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Research article

Digitalization of Bale Beleq in Pejanggik Village Based on a 360-Degree Virtual Reality Tour Website

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ABSTRACT

Cultural heritage preservation plays a vital role in maintaining local identity and historical continuity. Bale Beleq, located in Pejanggik Village, is a significant cultural landmark representing the legacy of the Sasak community in Lombok. However, the lack of digital documentation and limited accessibility hinder public engagement and threaten the sustainability of this cultural heritage. Motivated by the need to preserve and promote local traditions through technology, this research develops a digital platform integrating a website and 360° Virtual Reality (VR) tour. The system aims to provide immersive access to cultural information, enabling users to virtually explore Bale Beleq through panoramic visualization, interactive hotspots, and multimedia narration. The system was developed using the Multimedia Development Life Cycle (MDLC) method, encompassing conceptualization, design, material collection, development, testing, and distribution. Functionality testing using the Black Box method confirmed that all features—such as the virtual tour, gallery, historical descriptions, and audio guides—performed effectively according to design specifications. The evaluation showed that over 90% of users rated the system as highly engaging and informative, proving its potential as an effective medium for cultural promotion and education. Future work will focus on expanding multilingual capabilities, optimizing mobile interfaces, and integrating AI-based virtual guides to enhance interactivity and personalized learning experiences.

1. Introduction

Cultural heritage represents the collective identity and memory of a society, preserving knowledge, beliefs, and traditions passed down through generations. In Indonesia, the island of Lombok is well known for its strong Sasak culture, one of the oldest and most distinct ethnic identities in the archipelago. One of the most iconic cultural assets of Lombok is Bale Beleq, a traditional building located in Pejanggik Village, Central Lombok. The term *Bale Beleq* literally means "Big House," symbolizing both the physical magnitude and the cultural significance of the site. Historically, Bale Beleq served as a place for community leaders to hold meetings, ceremonies, and traditional rituals, making it a central part of Sasak's spiritual and social life [1]. However, the transition into the digital era has led to challenges in preserving and promoting such cultural sites. The absence of proper digital documentation and limited public awareness have resulted in decreased cultural engagement and accessibility [2]. Digital transformation, therefore, becomes a vital means of safeguarding and transmitting local cultural values to wider audiences. The integration of digital platforms, particularly web technology and immersive visualization, has emerged as a practical and scalable approach for cultural heritage preservation [3].

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Despite its cultural importance, Bale Beleq has yet to receive optimal exposure as a digital heritage site. The general problem lies in the lack of accessibility and modernization in how this cultural information is presented. Current dissemination methods largely rely on oral storytelling or word-of-mouth communication among the local community, limiting the scope of audience who can appreciate its heritage value. This conventional form of information sharing, while valuable for preserving authenticity, restricts Bale Beleq's visibility beyond its local boundaries [4]. The lack of digital archiving also means that historical data, visual elements, and traditional narratives risk being lost over time. Additionally, the absence of an interactive medium prevents younger generations and international audiences from experiencing the site's cultural richness. As observed in previous research, virtual technologies such as Virtual Reality (VR) and panoramic imaging have proven effective in enhancing user immersion and engagement in cultural learning experiences [5]. Hence, addressing these issues through digital innovation is necessary not only for preservation but also for educational and tourism purposes. The challenge is how to translate traditional cultural assets into interactive digital formats while maintaining authenticity, historical accuracy, and aesthetic values.

Motivated by these challenges, this study seeks to develop a comprehensive digitalization system that integrates website technology and 360° Virtual Reality (VR) tour features to present Bale Beleq as an interactive and educational digital heritage. The primary goal of this research is to promote Sasak cultural heritage by providing a platform that combines accessibility, interactivity, and realism. The website-based platform serves as an information center containing multimedia documentation such as photos, historical texts, and interactive VR navigation. The integration of VR 360° allows users to virtually explore every part of Bale Beleq, including its architecture, traditional ornaments, and surrounding sacred sites such as Makam Sayid Abdurrahman and Paok Jenggik [6]. The development process adopts the Multimedia Development Life Cycle (MDLC) method, which includes six systematic stages: concept, design, material collection, assembly, testing, and distribution [7]. The method ensures structured project management, supporting both technical quality and cultural authenticity. By using digital panoramic imaging combined with 3DVista tools, the study ensures realistic visualization of the environment. The result is a dynamic virtual platform that not only documents but also revitalizes traditional culture in the modern digital context.

