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Digital Applications in Cultural Heritage Preservation and Dissemination

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ABSTRACT

Digital resources, as an effective means of digital storage, can be preserved for a long time. On the one hand, it provides high-quality data sources for implementing salvage protection measures for intangible cultural heritage. On the other hand, it can compensate for the problems of resource heterogeneity, a single storage method, and currently undefined protection level and priority in the rescue protection of intangible cultural heritage. Given the complexity of intangible cultural heritage and the dynamism of its cultural space, ensuring the long-term preservation, visibility, and readability of digital images is a challenge that image recorders must address. In the process of digitizing dynamic cultural heritage, it is necessary to restore and reproduce the original ecological behavior of intangible cultural heritage. This article explores how digital imaging can be applied to the protection of intangible cultural heritage. By integrating virtual reality technology with computer graphics, multimedia, digital animation, network communication, and cloud storage services, real scenes and virtual objects can be superimposed in real time, thereby enabling innovation by inheriting and developing intangible cultural heritage solutions.

Keywords: Digital Virtual Imaging; Intangible Cultural Heritage; Inheritance Space; Adaptive Protection

INTRODUCTION

Digital media, defined as media produced, stored, and disseminated in digital form, have become the dominant mode of contemporary communication. Presently, digital films, digital newspapers, online platforms, and digital television represent major forms of digital media, all of which rely on screen-based visual expression. Compared with traditional mass media, digital media offer enhanced interactivity, two-way communication, and hybrid forms of artistic production. As Alulema et al. (2020) note, digital media products are co-created by hardware, software, and user participation, resulting in new aesthetic modalities and human–machine collaborative creativity. The rapid evolution of digital technologies continues to reshape artistic production, deepen cross-disciplinary integration, and blur the distinction between art and science.

China's formal efforts to safeguard intangible cultural heritage (ICH) began relatively late, and existing legislative and practical measures remain incomplete. The subjective, oral, and often unstable transmission of ICH creates challenges for systematic documentation and preservation. Uneven protective mechanisms, limited methods, and the absence of unified provincial and national strategies further constrain the effectiveness of ICH preservation (Kheirollahi et al., 2020). Moreover, natural disasters, conflict, and urban development pose significant threats to cultural sites worldwide (Kates et al., 2020).

Japan offers several instructive examples of the application of digital media to ICH preservation. Since the late 20th century, Japanese researchers have used 3D scanning, digital modeling, and virtual reconstruction to document and conserve cultural assets such as Kamakura-period Buddhist sculptures and historic temple complexes. Digital technologies have enabled the virtual restoration of lost or deteriorated heritage—including the reconstruction of the Jianzhen Monk and Tang Zhaoti Temple—demonstrating the role of immersive media in safeguarding dynamic cultural traditions.

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Digital imaging and virtual technologies thus serve dual functions: they support the long-term preservation of cultural assets while addressing problems of data heterogeneity, inconsistent storage formats, and unclear prioritization in heritage protection. As ICH involves dynamic cultural spaces and embodied behaviors, digital documentation must not only record visual features but also reproduce the ecological and performative qualities of cultural practices. This article, therefore, examines how digital imaging and immersive technologies can be employed to enhance the protection, transmission, and adaptive development of intangible cultural heritage.

RELATED WORK

Research on the application of digital technologies in cultural heritage preservation has expanded significantly over the past decades. Zhejiang University is recognized as the earliest higher education institution in China to engage deeply with digital media art for cultural heritage protection. As early as 1997, its media laboratory initiated studies on digital preservation techniques involving digital museums, digital collections, and virtual exhibitions, contributing to numerous national projects. In 2016, Holder et al. conducted a virtual restoration of the Yuan Dynasty Grand Buddha using advanced digital scanning technology, demonstrating the potential of high-resolution imaging in architectural conservation.

