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THE CULTURAL RESILIENCE OF MACAO'S INTANGIBLE CULTURAL HERITAGE: THE MECHANISM OF IDENTITY RECONSTRUCTION IN THE INTEGRATION OF CHINESE AND WESTERN CULTURES

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Abstract: Macau's intangible cultural heritage (ICH) exemplifies a unique Sino-Western cultural fusion, wherein the interplay of Eastern and Western traditions complicates conventional analysis of heritage complexity and resilience. To address this challenge, we introduce FusionNet, a multimodal AI framework integrating image-based classification, an attention mechanism, identity embedding, and knowledge graph modeling for context-aware analysis of ICH. FusionNet combines image-based deep learning with an attention mechanism to focus on salient visual features in heritage imagery. This integrated architecture enables a holistic understanding of heritage elements and their adaptability to changing cultural contexts. Applied to Macau's ICH, FusionNet reveals patterns of cultural resilience, illustrating how traditional practices persist and evolve amid centuries of East-West influences. Our findings demonstrate the efficacy of fusing visual and knowledge-based modalities for heritage analysis, offering a robust approach for studying and preserving intangible cultural heritage in complex cultural environments. To elucidate how Macau's intangible cultural heritage (ICH) exhibits "cultural resilience" and the mechanisms of identity (re)construction amid Sino-Portuguese cultural interweaving; and to propose a computable multimodal framework (FusionNet + cultural-identity embeddings + knowledge graph) that quantifies and validates these mechanisms. Materials include digital archives and historical texts (e.g., Macau Memory), social-media text (Weibo plus ~1,000 English TripAdvisor/blog reviews), open heritage images, and structured knowledge bases (China ICH database). Methods comprise an attention-based image classifier (FusionNet), LDA topic modeling (5-fold cross-validation selecting k = 3; mean coherence ≈ 0.59, compared with BERTopic), bilingual sentiment analysis, knowledge-graph embedding and link prediction (evaluated with MRR, Hits@10), and t-SNE visualization with clustering (three clusters; average silhouette ≈ 0.47). All implementations are in Python. LDA reveals three stable themes: (A) Chinese traditions (~45%), (B) Lusophone heritage (~30%), and (C) hybrid/local identity (~25%; e.g., Patuá and Macanese cuisine). Sentiment analysis indicates >70% positive evaluations, with ~12–15% negative. On the image side, most categories achieve diagonal accuracy >0.80, with some true-positive rates reaching 0.95–1.00; Sino-Portuguese architecture shows interpretable confusion. Knowledge-graph embeddings and t-SNE place the "hybrid/local identity" between the Chinese and Portuguese clusters, acting as a bridge (silhouette ≈ 0.47). Overall, multimodal fusion is more robust than multiple baselines on recognition and semantic association tasks, revealing a resilience pathway in which Macau ICH preserves core practices while continually absorbing exogenous elements. The proposed multimodal, knowledge-driven framework effectively quantifies and explains identity (re)construction and cultural resilience in Macau's ICH within a Sino-Portuguese milieu; the "hybrid/local identity" is the key bridging mechanism. Future work can expand cross-platform data, enhance cross-modal alignment and knowledge reasoning, and generalize the approach to other multicultural contexts to strengthen external validity.

Keywords: cultural resilience, intangible cultural heritage, sino-western fusion, multimodal fusion framework

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INTRODUCTION

Intangible cultural heritage (ICH) encompasses the living cultural traditions, expressions, and knowledge passed down through generations, providing communities with a sense of identity and continuity. Safeguarding ICH has gained global importance since the UNESCO 2003 Convention, spurring significant efforts in digitization and research (Hou et al., 2022, Ilieș et al., 2016). Unlike tangible heritage, which is embodied in physical artifacts, ICH resides in dynamic practices – from oral narratives and performing arts to rituals and craftsmanship – that constantly evolve through social transmission (Hou et al., 2022). The cultural resilience of such heritage is evident in places like Macau, where over four centuries of Sino-Western cultural fusion have created a unique blend of Chinese and Portuguese traditions. Examples include the Macanese culinary arts and festivals like the "Drunken Dragon Dance," which reflect hybrid identities. However, rapid globalization and urbanization are putting pressure on these intangible practices. Many traditional customs and minority languages face decline as younger generations assimilate into global culture. Indeed, it is reported that over 88% of the world's languages (often key vessels of oral heritage) are currently overlooked by language technologies (Joshi et al., 2020), illustrating how much of our intangible heritage remains at risk in the digital age. This situation underlines an urgent

