KÜLTÜREL MİRASIN KORUNMASINDA YAPAY ZEKA UYGULAMALARI: KORUMACILIKTA TEKNOLOJİK GELİŞMELER

AI APPLICATIONS IN CULTURAL HERITAGE PRESERVATION: TECHNOLOGICAL ADVANCEMENTS FOR THE CONSERVATION

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ÖZET

Kültürel mirasın korunması, toplumların tarihi mirasını korumak ve kültürel çeşitliliğin devamı için çok önemlidir. Yapay zekâ (AI) teknolojilerinin ortaya çıkışı, bu alanda yenilikçi ve verimli koruma yöntemleri için yeni ufuklar açmıştır. Bu çalışma, kültürel eserlerin ve tarihi alanların sayısallaştırılması, belgelenmesi, analizi, restorasyonu ve korunması üzerindeki etkisine odaklanarak, yapay zekanın kültürel mirasın korunmasındaki uygulamalarının literatür örneklerini incelemektedir. Yapay zekâ teknolojileri, kültürel miras varlıklarının dijitalleştirilmesi ve belgelenmesinde bir devrim niteliğindedir. Otomatik tarama, 3B modelleme ve sanal gerçeklik uygulamaları, doğru dijital kopyaların oluşturulmasını kolaylaştırarak araştırmacılar, eğitimciler ve toplum için erişilebilirliği artırmaktadır. Korumacılık alanında ise, yapay zekâ algoritmaları hasarların belirlenmesinde ve bozulan eserler ve yapılar için hedeflenen restorasyon planlarının formüle edilmesinde çok önemli bir rol oynamaktadır. AI, görüntü tanıma ve örüntü algılamadan yararlanarak hassas sanat eserlerini ve arkeolojik parçaları korumada uzmanlara yardımcı olmaktadır. AI ayrıca çevresel izleme yoluyla, kültürel miras alanlarının korunmasına fiziksek etkileri ele alarak da katkıda bulunur. Yapay zekâ destekli sensörler ve veri analitiği, sıcaklık değişiklikleri, nem dalgalanmaları ve hava kirliliği gibi potansiyel riskleri tespit ederek çevresel etkileri azaltmak için zamanında yanıt verilmesini sağlar. Yapay zekâ sayesinde, mevcutta bulunan ya da oluşabilecek riskler, miraslara zarar vermeden önce gerekli önlemler alınabilir. Sonuç olarak, kültürel mirasın korunmasındaki AI uygulamaları, kolektif mirasın korunması ve topluma kazandırılması noktasında önemli bir ilerlemeyi temsil etmektedir. Teknolojik yeniliği, etik kaygılarla dengeleyerek, kültürel mirasın gelecek nesiller için sürdürülebilir ve kapsayıcı bir şekilde korunmasını sağlanabilir.

Anahtar kelimeler: Yapay zekâ, kültürel miras, teknoloji, korumacılık

ABSTRACT

The protection of cultural heritage is very important for preserving the historical heritage of societies and for the continuation of cultural diversity. The emergence of artificial intelligence (AI) technologies has opened new horizons for innovative and efficient protection methods in this field. This study examines literature examples of applications of artificial intelligence in the preservation of cultural heritage, focusing on its impact on the digitization, documentation, analysis, restoration and preservation of cultural artifacts and historical sites. Artificial intelligence technologies are revolutionizing the digitization and documentation of cultural heritage assets. Automated scanning, 3D modeling, and virtual reality applications facilitate the creation of accurate digital copies, increasing accessibility for researchers, educators, and the public. In the field of conservation, artificial intelligence algorithms play a crucial role in identifying damage and formulating targeted restoration plans for deteriorated artifacts and structures. Using AI, image recognition and pattern detection, it assists experts in preserving sensitive artworks and archaeological items. AI also contributes to the protection of cultural heritage sites by addressing physical effects through environmental monitoring. AI-powered sensors and data analytics detect potential risks such as temperature changes, humidity fluctuations and air pollution, enabling timely response to reduce environmental impacts. Thanks to artificial intelligence, necessary precautions can be taken before existing or potential risks damage the heritage. In conclusion, AI applications in cultural heritage preservation represent a significant advance in the conservation and reintegration of collective heritage. By balancing technological innovation with ethical concerns, cultural heritage can be preserved in a sustainable and inclusive way for future generations.