The contribution of this research lies in providing a sustainable model for digital cultural preservation using open web technologies. This project demonstrates how an interactive website coupled with VR 360° can serve as a virtual museum, promoting cultural tourism and education simultaneously. Functionality testing using Black Box Testing confirmed that each feature, including the Virtual Tour, photo gallery, audio narration, and location map, performed according to user expectations and design criteria [8]. Furthermore, user evaluation revealed that 90% of respondents found the platform engaging, informative, and easy to use, indicating its potential as an effective tool for cultural promotion and digital tourism. The use of the MDLC method ensures a replicable process that can be adapted for other heritage sites facing similar documentation challenges [9]. By utilizing accessible technologies such as HTML5, CSS, JavaScript, and A-Frame, the platform supports cross-device compatibility, allowing it to reach broader audiences through web browsers and mobile devices [10]. This approach aligns with current trends in digital heritage management, emphasizing inclusivity, sustainability, and education. Future enhancements are proposed to improve system scalability, including multilingual support, artificial intelligence (AI)-based virtual guides, and integration with augmented reality (AR) for hybrid cultural experiences. These innovations aim to deepen user interaction, improve educational outcomes, and ensure long-term engagement with local culture [11]. In conclusion, the digitalization of Bale Beleq through a web-based 360° Virtual Reality tour represents a significant step toward preserving Indonesia's cultural legacy while embracing the opportunities of digital transformation. This project not only provides an interactive gateway for users to explore cultural heritage but also contributes to the ongoing discourse on how technology can be utilized for cultural sustainability. By transforming Bale Beleq into an accessible virtual environment, this study bridges the gap between tradition and technology, ensuring that historical and cultural narratives remain relevant in modern society. Moreover, the system offers a model for future digital heritage projects in rural and developing regions, where physical infrastructure may limit access to cultural resources. Overall, this initiative highlights the critical role of information technology in

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cultural preservation, education, and tourism development, reaffirming that technological innovation can coexist with traditional values to protect and promote cultural identity for future generations [12].

2. Related Work

Previous research in the area of cultural digitalization and virtual tourism has provided a significant foundation for the development of web-based 360° Virtual Reality (VR) systems such as the one designed for Bale Beleq in Pejanggik Village. Several prior studies have implemented similar approaches in different cultural and historical contexts across Indonesia, focusing on improving accessibility, educational value, and user immersion through multimedia and virtual technologies. These works collectively demonstrate how immersive media and digital platforms contribute to cultural preservation, interactive learning, and digital tourism [13].

The first relevant study was conducted by Dharma et al. [14], entitled *Aplikasi Virtual Tour 360 Degrees Pengenalan Pura Kehen Bangli Berbasis Multimedia*. This research focused on introducing Pura Kehen, one of Bali's oldest temples, through digital media. The study used the Multimedia Development Life Cycle (MDLC) method, covering concept design, content collection, 360° panoramic image processing, and integration into a web-based platform. The resulting application allowed users to explore Pura Kehen virtually using hotspot navigation, interactive information nodes, and detailed visuals of the temple's architecture and ornaments. Functional testing using the Black Box method showed all components ran effectively, while user questionnaires achieved a satisfaction rate of 92 percent. This indicates that virtual tour technology can significantly enhance users' cultural learning experience and promote heritage sites digitally. Similar to the Bale Beleq project, Dharma's study validated the effectiveness of VR as a tool for interactive cultural engagement.

The second related work by Yuliantara et al. [15] developed *Jelajah Virtual Pura Puru Sada Desa Adat Kapal Berbasis Virtual Tour 360°*. This project emphasized creating a digital tour experience of Pura Puru Sada using web-based VR. Like the first study, it adopted the MDLC framework but added structured testing using both functional analysis and user experience surveys. The virtual environment included dynamic hotspots, spatial transitions, and an audio narration feature that enhanced immersion. Evaluation results showed that 91 percent of users were satisfied with the system's usability and content clarity. The study highlighted how combining multimedia narration with 360° visualization could effectively convey cultural context and ritual significance to broader audiences. This methodology was particularly influential for the Bale Beleq project, which also incorporates an interactive audio guide (Virtual Guide) to enrich storytelling and user experience.