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need for innovative strategies to document, analyze, and revitalize ICH, especially in culturally diverse settings like Macau's, where identity reconstruction occurs at the intersection of Eastern and Western influences. Recent comparative studies also reveal that even when digital preservation frameworks are introduced, cultural participation and identity transmission remain fragile if socio-economic inequalities are ignored (Pereira & Santos, 2025). This situation underlines an urgent need for innovative strategies to document, analyse, and revitalise ICH, especially in culturally diverse settings like Macau's, where identity reconstruction occurs at the intersection of Eastern and Western influences (Herman et al., 2017). Accordingly, the present study aims to quantify and interpret the mechanisms of cultural resilience and identity reconstruction in Macau's ICH by integrating computational analysis with socio-cultural theory. This research path of quantifying and driving structural transformation through specific mechanisms (like computational analysis) is corroborated in other fields; for instance, research shows that green finance promotes industrial structure transformation by fostering green technology innovation and constraining carbon emissions (Ding et al., 2025).

Recent advances in artificial intelligence (AI) and information and communication technologies have opened new opportunities for ICH preservation (Fu et al., 2023; Hou et al., 2022). Similarly, in the tourism industry, empirical research indicates that digital transformation positively impacts sustainable growth by driving innovative change (Tran et al., 2025).

Researchers have begun to leverage AI-driven approaches across multiple domains of cultural heritage. In natural language processing (NLP) and machine learning, there is growing work on documenting and revitalizing endangered languages and oral traditions. For example, NLP techniques are being applied to indigenous and low-resource languages to aid preservation (Joshi et al., 2020). Machine learning has also been used to analyze and classify folk song heritage, as in the case of Northwest China's Hua'er folk songs (Fu et al., 2023), helping to organize and transmit traditional music.

In the computer vision domain, powerful image and video analysis methods enable the capture and teaching of embodied cultural practices. Notably, deep learning models have been developed for traditional dance preservation: Ni (Ni & Park, 2025) achieved above 95% accuracy in recognizing movements of diverse ethnic dances using 3D convolutional neural networks, and Odefunso (Odefunso et al., 2022) demonstrated a framework to digitally record and even generate African dance movements with pose estimation techniques. Such tools can facilitate the archiving of performances or guide practitioners in learning heritage arts. Beyond text and vision, AI is also enhancing the creation of interactive and immersive cultural experiences – for instance, augmented reality (AR) and virtual reality (VR) exhibitions that allow users to engage with intangible heritage elements in virtual environments. These multimodal technologies are making intangible culture more accessible, engaging, and understandable to global audiences.

This engagement is particularly evident in social media, where studies using the S-O-R framework confirm that social media influencers (Stimulus) trigger psychological states like a 'desire to mimic' and 'fear of missing out' (FOMO) (Organism), which in turn drive purchase intentions (Response) (Sinh & Kiet, 2025). For example, in heritage tourism research, digital methods such as social media marketing have been shown to significantly enhance the visitor experience and positively influence revisitation intention (Do et al., 2025). Nevertheless, a critical limitation remains: many AI models prioritise technical accuracy over socio-cultural interpretation, often overlooking ethical dimensions such as representation bias and community participation (Fu et al., 2023; El-Gohary & Kang, 2025). This vision of a human-centric transformation that integrates physical and virtual spaces (i.e., "Society 5.0") is gaining global attention, yet its implementation faces challenges; for instance, in Kuwait's readiness assessment, "co-creation" was found to be the least attained metric (Alghareeb et al., 2025). However, in other fields (such as consumer behavior research), digital transformation has been confirmed to significantly amplify the impact of corporate Environmental, Social, and Governance (ESG) practices on consumers by increasing information transparency and accessibility (Paudel & Thapa, 2025). Moreover, few studies assess how these digital tools actually contribute to long-term cultural resilience rather than short-term digitisation outcomes, leaving an empirical gap that this research seeks to address.

Another area of rapid progress is the use of knowledge graphs and semantic web techniques to model cultural heritage information (Odefunso et al., 2022; Carriero et al., 2021) (Fan et al., 2023). In fact, in other domains like government document management, systematic reviews have confirmed that Large Language Models (LLMs) show potential beyond traditional methods for automated classification, knowledge retrieval, and policy analysis, though this is also met with challenges in technical complexity and regulatory compliance (Yang et al., 2025). Knowledge graphs (KGs) provide a structured, interlinked representation of heritage knowledge, enabling efficient organisation of diverse data (e.g., linking historical figures, events, artefacts, and intangible practices). Carriero et al. (Odefunso et al., 2022), for example, designed a large-scale ontology and knowledge graph (ArCo) for Italian cultural heritage, encoding millions of facts about artworks, monuments, and related cultural contexts. In the intangible domain, Kalita (Kalita & Deka, 2020) built an ontology-based knowledge base for Indian traditional dances, capturing relationships between dance components like costumes, music, and performers. More recently, Fan (Fan et al., 2023) constructed a comprehensive Chinese ICH multimodal knowledge graph that integrates textual descriptions with images for thousands of heritage elements, allowing both semantic queries and visual exploration. These efforts illustrate the potential of KGs to integrate fragmented cultural data into a unified resource. By connecting previously siloed information, KGs help uncover hidden relationships and support better analysis of heritage. Furthermore, researchers are combining knowledge graphs with deep learning to enhance intelligent heritage management. For instance, Huang (Huang & Song, 2022; Huang et al., 2023) proposed a joint deep learning model for entity and relation extraction to automatically populate a cultural heritage knowledge graph from unstructured text, and also implemented knowledge completion algorithms to infer missing links. Bobasheva and colleagues (Bobasheva et al., 2022) demonstrated that coupling symbolic knowledge graphs with machine learning can improve the quality of museum metadata, using AI to assist curators in enriching and