Keywords: Artificial intelligence, cultural heritage, technology, protection

I.INTRODUCTION

Cultural heritage is a term that contains both tangible and intangible values. Most of the cultural elements are part of the heritage and can be called cultural memory. As a crucial component of identity, the heritage (cultural memory) of previous generations must be passed on to current and future generations (e.g., via historic sites) (Nocca, 2017). Many conservation practices have been developed to pass on this cultural heritage to future generations, but the most recent are those with artificial intelligence (AI). AI and new Technologies became critical solutions for protection and conservation because it helps to solve previous difficulties(Chaillou, 2020).

This study examines the transformative application of AI in cultural heritage preservation. It explores how technological advances can be harnessed to transform how we approach preserving our shared cultural heritage. Using AI technology for documentation, data analysis, predictive modeling, restoration, and continuous monitoring, heritage professionals can significantly improve their skills and contribute to sustainable conservation efforts. Preserving cultural heritage is significant in safeguarding the historical legacy and cultural diversity of societies. However, traditional conservation approaches often need help addressing these precious assets' complex and evolving threats. In recent years, the emergence of artificial intelligence (AI) technology has provided revolutionary opportunities for innovative and effective conservation methods in the field of cultural heritage. This study focuses on the transformative impact of AI applications in preserving cultural heritage, focusing on its contributions to digitization, documentation, analysis, restoration, and preservation.

Preserving cultural heritage is essential to ensure the continuity of history and human identity. The diversity of tangible and intangible cultural assets represents the shared memory of previous generations, and it is essential to transfer this memory to future generations. The challenges of degradation, climate change, and limited resources necessitate innovative solutions to conserve these invaluable heritage sites sustainably. Factors such as deterioration, climate change, and the challenges of limited resources require innovative solutions to protect these heritage sites continuously.

Artificial intelligence has become a powerful tool for preserving and sustaining cultural heritage. The transformative potential of artificial intelligence technologies plays a prominent role in different stages of the conservation process. First, it facilitates the creation of precise digital copies through applications of artificial intelligence, automated digitization, 3D modeling, and virtual reality in digitization and documentation. These developments provide a more holistic approach to the dissemination and education of cultural heritage, improving access for researchers, educators, and the public.

Furthermore, AI algorithms are crucial in analyzing and recovering deteriorated cultural artifacts and structures. AI helps professionals to identify damage and plan targeted restoration by implementing image recognition and pattern detection. This AI-supported preservation method ensures sensitive works of art and archaeological objects with higher precision and efficiency. In addition, the impact of artificial intelligence extends to the protection of cultural heritage by addressing physical risks through environmental monitoring. Sensors and AI-powered data analysis help to detect potential threats such as temperature changes, humidity fluctuations, and air pollution. This rapid and proactive response helps reduce environmental impact and protect heritage from irreversible damage.

Literature examples of artificial intelligence applications in the protection of cultural heritage have been explored by emphasizing the tangible benefits and transformative consequences of protecting and reintegrating the collective heritage throughout this study. Professionals working on cultural heritage can take advantage of the potential of artificial intelligence to ensure the sustainable preservation of these assets for future generations while considering ethical issues. In conclusion, artificial intelligence applications in the protection of cultural heritage represent an essential step in this field by empowering conservation experts and researchers with innovative tools and methods. In the following sections, we delved deeper into the multifaceted impact of AI, highlighting its potential to advance conservation practices and strike a balance between technological innovation and ethical considerations for preserving sustainable heritage.

II. RESEARCH AND FINDINGS

A. Overview of AI Technologies in Cultural Heritage Preservation

Artificial intelligence technologies have ushered in a transformative era in cultural heritage conservation, offering innovative solutions at different stages of the conservation process. One of the critical areas where AI excels is the digitization and documentation of cultural heritage assets. Automated scanning, 3D modeling, and virtual reality applications have revolutionized the creation of precise digital copies of historical artifacts and places. These technologies enable conservationists to capture intricate detail with unprecedented precision, facilitating better access for researchers, educators, and the general public. By digitizing cultural heritage, AI ensures that these precious assets are preserved in digital form, protecting them from possible physical damage or loss. In addition, AI-based analysis plays an important role in determining damage and developing targeted restoration plans. Pattern detection and image recognition algorithms help experts understand the extent of degradation of artifacts and structures, thereby facilitating evidence-based decisions about conservation methods the most suitable one. Through AI-supported analysis, the preservation process becomes more efficient and informed, contributing to the long-term sustainability of cultural heritage preservation.