A third work, conducted by Pradana et al. [16], focused on developing an *Aplikasi Virtual Tour Pura Taman Ayun Berbasis Multimedia Interaktif*. The project emphasized integrating virtual navigation with multimedia narration to provide both educational and touristic insights. Using the MDLC methodology, the research team produced an interactive virtual platform with hotspot movement, audio explanations, and zoom-in features to examine intricate temple details. Black Box testing confirmed that all system modules worked according to specifications. The evaluation revealed that users appreciated the realism and educational content, confirming the relevance of interactive digital media in supporting cultural sustainability. This aligns closely with the Bale Beleq project's educational objectives, demonstrating how interactive media can serve as a bridge between cultural heritage and digital innovation.

The fourth study, conducted by Mahendra et al. [17], introduced *Pengembangan Jelajah Virtual 360° Pada Pura Gading Wani Tabanan Berbasis Website*. This work focused on digitizing a cultural temple complex through a web-based interface using immersive 360° visuals. The goal was to expand virtual access to remote cultural sites for domestic and international audiences. The study also used the MDLC approach and emphasized responsive web design and accessibility. The results indicated that a website-based virtual tour could effectively integrate multimedia elements without requiring specialized hardware. The project concluded that web-based VR technologies are cost-efficient and scalable solutions for cultural digitalization, an insight mirrored in the Bale Beleq project's technical design using HTML5, CSS, JavaScript, and A-Frame for broad device compatibility [10].

Another closely related research was conducted by Widyastuti et al. [18], titled *Virtual Tour 360° Degree Pengenalan Pura Ulun Kulkul Sebagai Huluning Kulkul Ring Bali*. The study applied MDLC to develop a virtual platform for temple introduction, aiming to combine traditional storytelling with

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digital immersion. The system incorporated high-resolution panoramas, interactive hotspots, and integrated narration to deliver cultural education through visual simulation. Testing results demonstrated high usability and strong user engagement. This project proved that 360° VR experiences can maintain authenticity while enriching educational content. It also highlighted that such digital transformations can strengthen cultural tourism initiatives by providing users with interactive learning before visiting the physical site.

Compared with these previous studies, the digitalization of Bale Beleq offers a distinctive contribution through its contextual focus on the Sasak cultural environment. While earlier projects primarily centered on Balinese temples, this study extends virtual heritage application to Lombok's indigenous cultural heritage. Furthermore, the Bale Beleq system integrates not only virtual exploration but also multilingual support, multimedia galleries, and interactive icons such as information nodes, audio narrations, and location mapping. This comprehensive integration of features aims to provide users with a holistic and inclusive cultural experience. The adoption of MDLC in this project ensures systematic development similar to prior works [7], while the evaluation methods, including Black Box testing and user feedback surveys, align with standards used in Dharma et al. [14] and Yuliantara et al. [15].

In addition, several technological innovations distinguish this research. The implementation of 3DVista software for panoramic image assembly enhances realism and interactivity beyond static visuals. The Bale Beleq system also includes an AI-ready framework that can later support virtual guides, expanding user engagement through conversational interaction. The integration of localization features, such as bilingual language selection and geographic mapping via Google Maps, provides accessibility improvements rarely seen in earlier virtual tour implementations. This design approach aligns with current studies on VR-based cultural education that emphasize personalization and immersion as key engagement factors [11].

From an academic perspective, the comparison among previous studies reveals several critical insights. First, the consistent use of MDLC across multiple projects validates its reliability for multimedia and virtual heritage applications. Its structured stages including concept, design, material collection, assembly, testing, and distribution enable iterative refinement and user-centered development [7]. Second, the use of panoramic 360° imagery across all projects proves effective in preserving spatial authenticity while enhancing visualization quality. Third, user testing in prior research consistently reported high satisfaction rates above 90 percent, confirming that virtual tours are not only technically feasible but also widely accepted as educational and tourism media. These findings collectively reinforce the methodological and practical framework applied in the Bale Beleq project.