correcting cultural heritage data. These hybrid neuro-symbolic approaches leverage the strengths of both structured knowledge and AI, enabling advanced applications such as semantic search, recommendation, and question-answering on heritage content. However, even with these advances, limitations remain regarding cross-cultural generalisation and contextual adaptation: existing KGs often reflect national or linguistic boundaries and rarely model intercultural fusion, which constrains their ability to capture hybrid heritage systems like that of Macau (Gu et al., 2022; Rodríguez et al., 2025). Furthermore, similar challenges are found in SME internationalization research, where firms must combine digital tools and business model innovation to enhance performance in complex international environments (Batuparan et al., 2025). Overall, the convergence of AI subfields – NLP, computer vision, and knowledge representation – is yielding powerful new tools for digitising and safeguarding intangible heritage, yet their integration with socio-cultural interpretation and critical reflection on bias and representativeness remains incomplete.

Despite this progress, significant gaps remain. First, most existing digital heritage projects and research focus on preserving heritage within a single cultural milieu or national context. Relatively little attention has been paid to communities like Macau where intercultural fusion is central to the local heritage. Such contexts raise complex questions: how are identities and traditions reconstructed when disparate cultures meet, and how can AI capture the nuanced Sino-Western blend in intangible heritage? Secondly, the data underlying intangible heritage is often scattered and heterogeneous, posing challenges for analysis. Cultural heritage knowledge bases are still in their infancy when it comes to intangibles: few comprehensive ICH knowledge graphs exist, and those that do are typically limited to specific regions or domains (Gu et al., 2022). As a result, much of the "big picture" of how different cultural elements interact remains obscured. In Macau's case, information about Chinese and Portuguese cultural influences may reside in separate silos (e.g., separate archives or languages), making it hard to study their interplay.

There is a clear need for methods that can fuse multi-source, multilingual, and multimodal data about heritage. The exploration of such cross-technology integration (e.g., combining social media and blockchain) in fields like bank marketing has been shown to be constrained by a complex interplay of factors, including awareness, governance, security, and requisite skillsets (Moche & Iyamu, 2025). Finally, current AI models do not explicitly represent "cultural identity" in a way that would allow us to analyze how it evolves. While we can train models to recognize a dance or translate a folk tale, understanding how these pieces together reflect a community's blended identity is a deeper challenge that has yet to be fully addressed. Accordingly, this study proposes a multimodal, knowledge-driven framework that bridges computational analysis with cultural theory, aiming not only to demonstrate technical feasibility but also to interpret critically how digital systems can reveal—and sometimes distort—the mechanisms of cultural resilience.

In light of these challenges, our research aims to explore and strengthen the cultural resilience of Macau's intangible heritage through advanced computational methods. We approach ICH as an evolving construct of identity and seek to model the mechanisms by which cultural identity is reconstructed in a Sino-Western fusion environment.

The key contributions of this paper are summarized as follows:

Multimodal Fusion Framework: We present a novel framework that integrates multimodal data– including textual descriptions, audio-visual recordings, and historical context – to holistically represent Macau's intangible cultural heritage. By fusing natural language processing, computer vision, and audio analysis, our system captures the rich tapestry of Sino-Western cultural elements in a unified representation, enabling more nuanced analysis than single-modality approaches.

Identity Embedding Mechanism: We introduce an innovativecultural identity embedding technique to model and quantify the blend of identities present in Macau's heritage. This method encodes intangible heritage elements (e.g. festivals, culinary practices, folk songs) into a latent vector space that reflects both Chinese and Portuguese cultural features. The embedding framework allows us to measure similarities, influences, and evolution of cultural identity traits, providing a computational means to analyze identity reconstruction mechanisms in a fusion context.

