Cultural heritage preservation in the digital age, harnessing artificial intelligence for the future: a bibliometric analysis

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Abstract

Purpose – This study aims to investigate the performance analysis, science mapping and future direction of artificial intelligence (AI) technology, applications, tools and software used to preserve, curate and predict the historical value of cultural heritage.

Design/methodology/approach – This study uses the bibliometric research method and utilizes the Scopus database to gather data. The keywords used are "artificial intelligence" and "cultural heritage," resulting in 718 data sets spanning from 2001 to 2023. The data is restricted to the years 2001−2023, is in English language and encompasses all types of documents, including conference papers, articles, book chapters, lecture notes, reviews and editorials.

Findings – The performance analysis of research on the use of AI to aid in the preservation of cultural heritage has been ongoing since 2001, and research in this area continues to grow. The countries contributing to this research include Italy, China, Greece, Spain and the UK, with Italy being the most prolific in terms of authored works. The research primarily falls under the disciplines of computer science, mathematics, engineering, social sciences and arts and humanities, respectively. Document types mainly consist of articles and proceedings. In the science mapping process, five clusters have been identified. These clusters are labeled according to the contributions of AI tools, software, apps and technology to cultural heritage preservation. The clusters include "conservation assessment," "exhibition and visualization," "software solutions," "virtual exhibition" and "metadata and database." The future direction of research lies in extended reality, which integrates virtual reality (VR), augmented reality (AR) and mixed reality (MR); virtual restoration and preservation; 3D printing; as well as the utilization of robotics, drones and the Internet of Things (IoT) for mapping, conserving and monitoring historical sites and cultural heritage sites.

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Practical implications – The cultural heritage institution can use this result as a source to develop AI-based strategic planning for curating, preservation, preventing and presenting cultural heritages. Researchers and academicians will get insight and deeper understanding on the research trend and use the interdisciplinary of AI and cultural heritage for expanding collaboration.

Social implications – This study will help to reveal the trend and evolution of AI and cultural heritage. The finding also will fill the knowledge gap on the research on AI and cultural heritage.

Originality/value – Some similar bibliometric studies have been conducted; however, there are still limited studies on contribution of AI to preserve cultural heritage in wider view. The value of this study is the cluster in which AI is used to preserve, curate, present and assess cultural heritages.

Keywords Cultural heritage, Artificial intelligence, Cultural heritage preservation, Sustainable tourism development, Technology

Paper type Research paper

Introduction

Cultural heritage is one of the issues widely discussed in the digital era. Many individuals, organizations and countries pay attention to the preservation of cultural heritage. For a nation, the existence of cultural heritage is sought to remain, to be remembered and to serve as wisdom for its people for generations to come. Many nations cherish their cultural heritage because it is considered the root of their civilization and the source of their uniqueness, setting them apart from other nations. However, with the development of globalization, which erases boundaries between regions and countries, and the advancement of information technology, cultural heritage has become blurred. Many people adopt elements from other cultures and blend them with their own.

The role of information technology is also crucial in the preservation, curation (Jalandoni *et al.*, 2022; Neudecker, 2022), classification (Pepe *et al.*, 2022; Kosmopoulos *et al.*, 2021), dissemination (Vázquez de Ágredos Pascual *et al.*, 2022), exhibition (Dubarova-Kostadinova *et al.*, 2022), storage, restoration (Bombini *et al.*, 2022) and monitoring (Mishra *et al.*, 2022) of cultural artifacts scattered and hidden in various places.

Artificial intelligence (AI)-based information technology has also been developed to facilitate the process of maintaining cultural heritage, both tangible and intangible. Several cultural heritage projects are carried out by organizations such as the World Bank, United Nations Educational, Scientific and Cultural Organization (UNESCO), the European Union and the Heritage Research Hub. Many consortia have been formed to preserve culture, especially those involving multiple countries, which often require substantial financial investment. One example is a consortium of several European countries, chaired by the Athena Research Center, which is overseeing an AI-based project focused on the preservation of performing arts. The project involves the preservation of dance and theater using AI, extended reality (XR) and 3D technologies. Its objectives include increasing understanding, preservation, enjoyment and accessibility of performing arts (Heritage research hub, 2022).