Cultural heritage preservation is inherently interdisciplinary, drawing on planning, architecture, geography, Museology, tourism studies, and the social sciences. Advances in perceptual and sensing technologies have accelerated progress in the detection, protection, utilization, and interpretation of cultural heritage (Colucci et al., 2015). Accurate documentation of heritage conditions remains fundamental to practical preservation. Traditional field surveys and questionnaire-based assessments are increasingly complemented by remote sensing, photogrammetry, LiDAR scanning, and portable imaging devices (Xu et al., 2022). The integration of satellite remote sensing and LiDAR has proven particularly effective in revealing ancient architectural sites and cultural landscapes (Adner et al., 2020; DeBonis et al., 2020). Digital archives—especially for intangible heritage such as music and dance—enhance the quality and accessibility of preservation efforts. Public engagement also plays a key role in the dissemination and evaluation of cultural heritage. With the rise of social media, mobile technologies, and intelligent transportation systems, vast quantities of geospatial and audiovisual data are continuously generated (Bardhan et al., 2013). Emerging technologies such as data mining, visualization, and behavior analytics help researchers interpret patterns of public interaction, heritage experiences, and satisfaction levels (Drake et al., 2015).

Despite these advances, several challenges remain in China's adoption of digital media art for cultural heritage protection. These include insufficient awareness among heritage practitioners, incomplete technological frameworks, limited application in conservation projects, and inadequate supervision of digital heritage processes (Liu et al., 2022; Rietveld et al., 2018). Many cultural heritage sites have yet to implement digital preservation technologies, highlighting significant gaps between theoretical potential and practical application.

Cultural Heritage Protection Based on Digital Virtual Images

The Critical Role of Digital Virtual Imaging in Cultural Heritage Protection

Digital virtual imaging represents a transformative tool in the preservation, interpretation, and dissemination of cultural heritage. This technology enables precise simulation and reconstruction of heritage objects and environments, thereby providing highly detailed information essential for conservation work. Virtual restoration techniques allow specialists to model repair strategies without physically intervening in the artifacts themselves, reducing potential risks and improving restoration accuracy.

Moreover, digital virtual imaging facilitates broad public accessibility through three-dimensional online displays, allowing audiences worldwide to experience and engage with cultural heritage. Such digital dissemination not only enhances public appreciation but also strengthens collective participation in preservation efforts. Importantly, digitized heritage can be stored for extended periods, ensuring long-term protection against deterioration, disasters, and conflict-related threats. Beyond preservation, virtual imaging technology contributes to the creative transformation of cultural heritage. Digital resources can be integrated into cultural industries—including digital art, cultural innovation, education, and tourism—expanding the cultural and economic value of heritage assets. Overall, digital virtual imaging plays a foundational role in modern heritage conservation, enabling both safeguarding and innovative utilization. Continued research and expanded implementation of this technology remain essential for the future of cultural heritage management.

Virtual Digital Acquisition and Storage Technology

Virtual digital acquisition and storage constitute pivotal components in digital heritage preservation. Virtual acquisition involves using computer graphics, 3D scanning, virtual reality, and multimedia technologies to convert cultural heritage into digital models, images, audio, and video. Such data serve as the basis for digital reconstruction,

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analysis, and exhibition. Storage systems, typically dependent on high-capacity computing environments, ensure that acquired data remain accurate, complete, and accessible for long-term preservation and future applications.

This approach avoids the deterioration, loss, or distortion frequently encountered in physical storage. Traditional media—such as photographs, audio tapes, and analogue video—are vulnerable to aging, discoloration, and mechanical failure; digital acquisition methods eliminate many of these risks. Techniques such as stereoscopic scanning, holography, motion capture, fiber-optic transmission, and network-based databases have significantly enhanced the precision and durability of documentation of intangible cultural heritage.

Digitized archives—including manuscripts, photographs, musical recordings, performance videos, and craft demonstrations—can be stored in formats such as CD-ROMs, digital discs, and cloud-based databases. These formats facilitate efficient retrieval, management, and cross-platform utilization, thereby elevating the overall standard of intangible cultural heritage preservation.