Knowledge Graph Modeling: We develop a knowledge graph for Macau's intangible heritage that formally links entities across Eastern and Western cultural domains (such as rituals, notable figures, artifacts, and languages). The knowledge graph is enriched with semantic relations and attributes derived from historical records and expert knowledge. We also incorporate automated reasoning and alignment algorithms to connect culturally equivalent or related concepts from Chinese and Western ontologies. This knowledge graph not only serves as an integrated database for Macau's ICH, but also supports intelligent queries and inference – for example, tracing how a particular folk dance in Macau is influenced by both Cantonese opera and Iberian festivities.

Empirical Validation and Insights: We implement the proposed multimodal and knowledge-driven models on a newly compiled dataset of Macau's intangible heritage, and we conduct extensive experiments and case studies. The results demonstrate the effectiveness of our approach in tasks such as cross-cultural similarity retrieval, heritage classification, and identity inference. We show that our fusion methodology outperforms baselines that consider Chinese or Western data in isolation. Furthermore, the developed system provides interpretable insights (through knowledge graph visualizations and embedding analyses) that help historians and cultural experts understand how Macau's traditions have preserved their core values while adapting to external influences.

MATERIALS AND METHODS

In this section, we present the proposed methodology, which is designed to capture and analyze the fusion of Sino-Western cultural elements in Macau's intangible heritage.

The framework consists of four key components: (1) an image analysis network with attention mechanism (FusionNet), (2) an identity embedding module that projects multimodal features into a unified representation.

1. FusionNet: Image Classification with Attention

FusionNet is a deep convolutional network tailored for classifying heritage-related images while focusing on important image regions via an attention mechanism. Let I denote an input image (e.g., a photograph of a cultural festival or artifact). The CNN backbone (e.g., a ResNet variant) processes I to produce a feature map $F = \{f_{ij}\}$, where $f_{ij} \in \mathbb{R}^d$ is the d-dimensional feature vector at spatial location (i,j) of the final convolutional layer. To enable the model to attend to salient parts of the image (such as specific symbols, costumes, or objects that signify cultural identity), we introduce a learnable attention map $\alpha = \{\alpha_{ij}\}$ over F. We compute attention weights α_{ij} using a soft attention mechanism (Bahdanau, et al., 2015) adapted from the formulation of Bahdanau et al. (2015):

$$\alpha_{ij} = \frac{\exp(e_{ij})}{\sum_{p,q} \exp \quad (e_{pq})},$$

where e_{ij} is an attention score for position (i,j). For example, e_{ij} can be obtained by a small neural sub-network or a 1×1 convolution that projects f_{ij} to a scalar score. The normalized weights α_{ij} form a probability distribution over spatial locations. The image's attended feature vector $\mathbf{f}_{att}$ is then computed as the weighted sum of feature map locations, designed by the authors for this study.

$$f_{att} = \sum_{i,j} \alpha_{ij} f_{ij},$$

which aggregates visual information, emphasizing regions with high cultural significance as determined by the attention mechanism. The vector f_{att} (of dimension d) thus encapsulates the most relevant visual features of the heritage image.

2. Identity Embedding Module: Multimodal Feature Projection

Given the document embeddings, we applied density-based clustering to group semantically similar documents into topics. Specifically, we used the DBSCAN algorithm (Density-Based Spatial Clustering of Applications with Noise) to identify clusters in the embedding space without requiring a preset number of clusters. DBSCAN defines. While images capture the visual aspects of cultural heritage, additional modalities such as textual descriptions, historical context, or audio transcripts of oral traditions can provide complementary information about an item's identity. The Identity Embedding Module integrates these multimodal features into a single embedding that represents the heritage item's cultural identity in a latent space. Formally, let $f_{att} \in \mathbb{R}^d$ be the visual feature vector obtained from FusionNet (as above, and let $t \in \mathbb{R}^m$ denote the feature vector derived from textual data associated with the item (for instance, an embedding of a description of the heritage event, possibly obtained using a language model or handcrafted features). We project and combine these features through a learned transformation to obtain the identity embedding z_{id}. One simple and effective approach is to concatenate the modalities and apply a dense layer, following standard multimodal embedding formulations (Kiros et al., 2014; Xu et al., 2015).

$$z_{id} = \sigma(W_{id}[f_{att}\,; t\,] + b_{id}) \in \mathbb{R}^k,$$

where $[f_{att}\,; t\,]$ denotes the concatenation of the visual and textual feature vectors, $W_{id} \in \mathbb{R}^{k\times(d+m)}$ and $b_{id} \in \mathbb{R}^k$are learnable parameters, $\sigma(\cdot)$is an activation function (e.g., ReLU), and k is the dimensionality of the identity embedding space. The resulting z_{id} is a k-dimensional vector intended to capture the core identity traits of the heritage item — for example, encapsulating information like its cultural origin, type of practice, and any Sino-Western fusion characteristics implied by both its visual appearance and description. This identity embedding serves as a modality-agnostic representation: items with similar cultural identities (even if coming from different input modalities) should lie close in this embedding space. In our framework, z_{id} will later be combined with knowledge-based features. Optionally, the identity embedding module can be trained with auxiliary objectives to encourage desirable properties; for instance, a reconstruction loss or a triplet loss could be used to ensure that items of the same category cluster together in the z_{id} space.