The role of AI in preserving cultural heritage is highly beneficial, and the emergence of various intelligent applications can streamline the preservation process. Many countries, institutions and individuals face challenges in preserving AI-based culture due to factors such as limited information technology skills, high costs and a lack of knowledge about the heritage itself. However, there are now numerous applications available for organizations and individuals to use in their efforts to preserve culture. Here are some AI applications that can be used for cultural preservation.

Some studies on bibliometrics in cultural heritage or the intersection of cultural heritage and AI have been conducted. One study utilized bibliometric methods to investigate intangible cultural heritage, using CiteSpace software (Su *et al.*, 2019). Additionally,

research on cultural heritage has been explored using the Web of Science (WoS) database (Vlase and Lähdesmäki, 2023). There is also bibliometric research on cultural heritage tourism (Lin *et al.*, 2021; Bozkurt *et al.*, 2022; Zhang *et al.*, 2023b; Kodalak and Baltaci, 2023), the utilization of information technology to preserve cultural heritage through bibliometric analysis (Salleh, 2022), semantic technology for cultural heritage (Desul *et al.*, 2023) and studies exploring trends or mapping of cultural heritage research (Godinho, 2022; Zhu *et al.*, 2022; Liu and Pan, 2023).

From these studies, it is evident that significant bibliometric research has been conducted in the past three years, with tourism-related cultural heritage and research trends receiving widespread attention. Some technological aspects related to cultural heritage have also been studied, but there remains a lack of research on AI and cultural heritage, particularly within the realm of bibliometrics.

Recognizing this gap, researchers aim to explore the utilization of AI in cultural heritage through bibliometric study. The research questions posed are: (1) How does the performance analysis of research on artificial intelligence to support cultural heritage from 2001 to 2023? (2) What is the science mapping of AI applications in cultural heritages? and (3) What are the future directions for the study of AI and cultural heritage, and how can AI benefit cultural heritage preservation?

Utilization of AI for cultural heritage preservation

AI, as a cutting-edge and multifunctional technology, can serve as a valuable tool for maintaining, managing and preserving cultural heritage. China has successfully used AI to swiftly identify ancient coins without compromising their integrity (Jin *et al.*, 2023). In this country, AI has also been used to enhance the digitization process of architectural heritage, yielding efficient and effective 3D documentation results (Zhang *et al.*, 2022). Similarly, in Italy, AI was used as a 3D reconstruction tool for the Temple of Hera (Pepe *et al.*, 2022). These examples illustrate how AI can be harnessed as a means of cultural heritage preservation, with numerous other methods being used for this purpose.

Deep learning (DL), a method within artificial intelligence, provides instructions to devices enabling them to process data akin to the human brain. This approach enables AI to recognize patterns in various forms such as images, text, sound or other encrypted formats. The sophistication of DL technology makes it particularly useful for identifying historical objects, including ancient coins (Jin *et al.*, 2023). Using deep learning for identifying cultural heritage objects reduces the risk of damage to these artifacts during the identification process, while also achieving faster results with precision and accuracy. An example of a DL application aiding in the preservation of cultural heritage is easy DL, an open platform capable of recognizing and classifying historical objects, including ancient coins. Moreover, DL can automatically generate information models for cultural heritage buildings. Haznedar *et al.* (2023) demonstrated how deep learning can produce 3D visualizations of heritage buildings, facilitating their preservation efforts.

Machine learning, a branch of artificial intelligence, possesses the capability to operate autonomously without continuous direction from human users. Equipped with the ability to process data internally, machine learning uses data that has been previously input through statistics, mathematics and data mining. This is where artificial intelligence learns to analyze data. Sophisticated machine learning techniques can significantly contribute to efforts aimed at preserving cultural heritage. Zhang *et al.* (2022) demonstrate that machine learning can be effectively used for the 3D documentation of cultural heritage buildings in China.

Specifically, it enables the automatic identification of colors and paintings in Rock Art. Machine learning facilitates motif identification, object detection, object reconstruction, image knowledge graph creation and representation.