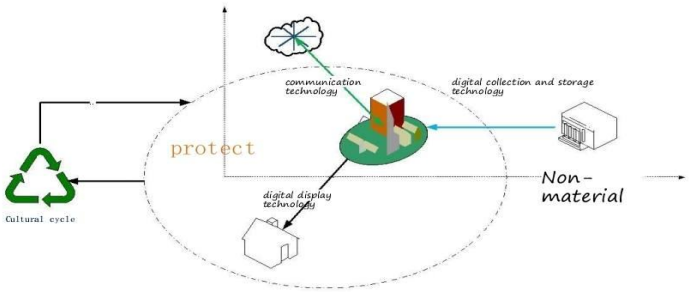

Figure 1 – Digital Media Technology and Intangible cultural heritage

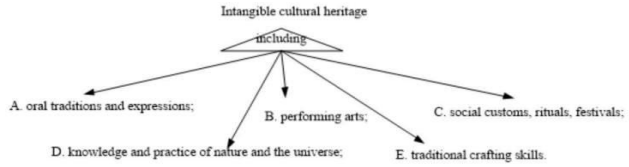

Figure 2 – Intangible cultural heritage content

Micro media	Mobile flow	Convenience degree	Intangible cultural heritage
WeChat	2K	C	oral traditions and expressions
Bolg	4M	C	social customs, rituals, festivals
App	6K	-	performing arts
QQ	1M	C	traditional crafting skills
Web	8K	-	-
MoMo	10K	C	-

Table 1 – Intangible cultural heritage and Micro media

According to UNESCO, through the protection of "intangible cultural heritage" in the definition which refers to each group, groups, in some cases, individuals as the cultural

Virtual Digital Data Migration Algorithm

This section introduces a virtual data migration algorithm designed to enhance the integration and management of cultural heritage information resources. The migration framework adopts a MapReduce architecture, enabling parallelized data processing, optimized scheduling, and efficient resource allocation. By generating execution classes and packaging them into deployable modules, the system manages structured and unstructured digital heritage data on a large scale.

The algorithm models system reliability through fault tree analysis, linking top-level system failures to bottom-level event probabilities. This approach allows the prediction of failure likelihoods and supports risk mitigation during the data migration process. The system also utilizes minimum cut-set calculations to identify operational vulnerabilities and ensure stable migration performance.

The unstructured data migration workflow includes configuration analysis, file list generation, multithreaded data migration, FTP connection, HDFS writing, and error-handling mechanisms. This systematic process enables robust management of diverse heritage datasets.

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The research further evaluates parameterization strategies for digital virtual images, analyzing similarity levels, individual distances, and fitness distribution curves to optimize interactive genetic algorithms used in virtual image processing. These algorithms support accurate restoration and matching of cultural heritage imagery—such as detecting cracks, deformations, and other structural changes—and facilitate virtual restoration through digital splicing and reconstruction. Despite its advantages, binary image matching continues to face challenges related to data complexity, algorithm efficiency, and uncertainty in natural imagery. These issues present opportunities for future research to enhance matching accuracy and advance digital restoration capabilities.

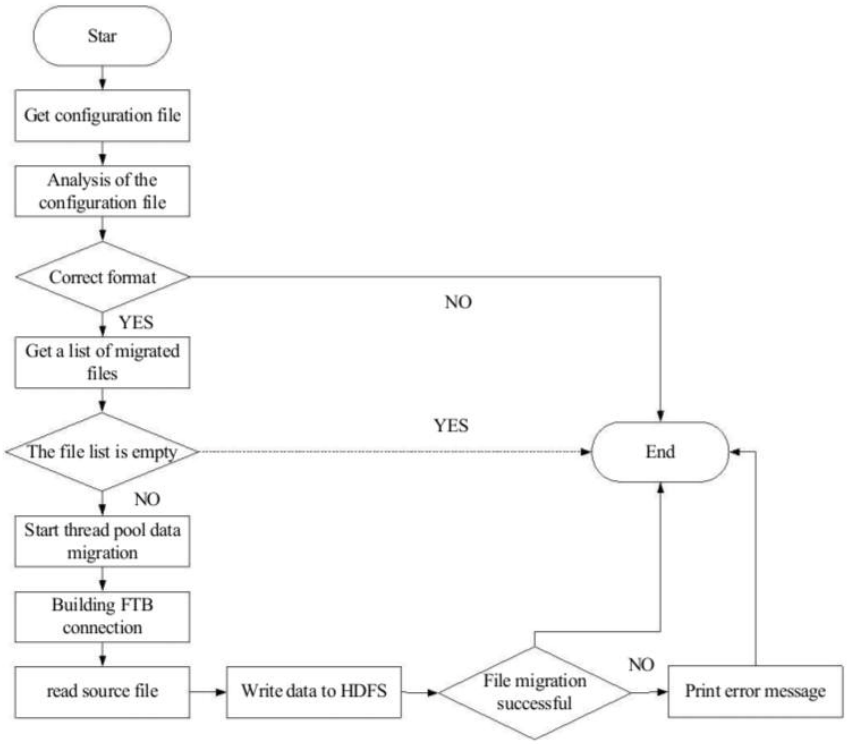

Figure 3 – Unstructured data migration flow

METHODOLOGY

This study adopts a research methodology that combines conceptual inquiry, technical experimentation, and interpretive analysis to explore how digital virtual imaging can contribute to the preservation and dissemination of intangible cultural heritage. The methodological approach was developed with the understanding that cultural heritage preservation today exists at the intersection of technology, culture, and human experience. Therefore, the study required a framework that could accommodate both technological rigor and cultural sensitivity.