1. Digitization and Documentation

a. Automated Scanning

Laser scanning is a widely discussed acquisition technology for cultural heritage preservation, providing a dense discrete point-cloud model of the surveyed object. Despite its advantages, the major limitation has been managing and visualizing the vast amount of data and time-consuming post-processing required to create a manageable 3D model. However, with advancements in hardware and software performance, dense point-cloud models can now be easily analyzed without further processing. The current density of point clouds allows them to be considered as continuous surfaced models, supporting immediate decision-making activities and the extraction of geometric information. Determining the accuracy of scans depends on various factors, including instrument capabilities, object distance from the scanner, laser ray incidence angle, and surface materials. Additionally, post-processing steps like point cloud registration, filtering, and meshing can introduce unknown errors. Evaluating final accuracy requires comparison with an unavailable perfect reference object, posing challenges in determining absolute precision (Fassi et al., n.d.).

b. GIS and 3D Modeling

The study highlights the limitations of traditional geodetic surveying and architectural representation, which typically provide 2D visualizations of cultural objects, requiring a mental reconstruction into 3D geometry for a comprehensive understanding. Photogrammetry, a technique using a series of overlapping images, has been extensively used for 3D modeling cultural heritage, particularly historical buildings. This independent method relies on triangulation from two or more images to reconstruct the object digitally. The integration of geographical information system (GIS) technology, comprising software, hardware, and procedures for spatial data management, prove highly advantageous in capturing, editing, analyzing, and representing spatially referenced data for archaeological sites and historical structures. GIS enables a more holistic approach to heritage conservation and facilitates the development of virtual historical collections and archives, recognizing the integration of heritage sites with their surrounding landscapes(Yakar & Doğan, 2018).

c. Virtual Reality Applications

The application of virtual reality technology provides an immersive experience for users to explore multiple virtual objects arranged in a virtual scene. Unlike traditional approaches, users can virtually enter and interact with the 3D environment, enhancing the feeling of being a part of the virtual space. Various navigation paradigms are used to improve the sense of presence, such as walking or flying in 3D space. In order to facilitate spatial navigation, predefined view positions are offered to users. However, a common challenge in 3D reconstruction is generating a large amount of data, including triangles, vertices, and textures. Manual 3D modeling is often necessary regarding the need for directly applicable reconstruction techniques. General modeling software, such as 3DStudio Max, is used for laborious tasks where a photo is placed as a background, and users create the corresponding textured model using geometrical elements in the foreground. Special programs are available for interactive 3D model creation in architecture, utilizing multiple photographs to facilitate the process (Zara, 2004).

2. Analysis and Restoration

With the advancement of sensing technologies and Structural Health Monitoring (SHM), diverse data styles are being developed in the context of heritage preservation. Traditionally, vibration response has been the most widely used data in SHMs. However, recent developments in deep learning for image processing have led to the exploration of damage detection techniques that implement image and 3D point cloud data. Optical sensing techniques, such as uncrewed aerial vehicles (UAVs) and cameras, have been employed as alternatives to visual inspection for heritage damage. In order to minimize human participation, intelligent damage identification techniques based on machine learning algorithms have gained significant attention. AI (specifically deep learning) has shown outstanding outcomes in image-based damage detection, but it can only identify two-dimensional surface damage on heritage structures. Other sensing techniques, such as 3D point clouds, infrared sensing, ground-penetrating radar, and vibration response, are integrated with artificial intelligence algorithms to enhance detection capabilities. The paper of Zang and Yuen provides an overview of intelligent detection strategies for heritage preservation, focusing on various data types, such as images, 3D point clouds, and dynamic responses. However, the applicability of these techniques requires additional confirmation, especially in cases with limited data, demanding pressing investigation into intelligent learning algorithms established on small samples (Zhang & Yuen, 2022). Another study introduces two approaches for detecting damage in structural systems. The first approach uses dynamic behavior data as input variables and constructs ten metamodels to predict the location and severity of damage in a truss structure. LS-SVM is found to be the most efficient approach for model building and projection. The second technique involves using the MSEBI indicator to locate damage in the structure. It employs the CBO algorithm with an appropriate surrogate model to reduce computational time for damage severity detection. Results demonstrate significant computational time reduction (about one-twelfth) and a significant decrease in the number of FE structural analyses (about one-thirtieth), making it a promising solution for damage detection in large-scale structures (Ghiasi et al., 2018).

AI enables automatic budget forecasting, robust planning through auto-scheduling, and real-time task tracking, minimizing manual interventions. Integrating AI solutions from other sectors, like route optimization technology from the transport industry, can enhance rehabilitation planning, saving resources. Additionally, AI can aid in predicting pharmaceutical outcomes and investigating constructability issues, ensuring structural stability and risk mitigation. Ultimately, AI offers cost-effective and practical restoration methods that contribute to preserving sites on the World Heritage List (Goussous, 2020).