3D Model, artificial intelligence offers the advantage of visualizing concepts through images. Leveraging this model, users can effectively and efficiently create three-dimensional objects that meet their expectations. There are different types of 3D models that can represent real objects in either three or two dimensions. Additionally, there is artificial intelligence capable of generating visual objects based solely on textual instructions. This level of sophistication was harnessed by Vázquez de Ágredos Pascual *et al.* (2022) to develop a "3D Virtual Museum." They used artificial intelligence to visualize cultural heritage sites in Rome, including the oldest apothecary in Europe. Their mission involves studying and archiving cultural heritage within a museum format, while also educating the public about the rich cultural history of Rome. The success of this mission relies on integrating various disciplines such as physics, culture, 3D technology models and artificial intelligence.

CoG Cnet, this innovation represents a breakthrough developed through the sophisticated capabilities of artificial intelligence devices. It proves to be instrumental in preserving intangible cultural heritage in China. Chen *et al.* (2022) demonstrate in their research that CoG CNet effectively addresses the challenge of preserving intangible culture amidst a diverse array of new entertainment and cultural forms. In this context, AI is used to manage data related to Chinese Cantonese Opera in a structured and systematic manner. The AI tool, named CoC CNet, is specifically designed to classify singing genres within Cantonese opera. This classification can be archived, thereby contributing to the implementation of sustainable development strategies that prioritize the preservation of intangible cultural heritage.

Rapid modeling, also known as rapid prototyping, is an iterative method used to visualize the appearance of websites and applications. Its purpose is to iteratively validate the needs of both users and developers. This method is also commonly applied in the field of AI. Hu (2022) uses this rapid modeling method in efforts to preserve intangible culture. The scientist has developed a technology for digitally safeguarding information controlled by AI. The operational system is straightforward: AI executes rapid modeling methods based on 3D scanning and continuously simplifies them. Digital protection of information related to intangible cultural heritage serves to accentuate cultural connotations in the digital era. Additionally, with the assistance of AI, the preservation of intangible cultural heritage becomes more manageable, thereby preventing its erosion by new cultures.

Computer image recognition represents one of the latest methods available to researchers for analyzing clothing depicted in water and land paintings, which are treasured cultural heritage artifacts of traditional Chinese art. This site has even been officially registered as a national intangible heritage site. The intangible cultural heritage that once flourished during the Ming Dynasty now requires preservation. Therefore, Meng *et al.* (2022) undertook research aimed at identifying a sophisticated database capable of caring for and preserving water and land paintings from the Ming Dynasty era. Leveraging the sophistication of AI, these paintings can be visualized and stored on computer devices, thereby facilitating their preservation efforts.

Digital storytelling is the latest medium for digital device users to share stories virtually. Bala *et al.* (2022) discovered in their research that text editing tools can support writer creativity. With digital scissors, a writer can seamlessly patch up their manuscript without wasting additional time. In the context of cultural heritage, this type of AI facilitates the development of cultural heritage text editing tools by sourcing data from Wikipedia and Wikidata.

Digital platforms, a form of artificial intelligence commonly utilized by digital native communities, can be used to safeguard intangible cultural heritage. Zhu and Pang (2022) proposed digitally protecting the Great Wall Cultural Belt by establishing a comprehensive database covering the site. Furthermore, the development of the Great Wall Cultural Belt can be facilitated through the creation of an application platform tailored to regional cultural characteristics. Digital platforms also facilitate engaging interactions between digital devices and humans, thereby fostering enthusiasm for preserving cultural heritage.

Neural networks, essentially a component of artificial intelligence falling under the machine learning category, enable AI to process data with high accuracy. Operating akin to the human brain, neural networks swiftly scan documents and accurately recognize textual, visual and audio cues. According to Barceló *et al.* (2022), neural networks prove highly beneficial in archaeological studies and cultural heritage preservation. AI serves as a tool for reconstruction, object recognition and remote sensing, significantly streamlining research efforts.

Virtual museums represent the latest option for updating the museum visit experience for digital native individuals. Vasic *et al.* (2022) successfully recorded virtual museum user activities using tracking methods to analyze user behavior. Artificial intelligence enhances the user experience of virtual museums and can track user preferences based on browsing behavior.

