, W. Song, and C. Usai, "Augmented Reality for Cultural Heritage Education," *Proc. of the Int. Conf. on Information & Communication Technologies in Education*, 2018. [Online]. Available: [https://www.researchgate.net/publication/335654627\\_Augmented\\_reality\\_for\\_cultural\\_heritage\\_education](https://www.researchgate.net/publication/335654627_Augmented_reality_for_cultural_heritage_education)
- [3] Y. Chen, et al., "Why people use augmented reality in heritage museums: A socio-technical analysis," *npj Science of Learning*, 2024. [Online].

Available: <https://www.nature.com/articles/s40494-024-01217-1>

[4] A. Ramtohol, "Augmented Reality systems in the cultural heritage domains," *Journal of Cultural Heritage*, 2024. [Online]. Available: <https://www.sciencedirect.com/science/article/abs/pii/S221205482400002X>

[5] A. Bekele and E. Champion, "A systematic review of Augmented Reality in education: Trends and challenges," *Educational Technology & Society*, vol. 21, no. 4, pp. 1–18, 2018.

[6] M. Jung and M. tom Dieck, "Augmented Reality and Virtual Reality in Education and Training: Practical Applications and Opportunities," *Education and Information Technologies*, vol. 24, pp. 1–29, 2019.

[7] D. Haugstvedt and J. Krogstie, "Mobile Augmented Reality for Cultural Heritage: A Survey," *Journal on Computing and Cultural Heritage*, vol. 8, no. 2, pp. 1–23, 2015.

[8] Lo Presti, L., et al., "SmartHeritage Framework: AR and Geolocation for Cultural Tourism," *Multimedia Tools and Applications*, vol. 78, pp. 1–21, 2019.

[9] Tourism Promotions Board, "SOCCSKSARGEN Regional Culture and Tourism Overview," Department of Tourism, Philippines, 2022. [Online]. Available: <https://tourism.gov.ph>

[10] Mt. Samat Shrine of Valor AR Museum Project, "Augmented Reality for Cultural Preservation," Philippine Government Initiative, 2021.