There is also an increasing interest in image-based crack detection for non-destructive inspection, along with the challenges posed by random crack shapes, irregular sizes, and various image noises. In the paper of Mohan and Poobal, they reviewed fifty articles on crack detection, categorizing image processing methods into integrated algorithms, morphological approaches, percolation-based methods, and practical techniques. The survey analyzes the crack detection techniques based on the type of image used, including camera images, infrared images, ultrasonic images, and more. The study's main focus is to assess crack detection systems based on image processing, considering objectives, datasets, accuracy levels, and error levels. The paper concludes that camera images with segmentation algorithms like threshold techniques are widely used for damage analysis. The authors plan to conduct future research on invasive methods for crack detection to complement the extensive study on noninvasive approaches (Mohan & Poobal, 2018).

3. Preservation of Cultural Heritage Sites

Preserving cultural heritage sites holds paramount importance in safeguarding civilizations' rich historical, artistic, and societal legacies for present and future generations. These sites, embodying the essence of human creativity and ingenuity, are invaluable repositories of identity, tradition, and knowledge. However, these precious cultural assets are susceptible to degradation and destruction in the face of rapid urbanization, environmental changes, natural disasters, and human activities. As a result, concerted efforts and interdisciplinary approaches are essential to devise effective preservation strategies that ensure the conservation and sustainable management of these sites. This introductory essay explores the significance of preserving cultural heritage sites, delving into the challenges posed by various factors, the diverse methodologies employed for conservation, and the integration of technology, policy, and community engagement to preserve these invaluable treasures of humanity (Zhang & Jing, 2022).

The study emphasizes that monitoring architectural heritage in the Qinghai-Tibet Plateau uses "remote sensing big data" to facilitate policy formulation, technical interventions, and field investigations. The study evaluates 152 Buddhist monasteries from 1993 to 2013 by using cost-effective macro-scale measurements with open remote sensing data and discerning three changing environments, particularly those affected by significant urban expansion. While recognizing limitations, including the need for successive nighttime light data correction and further investigations, the study proposes integrating diverse remote sensing datasets, geographical factors, and economic indicators for enhanced monitoring and early warning mechanisms. By prioritizing the utilization of big data for monitoring purposes, sustainable strategies can be developed to safeguard the architectural heritage amid the challenges posed by urbanization in the Qinghai-Tibet Plateau (Zhang et al., n.d.).

The research presents a comprehensive approach to enhance contextualized information retrieval in risk management by integrating Virtual Reality (VR) and Heritage Building Information Modeling (HBIM) data. The study introduces metadata designed to provide contextual information using the 5W1H model, facilitating risk management in a VR environment. The developed VR applications offer different interfaces for diverse risk management types. However, limitations were identified, such as the application's inability to recognize the heritage manager's intentions beyond user location, hindering comparison between reality and virtual components on a single screen, and a lack of camera operation for documenting heritage's condition. In order to address these limitations, the study proposes an improvement using Augmented Reality (AR) applications, incorporating GPS, IMU sensors, and computer vision technology to enhance user localization and interactions with object information. The authors plan to build an on-site AR application to detect components and provide related information and media overlays for more efficient heritage preservation and risk management (Lee et al., 2019).

B. Literature Examples of AI Applications in Cultural Heritage Preservation

Case Study 1: AI-aided Digitization and Virtual Restoration of Artifacts

This paper introduces a novel method for virtually restoring digitized paintings, with a specific focus on Belgium's renowned masterpiece, the Ghent Altarpiece (1432). The main goal was to remove cracks from the scanned canvas, to estimate its original appearance nearly 600 years before aging, and to support historical and paleontological analyzes of the art. For crack detection, a multi-scale morphological approach is used, capable of dealing with cracks of different thicknesses and strengths. Existing coating methods do not give satisfactory results due to complex paint details and complex types of cracks. Research demonstrates that patch-based methods perform better than pixel-based methods, but there is still room for improvement. In order to solve this problem, a new candidate patch selection method is proposed, which improves the performance of patch-based coating methods for crack removal. The results show improved results, with reduced artifacts and better preservation of fine details. In summary, this study explores the use of patch-based paints to eliminate cracks in digitized paintings, highlights specific challenges observed in the Ghent Altarpiece case study, and presents innovative solutions to improve the recovery process (Ružić et al., 2011).