Life prediction models based on artificial intelligence algorithms exemplify AI's sophistication in predicting future events. These predictions rely on embedded algorithms within the system, enabling AI to make accurate predictions. Cao (2022) used this sophistication for the benefit of preserving cultural heritage. Objects such as buildings and tools constituting cultural heritage are susceptible to damage over time due to various factors. Therefore, using AI to compare ancient buildings with modern structures can aid in assessing the condition of cultural heritage sites, thus preventing sudden damage.

Methods

This study uses bibliometric methods to explore research on artificial intelligence and cultural heritage from 2001 to 2023. Data was extracted from the Scopus database using the keywords "artificial intelligence" and "cultural heritage." Bibliometrics is used to provide insights into research trends and subject mapping, a method widely utilized across various fields of study, including social science (Donthu *et al.*, 2021). Given the breadth and volume of data in this field, bibliometrics analysis is preferred for conducting performance analysis and science mapping of research on artificial intelligence and cultural heritage.

Performance analysis examines publication metrics, focusing on the contribution of research to artificial intelligence and cultural heritage. Data typically includes information on authors, publications, countries and journals. Meanwhile, science mapping investigates the relationships and connections among constituents through citation analysis. Required data for science mapping include author information, citations, titles, journals, DOIs and references.

Data analysis and visualization are conducted using tools such as VosViewer, Scopus analytics and descriptive techniques to elucidate trends and maps. A total of 718 data sets have been gathered spanning from 2001 to 2023. The data sets consist of title, authors and affiliation, abstract, author keywords and countries. The data sets were exported to xls format, following this the data sets were imported to VosViewers for further analysis and visualization of science mapping.

Performance analysis

The results of this study indicate that performance analysis, based on various indicators such as the number of papers published per year, authors with the highest document count, countries and affiliations of authors, document subjects and document types. The results of performance

analysis will be presented in graphical, tabular and pie chart formats. The data are analyzed over the entire time range from 2001 to 2023 and specifically for the period of 2023.

The total number of documents related to artificial intelligence and cultural heritage published from 2001 to 2023 has reached 718. There is a gradual increase from 2001 to 2018, but a significant rise in AI publications supporting cultural heritage is observed from 2019 to 2023, reaching its peak in 2023. The number of documents published each year varies, with 2023 being the year with the highest number of publications, totaling 128 papers. In 2022, there were 112 papers, and before 2022, the annual publication count was below 100 titles (Figure 1).

Based on the displayed graph (Figure 2), the top 10 authors who have published documents related to artificial intelligence and cultural heritage are identified. Topping the list is Marina Paolanti from the University of Macerata, Italy, who has published nine research documents, including titles such as "Few-shot photogrammetry: A comparison between Nerf and MVS-SFM for the documentation of cultural heritage" and "Artificial intelligence and cultural heritage design and assessment of an ethical framework." In second place from Linkoping University, Sweden, is George Pavlidis, with eight documents, including titles such as "Digital twins for protecting cultural heritage against climate change" and "New technologies for the conservation and preservation of cultural heritage through a bibliometric

Source: Figure by author

Figure 1. Document on AI and cultural heritage from 2001 to 2023

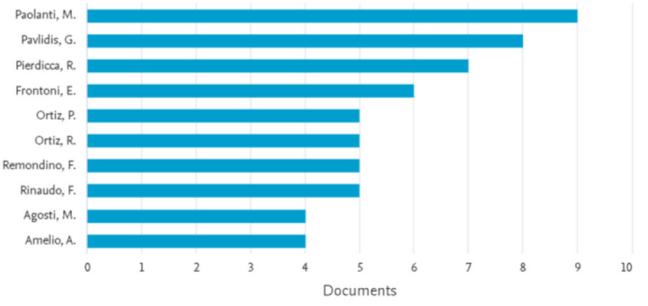

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Figure 2. Document on AI and cultural heritage by author

analysis." Pierdicca R has published seven documents, while Frontoni E has published six research documents. Ortiz P, Ortiz R, Remondino F and Rinaudo F have each published five documents. Agosti M and Amelio A have published four related documents (Table 1).

Based on the graph results (Figure 3), it is evident that documents related to artificial intelligence and cultural heritage from 2001 to 2023 come from various countries. Italy tops the list, contributing approximately 193 documents, followed by China with about 129 documents, Greece with about 55 documents, Spain with about 50 documents, the UK with about 45 documents, France with about 39 documents, the USA with about 34 documents, Germany with about 24 documents, The Netherlands with about 20 documents and India with about 20 documents.