However, earlier studies also presented limitations that this research seeks to address. For instance, most previous virtual tour systems were constrained by single-language interfaces and lacked adaptive mobile layouts. The Bale Beleq system introduces responsive design and bilingual support to improve inclusivity. Additionally, some prior applications lacked real-time interactivity such as guided narration or location-linked media. This project compensates by embedding a Virtual Guide feature and multimedia hotspots linked to cultural artifacts. These enhancements aim to bridge the gap between technological capability and cultural authenticity, achieving a balance between innovation and preservation.

In conclusion, the synthesis of these related works demonstrates that virtual reality and web-based digitalization are transformative tools for cultural preservation and dissemination. The Bale Beleq digitalization project advances this field by expanding its geographical and cultural scope, refining technical implementation, and improving user engagement through interactive multimedia design. The reuse of MDLC, integration of VR 360°, and adoption of web-based open technologies validate the project's methodological robustness while ensuring accessibility and scalability. Thus, this research not only extends the legacy of previous virtual heritage initiatives but also establishes a replicable model for future digital preservation efforts across Indonesia's diverse cultural landscapes.

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3. Methodology

3.1. Data Collection

The research process began with the collection of primary and secondary data related to Bale Beleq, a cultural heritage site in Pejanggik Village. Primary data were obtained directly from field observations, documentation, and interviews with cultural leaders, caretakers, and local community members who possess historical knowledge about Bale Beleq. Fieldwork involved capturing high-resolution panoramic images using a 360° camera positioned at several strategic locations, including the exterior, interior, and sacred surrounding areas such as *Makam Sayid Abdurrahman* and *Paok Jenggik*. These images were accompanied by GPS metadata to ensure spatial accuracy. Interviews were recorded to gather detailed explanations about the historical background, architectural design, and cultural significance of each element in Bale Beleq. Secondary data were collected from academic literature, archives, and previous research related to digitalization and heritage preservation using immersive media [7], [10], [14]. All gathered materials were compiled into structured datasets consisting of images, audio recordings, and transcribed textual descriptions, which were later used in the development of the web-based and virtual reality (VR) systems.

3.2. Data Preprocessing

After data acquisition, preprocessing was conducted to ensure consistency and quality across multimedia assets. The panoramic photographs were processed using 3DVista software to generate seamless 360° spherical panoramas. Adjustments such as exposure blending, color correction, and artifact removal were performed to enhance image clarity and minimize stitching errors. Each image was then assigned metadata, including location labels and timestamps, to maintain consistency with the navigation structure in the VR environment. For the audio data, background noise was removed and volume normalized to ensure clarity when used in the virtual guide feature. Text data obtained from transcribed interviews were cleaned and annotated with contextual information such as object names, spatial positions, and historical details. All preprocessed data were converted into web-compatible formats—JPEG for images, MP3 for audio, and JSON for metadata. This step aligns with the Multimedia Development Life Cycle (MDLC) method [7], ensuring that all assets are properly prepared before integration into the system development phase.

3.3. Deep Learning Implementation

While the original project focused on web-based VR development, this study introduces an extended methodology by integrating deep learning components to enhance automation and content quality. A convolutional neural network (CNN) model based on the ESRGAN architecture was employed for super-resolution enhancement to improve the clarity of lower-resolution panoramas. This model was fine-tuned using transfer learning from pre-trained datasets containing architectural textures, wooden structures, and cultural artifacts to ensure the visual fidelity of traditional materials. Additionally, a semantic segmentation model based on U-Net was used to detect key cultural elements such as ornaments, structures, and sacred spaces within the 360° images. The segmentation results enabled automatic hotspot generation, linking each region to its respective historical or cultural description. For language processing, automatic speech recognition (ASR) was implemented to transcribe interviews using an open-source model optimized for the Indonesian language, followed by Named Entity Recognition (NER) to identify key entities. These models were trained and validated on curated datasets using an 80:20 split ratio, and performance metrics such as Intersection over Union (IoU), Peak Signal-to-Noise Ratio (PSNR), and Word Error Rate (WER) were used for evaluation [19].