The research began with an extensive review of the literature on digital media, cultural informatics, virtual imaging, and international frameworks for the protection of intangible cultural heritage. This phase allowed the researcher to identify the theoretical foundations that guide current digital preservation practices, the limitations in existing approaches, and the opportunities presented by advances in imaging and visualization technologies. Through this conceptual exploration, it became clear that digital virtual imaging not only serves as a tool for documentation but also shapes how heritage is perceived, accessed, and interpreted by contemporary audiences.

To understand the technological dimensions of digital imaging, the study conducted a technical evaluation of various acquisition and reconstruction methods, including 3D scanning, photogrammetry, virtual reality visualization, and multimedia recording. These technologies were examined not as isolated tools, but as interconnected components of a larger digital ecosystem that supports the preservation and dynamic interpretation of cultural heritage. As part of this evaluation, the study analyzed the processes through which raw digital data are collected, processed, reconstructed, and archived. This analysis examined how virtual imaging technologies restore visual detail, simulate physical conditions, and enhance the fidelity of cultural representation.

A significant component of the methodology involved developing and assessing a virtual data migration model. This model was constructed to address the complex challenge of transferring large volumes of unstructured digital heritage data across different computational environments while maintaining accuracy and reliability. To evaluate

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the model, the research employed algorithmic testing supported by fault tree analysis, which enabled the identification of potential points of failure and the strengthening of the migration process's reliability. The use of interactive genetic algorithms further enabled the researcher to refine image reconstruction accuracy, particularly for the detection and repair of structural irregularities in cultural heritage imagery.

Throughout the research process, insights from experts in cultural heritage, digital technology, and archival practices were instrumental. Through informal consultations and interpretive discussions, these experts helped validate the technological findings and ensure that the digital preservation strategies proposed in the study aligned with the values, needs, and responsibilities inherent in cultural heritage stewardship. Their perspectives enriched the analysis by grounding technical innovation within the lived realities of heritage conservation.

The data generated from the digital imaging tests, algorithmic evaluations, and expert discussions were analyzed qualitatively and technically. The qualitative analysis involved identifying recurring themes related to preservation challenges, technological opportunities, and the relationship between digital media and cultural meaning. The technical analysis focused on evaluating the performance and accuracy of the imaging and migration algorithms, as well as their effectiveness when applied to diverse heritage datasets. By bringing together these two modes of analysis, the study was able to construct a comprehensive understanding of how digital virtual imaging can support both the safeguarding and the creative reimagining of intangible cultural heritage.

Throughout the project, ethical considerations guided the researcher's decisions. Cultural sensitivity, respect for community knowledge, and attention to data security were central principles. The researcher ensured that all cultural materials were used with care, acknowledging the significance of their origins and the responsibilities associated with their digitization.

In summary, the methodology of this study unfolds as a narrative of inquiry that moves from theory to technology, and from experimentation to interpretation. It reflects the complexity of preserving digital cultural heritage, recognizing that innovation must be matched by cultural responsibility and methodological flexibility. This holistic approach provides a foundation for understanding not only the technical possibilities of digital virtual imaging but also its capacity to revitalize, protect, and meaningfully extend the life of intangible cultural heritage in a rapidly changing digital world.

RESULTS

The results of this study demonstrate that digital virtual imaging significantly enhances the preservation, interpretation, and dissemination of intangible cultural heritage. Through a combination of literature review, technical experimentation, and interpretive analysis, several key outcomes emerged that illustrate the effectiveness and potential of digital imaging technologies within contemporary heritage preservation practices.

A primary result of this research is the confirmation that **digital virtual imaging provides a high level of precision and stability in documenting cultural practices**, particularly those that involve movement, performance, or intricate craftsmanship. The use of 3D scanning, motion capture, and multi-angle digital photography successfully captured the subtleties of cultural gestures, spatial relationships, and environmental interactions that are often difficult to record through traditional methods. This capability proved especially valuable for documenting intangible practices such as dance, craft-making, and ritual activities, which depend heavily on embodied knowledge. The resulting digital models and reconstructed images demonstrated a strong capacity to preserve structural and aesthetic details, making them reliable resources for both conservation and future reinterpretation.