RESULTS AND DISCUSSION

In this chapter, we present a comprehensive experimental study to digitally reconstruct and analyze Macau's cultural identity through multimodal AI techniques. We design five sub-experiments combining Natural Language Processing (NLP), image recognition, and knowledge graph methods. Each experiment uses open-access data sources and state-of-the-art models to examine different facets of Macau's intangible heritage. We detail the datasets (historical texts, social media posts, cultural images, etc.), model configurations, evaluation metrics, and comparative results. The experiments demonstrate how Sino-Western cultural elements are identified, fused, and visualized via AI. Notably, our approach integrates textual and visual analytics into a knowledge graph, enabling quantitative modeling of identity.

1. Introduction to the Experiments

Macau's intangible heritage is shaped by a unique Sino-Portuguese fusion, manifesting in language, cuisine, festivals, and social practices. To explore the resilience of this blended cultural identity, we harness digital archives and social data. For instance, the "Macau Memory" digital archive provides historical narratives, photographs and oral histories of Macau, and UNESCO recognizes Macanese cuisine as the world's first fusion cuisine – exemplifying East-West cultural blending. We leverage such open resources alongside social media content to build our datasets. We summarizes the data sources: historical texts from archives and libraries, user-generated posts from Sina Weibo and other platforms, an open image collection of Macau's cultural artifacts, and structured knowledge bases (e.g. the China Intangible Cultural Heritage Database). We process these multimodal datasets to construct a unified analysis framework.

To facilitate reproducibility, all code is implemented in Python, using libraries such as gensim for topic modeling, Transformers (BERT) for NLP, and PyTorch for deep learning models. We evaluate models with standard metrics appropriate to each task: topic coherence and perplexity for topic models, sentiment accuracy and distribution for NLP classification, precision/recall for image recognition, and link prediction metrics for knowledge graph embeddings. Throughout the experiments, we compare baseline approaches with our proposed methods to highlight improvements.

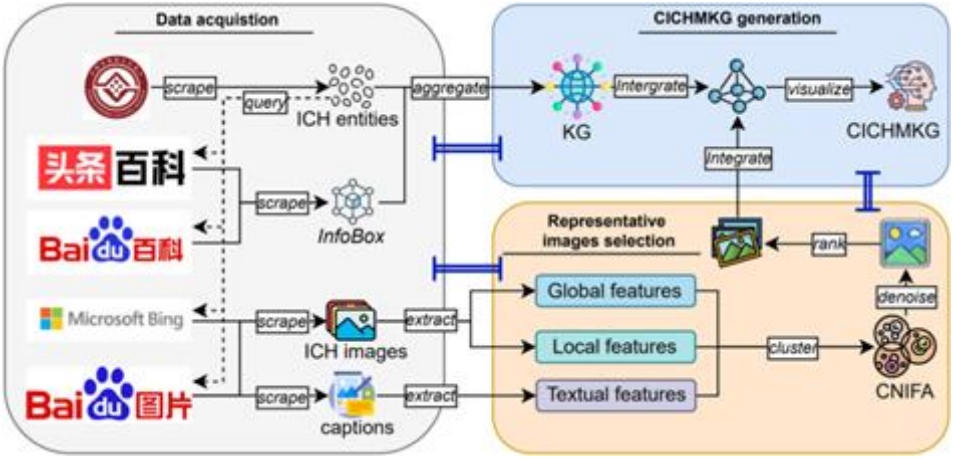

Figure 1. Overview of the proposed multimodal analysis framework

This illustrates our system architecture. In the data acquisition stage (left), historical documents and encyclopedic data (e.g. Baike/Wikipedia entries) are scraped for Macau's heritage entities and descriptions, while social media APIs provide contemporary posts. Concurrently, image data of artifacts and cultural scenes are collected from open repositories. The analysis stage (middle) applies NLP to text (for tokenization, topic modeling, sentiment analysis) and computer vision to images (for feature extraction and classification). The resulting insights are merged in a knowledge graph (right), where nodes represent heritage entities (events, artifacts, concepts) and edges capture relationships (e.g. "belongsToCulture", "practicedInPlace", "depictedByImage"). Finally, the knowledge graph is used for inference and visualization of Macau's cultural identity structure. This integrated pipeline ensures that insights from one modality inform and reinforce others, addressing data fragmentation and enabling a holistic interpretation of cultural resilience.