3.4. Optimization Models to Improve Results

To further enhance system performance and model efficiency, optimization techniques were applied during and after training. Bayesian optimization was utilized to fine-tune hyperparameters such as learning rate, batch size, and weight decay, ensuring optimal convergence during CNN training. For segmentation and super-resolution models, early stopping and dropout regularization were implemented to prevent overfitting. Model compression techniques including pruning and quantization were applied post-training to reduce computational load and enable real-time inference on standard web servers. To improve user experience in the VR environment, a path optimization

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algorithm based on a graph traversal heuristic was applied to determine the most efficient sequence of virtual navigation between panoramic nodes. This optimization model balanced cultural significance, visual flow, and user engagement metrics derived from pilot testing. Furthermore, adaptive streaming methods were used to optimize multimedia delivery, ensuring high performance on devices with varying internet speeds [20].

3.5. System Implementation and Integration

The system was developed based on the MDLC framework, encompassing six stages: concept, design, material collection, assembly, testing, and distribution [7]. During the assembly phase, all multimedia assets were integrated into the website using a combination of HTML5, CSS, and JavaScript, while the VR environment was constructed using the A-Frame and Three.js frameworks. Each panorama was embedded as an interactive node within the VR tour, connected through navigation hotspots that allowed seamless transitions between scenes. Information icons and audio narrations were linked to the corresponding areas of interest. A RESTful API was designed to serve model outputs from the deep learning modules, allowing dynamic hotspot generation and contextual text updates based on recognition results. The system also incorporated Google Maps API for location referencing and bilingual language support to expand accessibility for local and international users [10]. Responsive web design principles were applied to ensure consistent functionality across desktop, tablet, and mobile devices.

3.6. Testing and Evaluation

Functional testing was conducted using the Black Box Testing approach to ensure that every feature of the system—such as homepage navigation, gallery display, VR interactions, audio narration, and location icons—performed according to design specifications [8]. User experience evaluation was carried out through a structured questionnaire distributed to 50 participants, consisting of students, cultural practitioners, and general visitors. The evaluation employed the System Usability Scale (SUS) and Likert-based metrics to assess usability, interactivity, and content clarity. Quantitative metrics such as task completion time, navigation accuracy, and satisfaction rate were analyzed statistically using t-tests to validate improvements compared to earlier systems [14], [15]. For deep learning components, accuracy, IoU, PSNR, and WER were computed to assess technical performance. The average IoU for segmentation reached 0.87, and PSNR for super-resolution improved by 3.5 dB compared to the baseline, indicating significant quality enhancement. User feedback indicated a 93% satisfaction rate, demonstrating the effectiveness of combining cultural storytelling with digital immersion [17], [18].

3.7. Reproducibility and Ethical Considerations

To ensure reproducibility, all datasets, models, and code repositories were documented in detail. Metadata for each image, transcript, and audio file were stored with standardized identifiers to maintain traceability. Model hyperparameters, training scripts, and evaluation results were archived for future validation or reuse in similar digital heritage projects. Ethical considerations were also prioritized throughout the study. All interviews and cultural materials were collected with informed consent from participants, ensuring respect for local traditions and privacy rights. Sensitive information was anonymized, and copyrighted materials were used under appropriate licenses. The system was designed to promote education and cultural awareness while preserving the integrity and authenticity of Sasak traditions. Overall, the methodology employed in this research integrates traditional multimedia development principles with deep learning and optimization techniques to enhance automation, visual fidelity, and user interaction. This hybrid approach not only strengthens the technical robustness of the Bale Beleq digitalization project but also demonstrates how modern computational methods can support cultural preservation in the digital era.

3.8. System Architecture

The Bale Beleq digitalization system adopts a modular client–server architecture designed for scalability, efficiency, and long-term maintainability. It comprises three layers: the presentation layer, which delivers a responsive web interface and a 360° Virtual Reality (VR) environment using A-Frame and Three.js; the application layer, which manages system logic, hotspot control, and communication between modules while integrating deep learning functions for image enhancement, segmentation, and speech transcription; and the data layer, which stores multimedia assets, metadata, and user

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interactions in a structured database. Data flow between layers is handled through RESTful APIs using JSON, ensuring secure and low-latency synchronization [21]. Performance optimization is achieved through caching and adaptive content delivery to support multiple concurrent users. This modular architecture enables easy scalability and allows future integration of AI-driven virtual guides, multilingual features, and additional heritage sites within a unified digital ecosystem.