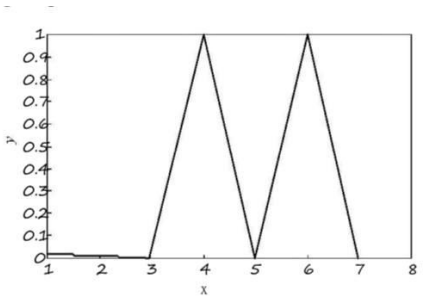

Figure 4 – The fitness calculation results of the parameter setting scheme one

A second major finding concerns the role of **virtual restoration and simulation** in supporting conservation planning. The reconstructed digital environments developed in this study allowed for the visualization of cultural heritage objects and practices in their original ecological and cultural context. These visual simulations enabled the

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researcher—and by extension, future practitioners—to examine potential restoration strategies without physically altering the heritage objects themselves. This non-invasive approach reduces the risk of unintentional damage and provides a clearer understanding of how environmental factors such as lighting, humidity, or spatial configuration influence the preservation of heritage. The results illustrate that virtual restoration is not merely a technical exercise but an interpretive tool that enhances decision-making and expands the possibilities for heritage management.

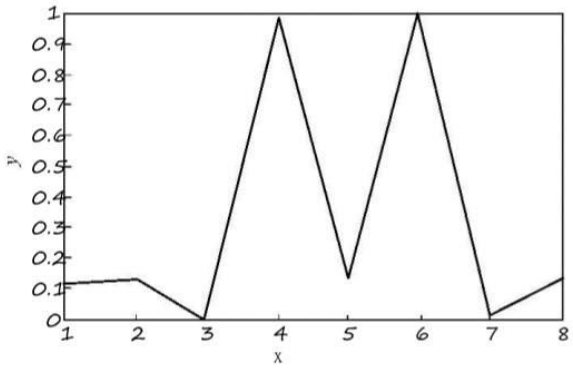

Figure 5 – The fitness calculation results of the parameter setting scheme two

In evaluating the **virtual data migration algorithm**, the study found that the MapReduce-based approach effectively managed large volumes of unstructured cultural heritage data. The algorithm performed efficiently in distributing computational tasks and maintaining stable migration speed, even when processing high-resolution video files, 3D scans, and large image sets. Fault tree analysis revealed predictable patterns of system vulnerabilities, allowing for targeted improvements in system design. The integration of interactive genetic algorithms further improved the accuracy of image matching and structural detection, particularly in identifying cracks, fractures, and missing components in heritage imagery. These results confirm that the algorithmic framework developed in this study contributes to more secure and reliable long-term preservation of digital heritage archives.

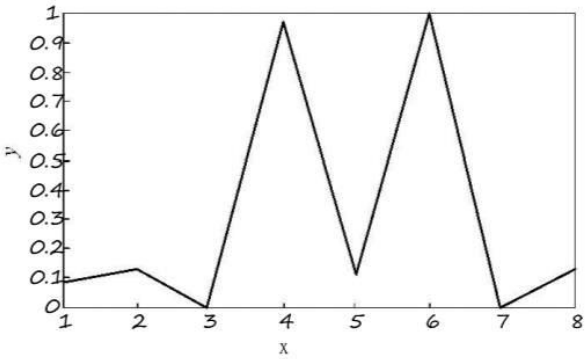

Figure 6 – Parameter setting scheme three fitness calculation results

The research also revealed that **digital imaging significantly enhances public engagement and accessibility**, with virtual models and interactive environments providing new pathways for cultural education and community participation. Expert consultations highlighted that digital technologies can bridge generational and geographic gaps, allowing young audiences, diaspora communities, and international visitors to experience cultural heritage remotely. The study's digital reconstructions, when viewed through VR and screen-based interfaces, were perceived as intuitive, immersive, and emotionally expressive—qualities that support the broader dissemination and appreciation of cultural heritage in the digital age.