Table 1. Author and affiliation detail

Author name	No. of documents	Affiliation	Country
Paolanti, Marina	9	Department of Political Sciences, Communication and International Relations of University of Macerata	Italy
Pavlidis, George	8	Linkoping University	Sweden
Pierdicca, R.	7	Department of Political Sciences, Communication and International Relations of University of Macerata	Italy
Frontoni, Emanuele	6	Department of Political Sciences, Communication and International Relations of University of Macerata	Italy
Ortiz, P.	5	Department of Physical, Chemical and Natural Systems, Universidad Pablo de Olavide	Spain
Ortiz, R.	5	Department of Physical, Chemical and Natural Systems, Universidad Pablo de Olavide	Spain
Remondino, F.	5	3D Optical Metrology (3DOM) unit, Bruno Kessler Foundation (FBK)	Italy
Rinaudo, F.	5	DAD, Department of Architecture and Design, Politecnico di Torino	Italy
Agosti, M.	4	Agosti M., Department of Information Engineering, University of Padua	Italy
Amelio, A.	4	InGeo, University "G. d'Annunzio" Chieti-Pescara	Italy

Source: Table by author

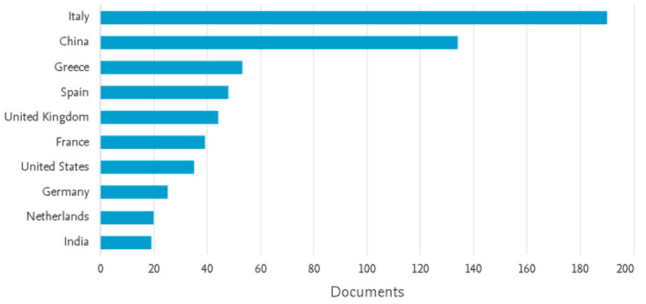

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Figure 3. Document by country from 2001 to 2023

However, in the year 2023, there is a surge in research documents, with the highest number coming from China and Italy. As seen in the above figure, documents reviewed from various countries include China and Italy with the highest total documents, approximately 35, Greece and Spain with a total of 12 and 11 documents, respectively, India with a total of eight documents, France and the UK with a total of six documents each, The Netherlands and the USA with a total of five documents each and Cyprus with a total of four documents. China and India represent Asia, and the USA represents the Americas, showing the dominance of European authors (Figure 4).

Figure 5 shows that documents related to artificial intelligence and cultural heritage have been reviewed based on types in the year 2023. From the diagram results, it is observed that there are 142 related documents, consisting of various types such as articles (approximately 58 documents), conference papers (approximately 61 documents), book chapters (approximately 8 documents), reviews (approximately six documents), conference reviews (approximately five documents), notes (approximately two documents), books (approximately one document) and editorials (approximately 1 document).

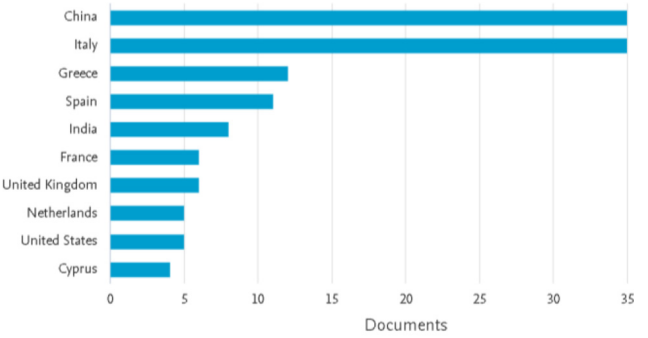

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Figure 4. Document by country on 2023

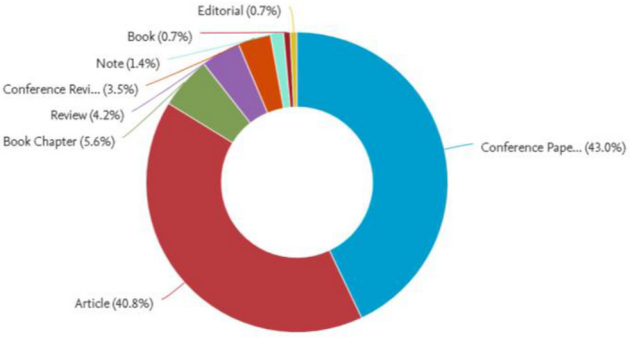

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Figure 5. Document by type in 2023