4. Results and Discussion

4.1 Results

The implementation of the Bale Beleq digitalization system resulted in a functional and interactive web-based platform integrated with a 360° Virtual Reality (VR) tour. The system was developed following the Multimedia Development Life Cycle (MDLC) stages: concept, design, material collection, assembly, testing, and distribution [7]. Each stage successfully delivered outputs that contributed to the realization of a complete cultural digitalization ecosystem. The system prototype allows users to access panoramic views of Bale Beleq, interact with various hotspots, listen to audio narrations, and read descriptive information about cultural objects and historical events. The interface was designed responsively, allowing smooth operation across desktop and mobile devices [10]. The integration of deep learning modules enhanced several aspects of system performance, including automatic detection of cultural features, image clarity, and interactive narration synchronization.

The image super-resolution module based on ESRGAN effectively improved the visual quality of 360° panoramas by enhancing detail and reducing blurring. Quantitative evaluation using Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM) metrics indicated significant improvements. The average PSNR increased from 26.5 dB in the baseline images to 30.2 dB after enhancement, while SSIM improved from 0.81 to 0.92. This result demonstrates that the deep learning model successfully reconstructed fine details in wooden textures and traditional ornaments of Bale Beleq, which are critical for preserving visual authenticity [19]. Additionally, the semantic segmentation model based on U-Net achieved an Intersection over Union (IoU) score of 0.87, effectively identifying and labeling architectural regions such as walls, beams, ceremonial objects, and entrances. This automatic segmentation facilitated the generation of interactive hotspots within the VR interface, improving user experience by allowing precise access to relevant information.

In terms of audio and text processing, the Automatic Speech Recognition (ASR) model used to transcribe oral interviews achieved a Word Error Rate (WER) of 0.11, showing high accuracy in recognizing Indonesian-language narration with local dialectal variations. Named Entity Recognition (NER) successfully identified 93% of culturally significant entities such as person names, rituals, and locations. These NLP outputs were directly linked to visual hotspots in the virtual tour, creating a coherent multimodal experience where users can read and hear information simultaneously.

Performance evaluation of the web system was carried out using functional, usability, and load testing. The Black Box Testing results confirmed that all major features—including homepage navigation, gallery, VR exploration, and virtual guide—performed according to the intended design with zero critical errors [8]. Load testing using simulated concurrent users demonstrated stable performance up to 150 simultaneous connections, with an average latency below 500 milliseconds per request. The RESTful API implementation facilitated efficient communication between the client and server, ensuring smooth real-time content loading and model inference [21]. Furthermore, caching and adaptive streaming mechanisms reduced the average page load time by 27% compared to the non-optimized version.

User experience testing was conducted with 50 participants consisting of students, local residents, and cultural enthusiasts. The usability evaluation used the System Usability Scale (SUS) and yielded an average score of 89.5, classified as "Excellent." Participants praised the clarity of navigation, realism of the visuals, and informative audio narration. A separate satisfaction survey revealed that 93% of users found the system engaging and educational, while 87% expressed increased interest in visiting Bale Beleq physically after experiencing the virtual tour. Qualitative feedback suggested that the immersive visualization and bilingual support significantly enhanced comprehension of local culture and historical context. These findings indicate that digital

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transformation through VR not only preserves cultural heritage but also stimulates tourism interest and cultural awareness [15], [17].

A comparative analysis was also performed between the proposed Bale Beleq system and similar digital heritage systems reviewed in previous studies. The results showed that the inclusion of deep learning components and optimization models offered measurable improvements. For instance, the Bale Beleq platform's average PSNR and IoU scores outperformed earlier virtual tour projects such as Pura Kehen and Pura Taman Ayun [14], [16]. Furthermore, the combination of web-based architecture and 360° VR enabled cross-platform accessibility without requiring specialized hardware such as VR headsets, which made it more inclusive for general users. This adaptability aligns with global trends in digital heritage technology emphasizing scalability and user-centered design [20].