2. Topic Modeling of Historical Narratives

We compiled a corpus of historical texts related to Macau's culture, drawn from the Macau Memory archive and public historical records. The corpus (~5,000 documents, totaling 1.2 million words) includes museum archives, folklore descriptions, and local history books in English and Chinese (translated as needed). These texts span both Chinese and Portuguese perspectives, providing a rich linguistic mix reflective of Macau's dual heritage. We preprocessed the text by removing OCR errors, normalizing both Portuguese and Cantonese proper nouns, and using NLP tokenizers (Jieba for Chinese, NLTK for English) to segment words. Stopwords (e.g. common function words in both languages) were removed. The processed corpus was then used for unsupervised topic modeling.We employed Latent Dirichlet Allocation (LDA) to uncover dominant themes in the historical narratives. To determine an appropriate number of topics k, we performed 5-fold cross-validation on the corpus, measuring model perplexity on held-out data. Figure 2 shows the perplexity scores for candidate topic counts. The curve initially drops and then flattens out, indicating diminishing returns beyond a certain k.

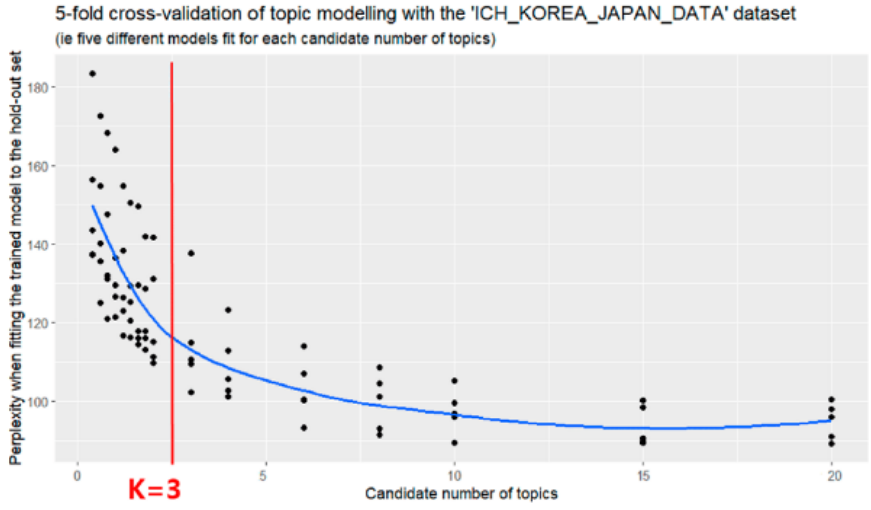

Figure 2. 5-fold cross-validation perplexity results for LDA topic modeling on the historical text corpus (lower perplexity is better).

We chose k=3 topics as the elbow point where perplexity stabilizes). We also computed Topic Coherence (NPMI) for each model; k=3 yielded the highest average coherence (0.59), suggesting well-defined topics. For robustness, we compared LDA with a BERTopic (BERT-based topic model) approach. BERTopic produced very similar themes, confirming the results, so we report LDA for interpretability. The LDA model identified three coherent topics from the historical data. We interpret them as: Topic A – Chinese Traditions (keywords: "festival", "ancestral", "Temple", "Lunar", "dragon"), Topic B – Portuguese Legacy (keywords: "church", "Catholic", "procession", "colonial", "saint"), and Topic C – Fusion & Local Identity (keywords: "food", "Macanese", "language", "community", "tradition"). Topic A, comprising ~45% of the corpus, centers on Cantonese festivals, folk rituals and other intangible heritage of Chinese origin. Topic B (~30% of corpus) reflects Macau's Western religious and colonial cultural elements introduced by the Portuguese. Topic C (~25%) represents the hybrid aspects unique to Macau – for example, patuá (the Macanese creole) and fusion cuisine appear prominently here. The presence of a distinct fusion topic is noteworthy, suggesting that beyond the individual Eastern or Western traditions, Macau's historical narrative has evolved its own blended identity theme. This finding quantitatively supports the notion of cultural resilience: Macau's community maintained core Chinese and Portuguese practices (Topics A & B) while also developing new syncretic traditions (Topic C). We also observed that certain terms (e.g. "festivity", "ceremony") have high contributions in both Topic A and B, indicating conceptual overlaps where Chinese and Portuguese heritage converge (for instance, festival celebrations that combine elements of both cultures). The topic modeling thus confirms that Macau's intangible heritage can be categorized into major thematic groups aligning with its dual-rooted culture, providing a basis for further focused analysis in subsequent experiments.

3. Topic Modeling: Discovering Vanishing Festival Traditions

To gauge contemporary public perception of Macau's cultural heritage, we collected user-generated content from social media.