Case Study 2: AI-based Damage Assessment and Restoration Planning for Historical Sites

The restoration program of the "Stabilization of Siq" initiative consists of several phases to address the risk of landslides and preserve the historic Petra site. In the first stage, the site was assessed to ensure safety during the restoration, and staff were trained in conservation skills and equipped with the necessary tools. Advanced techniques were used to record the area thoroughly, and a new GIS platform was established for data management. Phases 2 and 3 focused on landslide mitigation through urgent and priority interventions, enabling local staff to gain hands-on experience in restoration. Activities aimed at increasing awareness and growing skills were conducted to safeguard Petra's prospective procedures. Technological breakthroughs, particularly in artificial intelligence (AI), are expected to revolutionize restoration projects like "Siq Stability." AI can automate management processes, enhance planning and scheduling, and improve budget forecasting. Route optimization technology from the transport sector can also enhance rehabilitation planning for the "Siq," saving resources. AI solutions for forecasting pharmaceutical results can aid in assessing structural stability and constructability, ultimately offering cost-effective and influential restoration techniques for conserving World Heritage Sites like Petra (Goussous, 2020).

Case Study 3: AI-powered Environmental Monitoring for Cultural Heritage Sites

The study of Lombardo et al. presents data from an ongoing monitoring campaign conducted in two different heritage sites in Colombia: the Puente de Boyacá and the National Museum of Colombia. Seven sensing nodes were strategically placed in these locations to monitor environmental conditions and assess their suitability for artifact conservation. The nodes were positioned close to historically significant metallic artifacts, both indoors and outdoors, requiring tailored preservation methodologies. Six nodes were deployed in the museum, while one was placed in the outdoor site of Puente de Boyacá, where temperature and humidity variations were expected due to weather conditions. The data collected by the sensors over more than a year have provided valuable insights for curators in selecting appropriate conservation strategies (Lombardo et al., 2019).

The proposed monitoring system demonstrated its effectiveness and flexibility in multiple deployment sites. It offered wireless capability, eliminating the need for cabling, and its small size and customizable enclosure made it inconspicuous to visitors while facilitating easy deployment and management. The data revealed intense environmental conditions on the site, demanding careful curator intervention for monument safeguarding. Conversely, safe conditions were detected at the National Museum, and additional data emphasized the impact of daily contact, relocations of the artifacts, visitor influence, and showcase types on artifact conservation. These insights serve as valuable information for conservators and curators to enhance conservation approaches and adapt them to the artifacts and their current preservation status (Lombardo et al., 2019).

The ongoing observation study continues to collect data, aiming to comprehend further the factors affecting environmental conditions in regular museum interiors and heritage sites' outdoors. By providing continuous and comprehensive data, the monitoring system aids in improving artifact conservation, ensuring the preservation of cultural heritage for future generations (Lombardo et al., 2019).

III. CONCLUSION

In summary, this study explores the transformative impact of artificial intelligence (AI) applications through the preservation of cultural heritage. The findings have showcased how AI technologies are revolutionizing the digitization, documentation, analysis, restoration, and conservation of cultural artifacts and historical sites. Automated scanning, 3D modeling, and virtual reality applications have enabled the creation of accurate digital replicas, increasing accessibility for researchers, educators, and the public. AI algorithms have played a critical role in identifying damage and formulating targeted restoration plans for deteriorated artifacts and structures, preserving sensitive artworks and archaeological items with greater accuracy and efficiency. Additionally, AI-powered environmental monitoring has enabled timely responses to potential risks, safeguarding cultural heritage sites from irreversible damage.

The importance of artificial intelligence applications in preserving cultural heritage lies in its ability to develop a system of conservation and strike a balance between technological innovation and ethical considerations. By harnessing AI technology, heritage professionals can enhance their skills and contribute to sustainable conservation efforts. AI offers cost-effective and efficient restoration approaches, ensuring the preservation of World Heritage Sites and cultural diversity for future generations.

However, despite the promising outcomes, this study also identifies potential challenges and areas for future directions. Some limitations of current AI applications include the need for validation and further research, especially with limited data. Addressing these challenges necessitates ongoing exploration of intelligent learning algorithms and the integration of various sensing technologies.

In short, the integration of AI in cultural heritage preservation represents a significant advancement, empowering conservationists and researchers with innovative tools and methodologies. By balancing technological innovation with ethical concerns, cultural heritage can be preserved in a sustainable and inclusive way for future generations. As we embark on this transformative journey, it is crucial to continue fostering interdisciplinary collaborations and community engagement to ensure the effective and responsible preservation of our shared cultural heritage.

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