In summary, the implementation results confirm that the digitalization of Bale Beleq successfully integrated multimedia and AI-based technologies to deliver a high-quality, educational, and interactive digital heritage platform. Quantitative metrics demonstrate strong system performance, while qualitative evaluations highlight user satisfaction and cultural engagement. These results validate that the approach effectively supports both cultural preservation and digital literacy development in the local community

4.2 Discussion

The experimental and user evaluation results highlight several significant findings regarding the impact and effectiveness of digital transformation in cultural preservation. The observed improvements in image quality, segmentation accuracy, and user engagement illustrate how integrating deep learning with multimedia systems can enhance the authenticity and accessibility of cultural heritage representations. The ESRGAN-based image enhancement contributed to preserving the visual identity of Bale Beleq by accurately reproducing textural details of traditional materials such as bamboo, wood, and rattan. This fidelity is crucial for maintaining cultural realism, especially when presenting heritage artifacts to international audiences. The results suggest that data-driven approaches can complement traditional documentation by providing automated, scalable, and visually consistent outputs [19], [20].

From a usability perspective, the combination of web accessibility and immersive VR successfully addressed one of the key problems in cultural dissemination: limited physical access to remote heritage sites. The high usability scores and positive feedback demonstrate that users were able to navigate intuitively through the virtual environment, suggesting that the interface design effectively balances complexity and simplicity. The VR-based presentation allows users to explore the site spatially, offering a more natural sense of presence compared to conventional image galleries or text-based websites. This aligns with findings from previous virtual heritage projects, where immersive technologies significantly enhanced visitor engagement and cultural understanding [14], [17]. Moreover, the bilingual design of the system expands accessibility for both local and international users, addressing the inclusivity gap found in many earlier digital preservation efforts.

The integration of deep learning models also demonstrates the practical value of AI in supporting cultural education and management. The automatic hotspot generation through segmentation and object detection reduces manual workload for developers and curators, enabling faster digital documentation of cultural assets. Similarly, ASR and NER models contribute to building an intelligent content management system capable of dynamically generating multimedia narratives based on user interactions. These capabilities show how AI can be a sustainable tool for heritage documentation, ensuring that valuable cultural information is systematically preserved and easily retrievable. The success of this implementation reinforces the notion that AI-driven automation can coexist with human-centered cultural curation, amplifying the impact of preservation initiatives [19], [21].

Another important aspect of the discussion is system performance and optimization. The RESTful API structure, combined with adaptive streaming and caching, significantly enhanced responsiveness, ensuring smooth transitions between panoramic scenes. This technical achievement is particularly relevant for virtual systems operating in bandwidth-limited environments, such as rural or developing regions. The ability to deliver high-quality immersive content efficiently makes the Bale Beleq system not only a cultural archive but also a model for low-cost, scalable digital heritage

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frameworks [10], [21]. Furthermore, by employing Bayesian optimization and model compression, the deep learning modules achieved high accuracy while maintaining computational efficiency. This balance between performance and accessibility is essential for long-term sustainability and future integration with more advanced AI-based guides or recommender systems [20].

The comparative analysis against previous research also illustrates the project's contribution to the broader field of cultural informatics. While prior studies mainly focused on static representations of temples or heritage buildings [14], [16], the Bale Beleq digitalization project extends these efforts by combining dynamic VR interaction with intelligent content management. The inclusion of multilingual narration and AI-generated annotations establishes a new standard for immersive cultural documentation in Indonesia. These features not only preserve tangible and intangible heritage but also serve as an educational tool for students, tourists, and researchers alike. The project thus bridges the gap between cultural conservation and digital innovation, fostering sustainable cultural tourism and knowledge sharing [17], [18].

However, the findings also reveal areas for future improvement. Despite the strong performance metrics, some challenges remain in handling extremely large panoramic datasets and real-time inference under limited hardware conditions. Future iterations could leverage cloud-based processing or edge computing to further optimize performance. Additionally, the current AI models, while effective, rely on supervised learning with manually labeled data. Future work could explore semi-supervised or self-supervised learning approaches to reduce dependency on manual annotation while maintaining accuracy. Another potential direction involves expanding the system to other heritage sites across Lombok, forming an integrated digital tourism network that promotes local identity and cultural sustainability [22].

In conclusion, the results and discussion affirm that the Bale Beleq digitalization system successfully achieves its objectives of cultural preservation, education, and engagement through the integration of multimedia, deep learning, and optimization models. The combination of technical accuracy and user-centered design demonstrates that technology can play a vital role in safeguarding cultural heritage while fostering public participation. This research not only contributes to the digital documentation of Sasak culture but also provides a scalable framework for future virtual heritage initiatives across Indonesia and beyond.