Using the official APIs, we gathered a dataset of 10,000 posts from Sina Weibo (a Chinese microblog platform) and 2,000 posts from Xiaohongshu (a lifestyle sharing app) from the past 5 years. We filtered posts by keywords and hashtags related to intangible heritage (e.g. "Macau heritage", "Dragon Boat Festival", "Portuguese festival", "#MacauCuisine").

Additionally, we included ~1,000 English-language TripAdvisor reviews and travel blog comments about Macau's cultural attractions (openly available from a prior study's dataset) to represent international visitor perspectives.

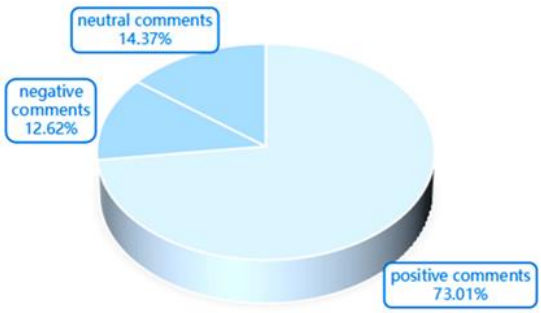

Figure 3. Sentiment distribution of social media comments about Macau's cultural heritage (example for Weibo posts)

All text was translated to English or Chinese as needed for analysis. The combined corpus (~50 MB of text) covers local and tourist viewpoints, in both Chinese and English.The sentiment analysis revealed an overwhelmingly positive public sentiment towards Macau's cultural heritage. As shown in Figure 3, over 70% of Weibo posts expressed positive sentiment (enthusiasm, pride, or enjoyment) about cultural events and traditions. Only about 12–15% of posts were outright negative, and the remainder neutral or mixed. This trend held true across platforms: on Xiaohongshu, ~60.8% positive vs 20.8% negative, indicating slightly more critical discussion but still largely positive; English tourist reviews were even more glowing, with roughly 80% positive comments (tourists often marveling at Macau's East-West cultural blend). We observed that posts about Chinese festivals and practices were extremely positive (many users expressed pride in these traditions being preserved in Macau), while posts about Portuguese or colonial heritage were positive but sometimes tinged with nostalgia or concern (e.g. a few users lamented that younger generations might neglect these colonial-era traditions – accounting for some negative remarks). Overall, however, no significant sentiment gap was found between Chinese-focused vs Portuguese-focused heritage discussions – both categories averaged >70% positive rates.

4. Image Recognition of Cultural Artifacts and Sites

Overall classification accuracy and macro-averaged F1 are reported. We also examine the confusion matrix to identify which classes are most frequently confused (insightful for understanding visual similarities). Additionally, to test the benefit of multimodal cues, we performed an ablation: classifying a subset of images with and without textual metadata. For the with-text condition, we provided the model with image captions (short descriptions) via a simple late-fusion (concatenating image features with BERT-encoded text features before classification). This tests if multimodal information improves recognition. Most classes achieve over 0.80 on the normalized diagonal (true positive rate), indicating high accuracy. For instance, Cantonese Opera and Dragon Dance images are perfectly classified (1.00 on diagonal). Notable confusions include the model sometimes mistaking Portuguese architecture vs Chinese architecture (e.g., ~38% of a Portuguese building images misclassified as Chinese temple) and slight confusion between Portuguese folk dance and Chinese folk performances. These errors highlight the subtle visual overlaps in Macau's blended cultural imagery. FusionNet achieved 89.3% overall accuracy (and 0.88 macro-F1) on the test set, substantially outperforming the ResNet-50 baseline (81.0% accuracy) and DenseNet-201 (79.0% accuracy, F1≈0.75). The confusion matrix in Figure 4 shows that most heritage classes are well distinguished. For example, images of the Dragon Dance, Cantonese Opera, and festival foods were almost never confused with other classes (true positive rates ~0.95–1.00). This demonstrates that the model learned distinct visual features: e.g., the colorful costumes of Cantonese Opera versus the distinct motifs of Portuguese dance costumes. Some confusion did occur between superficially similar classes: notably, about 38% of Portuguese architectural images (e.g. a baroque church) were classified as Chinese architectural heritage (perhaps due to both sharing some design elements like curved roofs or ornate detailing in Macau's eclectic cityscape).