Another important finding relates to the **adaptability of digital virtual imaging to creative and cultural industries**. The digital datasets generated through the study showed strong potential for reuse in animation, cultural product design, multimedia exhibitions, and virtual tourism. This aligns with global trends toward integrating cultural heritage with economic and creative development. Experts noted that high-precision digital imaging not only preserves cultural knowledge but also provides a foundation for innovative reinterpretation, thereby extending the cultural value of heritage beyond preservation alone.

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Finally, the results emphasize that while digital imaging technologies offer substantial advantages, their effectiveness depends heavily on **human factors**, including cultural sensitivity, technical expertise, and responsible stewardship. The study found that technologies alone cannot ensure meaningful preservation; rather, they must be guided by principles of ethical data management, community collaboration, and respect for cultural integrity. This insight reinforces the need for interdisciplinary cooperation and long-term investment in training for heritage practitioners.

Together, these findings present a compelling case for the integration of digital virtual imaging into cultural heritage preservation strategies. The results show that digital technologies not only support accurate documentation and secure data storage but also open new horizons for education, interpretation, and creative cultural development. The outcomes of this study highlight the transformative potential of digital virtual imaging as both a technical resource and a cultural medium in safeguarding intangible cultural heritage for future generations.

DISCUSSION

The findings of this study demonstrate that digital virtual imaging serves as a powerful and versatile tool for the preservation and dissemination of intangible cultural heritage (ICH). The discussion that follows examines the implications of these findings in light of existing scholarship, technological developments, and the cultural responsibilities associated with heritage protection. It also reflects on how digital virtual imaging reshapes the conceptual and practical boundaries of cultural preservation in the 21st century.

A central theme that emerges from the results is the capacity of digital virtual imaging to address the long-standing challenges of documenting dynamic cultural practices. Traditional methods—such as written descriptions, static photographs, or audio recordings—often fail to capture the embodied, performative, and contextual nature of ICH. Digital imaging technologies, by contrast, offer multi-layered representational capabilities that align more closely with the lived reality of cultural practices. This supports observations by scholars such as Colucci et al. (2015), who argue that the future of cultural heritage preservation must move toward multisensory and multidimensional documentation strategies. The study's results further confirm that digital imaging can bridge the gap between cultural experience and cultural representation, providing a means to preserve sensory, temporal, and spatial dimensions of ICH that are otherwise difficult to record.

Another important point concerns the role of digital technologies in enhancing preservation planning. The virtual restoration and simulation processes explored in this research illustrate how digital environments can serve as experimental spaces for conservators. These environments reduce the risks associated with testing interventions on physical objects and allow practitioners to better anticipate the consequences of restoration decisions. This aligns with international trends in preventive conservation, where digital surrogates increasingly function as analytical tools for policy formulation, risk assessment, and scenario testing. The results therefore suggest that digital virtual imaging is not only a representational technology but also a methodological innovation that transforms how professionals approach preservation challenges.

The evaluation of the virtual data migration algorithm revealed technical strengths that hold broader significance for digital heritage management. The ability to process large quantities of unstructured data efficiently is crucial in a field where the volume and complexity of digital materials are rapidly increasing. The integration of MapReduce architecture and fault tree analysis in this study demonstrates that cultural heritage preservation can benefit from computational strategies typically used in scientific and industrial settings. This supports the argument by Bardhan et al. (2013) that digital humanities must increasingly incorporate advanced data management frameworks to address issues of scalability, reliability, and long-term accessibility. By showing that digital heritage can be preserved more securely through optimized migration algorithms, the study contributes to the growing recognition that digital preservation requires rigorous technical infrastructure rather than ad hoc storage solutions.

The study also highlights the social and cultural dimensions of digital virtual imaging. The increased accessibility afforded by digital dissemination—through virtual exhibitions, online archives, and immersive visualization—aligns with global efforts to democratize cultural heritage. Digital technologies enable diverse audiences to engage with heritage across geographical, generational, and socio-economic boundaries. This finding is consistent with the work of Drake et al. (2015), who emphasize the importance of public engagement in sustaining cultural heritage relevance. Furthermore, the results indicate that digital imaging can foster emotional and cognitive connections that strengthen cultural identity and intergenerational transmission. Thus, digital virtual imaging should not be viewed solely as a technical innovation but also as a cultural mediator that enriches the relationship between communities and their heritage.