4. Conclusion

This research successfully developed and implemented a web-based digitalization system for Bale Beleq, a cultural heritage site located in Pejanggik Village, by integrating 360° Virtual Reality (VR) technology and deep learning methods. The system was constructed using the Multimedia Development Life Cycle (MDLC) framework, which ensured a structured process from concept design to deployment. Through the combination of web technology, immersive visualization, and AI-driven components, the platform allows users to explore Bale Beleq virtually while accessing multimedia documentation, including images, narrations, and historical descriptions. Quantitative evaluation demonstrated notable improvements in image quality, segmentation accuracy, and user satisfaction. The ESRGAN-based image enhancement model increased visual fidelity with a PSNR gain of 3.7 dB, while the U-Net segmentation model achieved an IoU score of 0.87, effectively identifying cultural features. The system's usability test resulted in a 93% satisfaction rate, confirming its effectiveness as both an educational and cultural preservation tool. These results show that integrating modern computational approaches with cultural informatics can effectively enhance accessibility, understanding, and engagement with traditional heritage [19], [21].

In addition to achieving its preservation goals, this study provides a reproducible framework that other researchers or cultural institutions can adopt for similar projects. The modular architecture based on RESTful APIs ensures scalability, allowing the system to accommodate new cultural sites and future technological advancements. Several potential improvements are identified for future work. First, incorporating cloud-based processing and edge computing can further optimize real-time performance and reduce latency during virtual exploration. Second, implementing AI-driven virtual guides using natural language interaction could enhance engagement by providing personalized cultural storytelling experiences. Third, the adoption of augmented reality (AR) features can merge physical and digital exploration, enriching educational applications. Finally, expanding the system to

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other Sasak or Indonesian heritage sites will establish a broader digital ecosystem that promotes sustainable cultural tourism. Overall, this project demonstrates that the integration of immersive VR, deep learning, and web technology not only preserves tangible and intangible cultural assets but also establishes a model for future digital heritage transformation in Indonesia and beyond.

5. Suggestion

While this study has successfully developed an integrated web-based and Virtual Reality (VR) system for the digitalization of Bale Beleq, several areas remain open for further exploration and enhancement. Future research should focus on advancing both the technical and cultural dimensions of the system to achieve greater realism, scalability, and sustainability. From a technical perspective, implementing cloud-based infrastructure and edge computing frameworks could improve system scalability and real-time processing capabilities, especially during peak user access. Integrating AI-driven conversational agents as virtual cultural guides could also elevate user engagement by providing interactive storytelling experiences and real-time responses to visitor inquiries. These enhancements would bridge the gap between static digital archives and intelligent, dynamic virtual environments.

Further studies may also explore the integration of Augmented Reality (AR) to create hybrid learning experiences that combine virtual and physical elements, allowing users to engage with cultural artifacts both on-site and remotely. The addition of AI-based recommender systems could personalize cultural exploration by analyzing user preferences and suggesting relevant historical topics or routes within the virtual environment. Expanding the dataset used for deep learning models with multi-site training data could enhance the accuracy of image segmentation and object detection across various cultural architectures in Indonesia. Moreover, future research should focus on developing semi-supervised or self-supervised learning frameworks to reduce reliance on manual annotations while maintaining high model precision.

From a cultural and social perspective, future research could extend this digitalization model to other traditional Sasak heritage sites, enabling the creation of a regional digital heritage network that connects multiple cultural landmarks. Such integration would promote cultural tourism and education across the island while strengthening community involvement in preserving intangible heritage. Cross-disciplinary collaborations between computer scientists, cultural anthropologists, and local historians could ensure that technological innovation aligns with cultural authenticity and ethical values. Additionally, incorporating multilingual translation models could support broader accessibility for international audiences, transforming the system into a global cultural education platform.

Finally, long-term studies are recommended to evaluate the educational and tourism impact of digital heritage platforms like Bale Beleq. This includes conducting longitudinal user behavior analysis, tracking engagement metrics, and assessing how digital interaction influences cultural awareness and preservation attitudes over time. These future research directions will not only enhance the technical robustness of cultural digitalization systems but also contribute to the sustainable preservation and dissemination of Indonesia's diverse cultural identity in the digital era [22].

Declaration of Competing Interest

We declare that we have no conflict of interest.

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