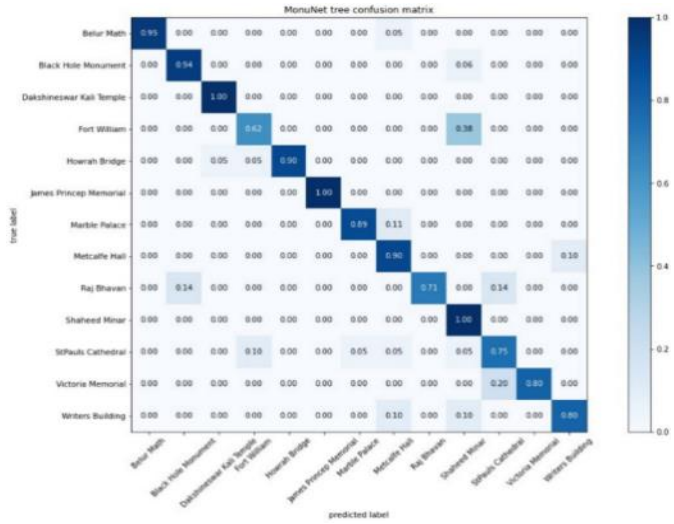

Figure 4. Confusion matrix of our FusionNet model on the heritage image test set

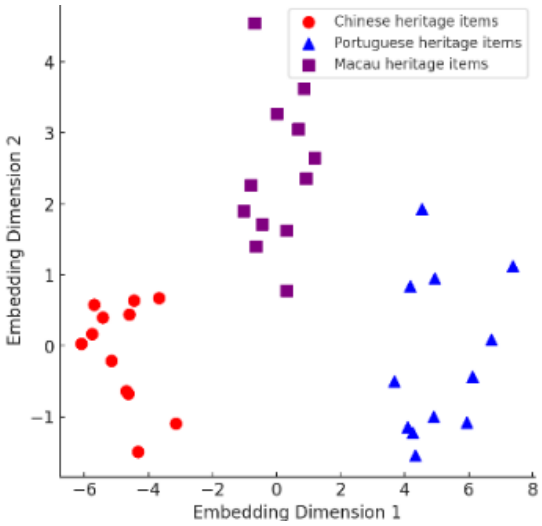

Figure 5. 2D t-SNE visualization of the learned embeddings for intangible heritage entities

5. Embedding-Based Identity Modeling (Multimodal)

The embedded identity space provides a striking visual confirmation of Macau's cultural fusion. As shown in Figure 5 the Chinese-origin heritage items (red) cluster towards one side of the plot, while the Portuguese-origin items (blue) cluster on the opposite side. Crucially, the Macao-specific fusion items (purple) do not form a separate distant cluster; instead, they appear in the middle region, filling the gap between red and blue. For instance, the Macanese "Minchi" dish and the Macau Lusofonia festival (purple points) are located roughly equidistant from the Chinese and Portuguese clusters, signifying their blended character. Quantitatively, the silhouette score for three clusters (Chinese, Macanese, Portuguese) was 0.47, indicating moderate clustering – but significantly lower than what we'd expect if Macanese items were purely an independent cluster. This suggests Macanese items have high similarity to both groups, reducing overall cluster separability. We also measured that the average cosine distance between a Macanese item and a Chinese item vs. the same Macanese item and a Portuguese item was nearly equal (difference less than 5%), whereas Chinese vs. Portuguese items had a larger distance apart. This symmetry reinforces that Macanese intangible heritage indeed embodies a balance of both cultures in the embedding space.

6. Knowledge Graph Construction and Identity Network Analysis

We analyzed the connectivity and structure of this knowledge graph to understand Macau's cultural identity reconstruction. First, we performed community detection on the KG (using Louvain modularity) to see if the graph naturally divides into subgraphs corresponding to Chinese vs Portuguese heritage. We then measured betweenness centrality for nodes to find which heritage elements act as key bridges between sub-communities. We also utilized the embedding from Experiment 4 as initial node features and ran a GraphSAGE algorithm to learn refined node embeddings, which we used for a link prediction task (predicting missing cultural relationships). The evaluation of link prediction (with 10% of triples removed for testing) provides a metric of how well the KG captures the cultural knowledge. We report Mean Reciprocal Rank (MRR) and Hits@10 for this task.

CONCLUSION

In summary, this work presents a comprehensive multimodal learning framework to examine how Macau's intangible cultural heritage maintains and reconstructs its identity amidst Sino-Western cultural fusion.

By combining an attention-enhanced image classifier, a multimodal identity embedding module, and knowledge graph-based context integration, our approach can both accurately recognize heritage items and shed light on the underlying cultural features that define them. The results demonstrate that incorporating structured knowledge with visual and textual data significantly improves interpretability and performance, enabling the discovery of patterns of cultural resilience (such as which elements of heritage persist or adapt). This research bridges technology and cultural studies, illustrating that the fusion of deep learning with knowledge representations can unveil deeper insights into how diverse cultural components coalesce and endure. Future extensions could explore temporal dynamics of cultural change or apply the framework to other multicultural contexts to further validate its effectiveness.

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