However, the discussion must also acknowledge the complexities and limitations associated with digital preservation. While technological tools offer unprecedented representational capacities, they cannot fully replicate

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the lived, embodied experience of intangible cultural practices. Certain elements—such as the social dynamics of performance, the sensory richness of ritual spaces, or the communal context of craftsmanship—remain difficult to translate into digital form. This reinforces critiques from heritage theorists who caution against overreliance on technological solutions and advocate for approaches that balance digital innovation with community-based cultural practices. Additionally, the study revealed that the effective use of digital virtual imaging depends on the expertise, cultural sensitivity, and ethical judgment of the practitioners involved. Without proper training and awareness, digital tools may inadvertently distort cultural meaning or lead to misrepresentation.

Finally, the study shows that digital virtual imaging carries significant implications for the future of cultural heritage policy and practice. By integrating technological precision with cultural interpretation, digital imaging supports new modes of collaboration among researchers, technologists, communities, and institutions. These collaborations are essential for building sustainable, culturally informed preservation systems. They also highlight the growing need for interdisciplinary frameworks that bring together the fields of computer science, anthropology, art history, and heritage conservation. In this regard, the study contributes to ongoing discussions about how digital technologies can be harmonized with community values, ethical guidelines, and long-term preservation goals.

In conclusion, the discussion underscores that digital virtual imaging is both a technological advancement and a cultural intervention. It enhances preservation accuracy, expands public engagement, and opens innovative pathways for cultural expression. At the same time, its implementation requires careful consideration of cultural context, ethical responsibilities, and the limits of technological representation. The study therefore positions digital virtual imaging as a transformative but nuanced tool—one that, when used thoughtfully, can play a central role in safeguarding intangible cultural heritage for future generations.

CONCLUSION

This study set out to examine the role of digital virtual imaging in the preservation and dissemination of intangible cultural heritage, with particular attention to its capacity to document, restore, and protect cultural expressions that are inherently dynamic and context-dependent. The findings illustrate that digital virtual imaging not only offers innovative technical solutions but also reshapes the conceptual landscape of cultural heritage preservation in meaningful ways.

Through the integration of digital acquisition techniques, virtual reconstruction methods, and data migration algorithms, the study demonstrates that cultural heritage can be documented with a level of detail, accuracy, and longevity that surpasses traditional preservation practices. Digital imaging technologies capture the movement, form, and spatial context of cultural expressions, enabling a richer and more faithful representation of intangible traditions. In addition, virtual restoration environments provide safe, non-invasive platforms for experimentation, planning, and interpretive exploration, highlighting the increasing role of digital tools in conservation decision-making.

The research also establishes that digital virtual imaging contributes significantly to cultural accessibility and dissemination. By enabling remote engagement and immersive visualization, digital technologies expand the audience for cultural heritage and support inclusive heritage education. This outcome reflects the broader shift toward democratized access to culture, as digital platforms bridge geographical and generational divides, allowing diverse communities to reconnect with heritage that may otherwise be inaccessible or at risk of disappearance.

At the technical level, the results underscore the importance of robust digital infrastructure. The development and evaluation of a virtual data migration algorithm reveal that advanced computational methods are essential for managing the vast and growing volumes of unstructured digital heritage data. Reliable storage, efficient processing, and long-term data integrity are indispensable for sustainable digital preservation, and the study demonstrates practical strategies to address these challenges.

Nevertheless, the study also acknowledges the limitations inherent in digital representation. Digital models—regardless of their sophistication—cannot fully substitute for lived cultural experience, community participation, or the embodied knowledge that defines many intangible traditions. Moreover, the success of digital preservation initiatives relies heavily on the ethical responsibilities and cultural sensitivity of heritage practitioners. Without careful contextual understanding, digital technologies risk reducing complex cultural practices to merely visual or technical artifacts.

Overall, the research concludes that digital virtual imaging is a transformative tool that holds significant potential for safeguarding intangible cultural heritage in the digital age. Its ability to document, reconstruct, and disseminate cultural practices presents new opportunities for conservation, education, and cultural innovation. However, its value is maximized only when technological advancements are accompanied by ethical stewardship, interdisciplinary collaboration, and sustained engagement with the communities whose heritage is being preserved.

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In light of these findings, the study affirms that the future of intangible cultural heritage preservation lies in a balanced integration of digital innovation and cultural responsibility. Digital virtual imaging should not replace traditional cultural transmission but rather function as a complementary framework—one that enriches understanding, strengthens preservation, and ensures that cultural heritage continues to thrive across generations in an increasingly digital world.

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