Based on the diagram above (Figure 6), it is revealed that documents related to artificial intelligence and cultural heritage have been reviewed based on all document types. Furthermore, documents have also been reviewed based on years, from 2001 to 2023, resulting in a total of 715 documents. Reviewed based on document types and years, it is found that the most common document type is conference paper, accounting for 58.3% or approximately 417 documents. The article type follows with 31.6% or approximately 226 documents. Conference review is at 4.3% or approximately 31 documents, book chapter at 3.1% or approximately 22 documents, review at 1.3% or approximately nine documents, book at 0.7% or approximately five documents, editorial and note each at 0.3% or approximately two documents and data paper at 0.1% or approximately one document.

Figure 7 depicts the documents related to artificial intelligence and cultural heritage have been reviewed based on subjects from 2001 to 2023, reaching a total of 718 documents. From the diagram results, it is observed that for the related documents, various subjects are covered, including computer science (approximately 554 documents), mathematics (approximately 205 documents), engineering (approximately 157 documents), social science (approximately 152 documents), art and humanities (approximately 70 documents),

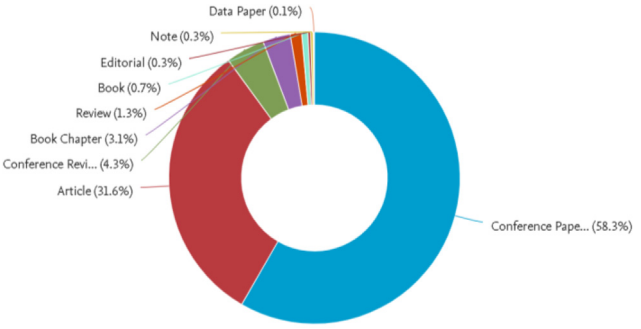

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Figure 6. Document by type from 2001 to 2023

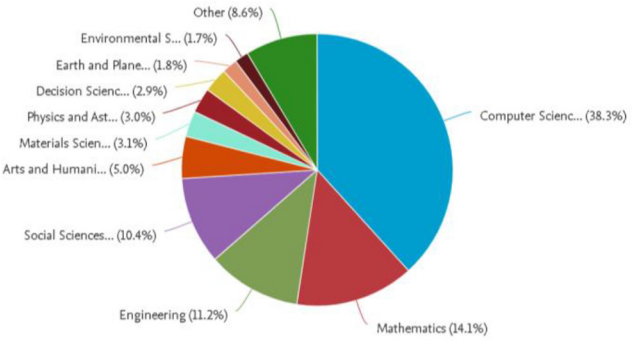

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Figure 7. Document by subject

materials science (approximately 42 documents), physics and astronomy (approximately 44 documents), decision sciences (approximately 45 documents), earth and planetary sciences (approximately 27 documents) and environmental science (approximately 25 documents).

Science mapping of AI for cultural heritage

This science mapping aims to examine the distribution and relationships of research results related to artificial intelligence and cultural heritage. Visualization of 718 data sets using VosViewer, with keyword occurrence analysis based on author keywords, produces visuals that will be further discussed. Upon reviewing the artificial intelligence related to cultural heritage search results (Figure 8), a connected network is shown through keywords. There are five dominant colors in these network groups, each representing research subject clusters on the use of AI in cultural heritage. The first cluster is indicated by the red color, representing "conservation assessment"; yellow for "exhibition and visualization"; purple for "software solutions"; blue for "virtual exhibition"; and green for "metadata and database."

The red cluster contains artificial intelligence supporting assessment and conservation processes for cultural heritage (Figure 9). It involves AI and cultural heritage related to machine learning, classification, learning systems, deep learning and e-learning. Machine learning is used in innovative AI applications, as seen in Deng *et al.* (2023) research, exploring AI-based Multimodal Unsupervised Image-To-Image Translation (MUNIT) for ethnic fashion design, specifically focusing on women's clothing in the Miao ethnic group.

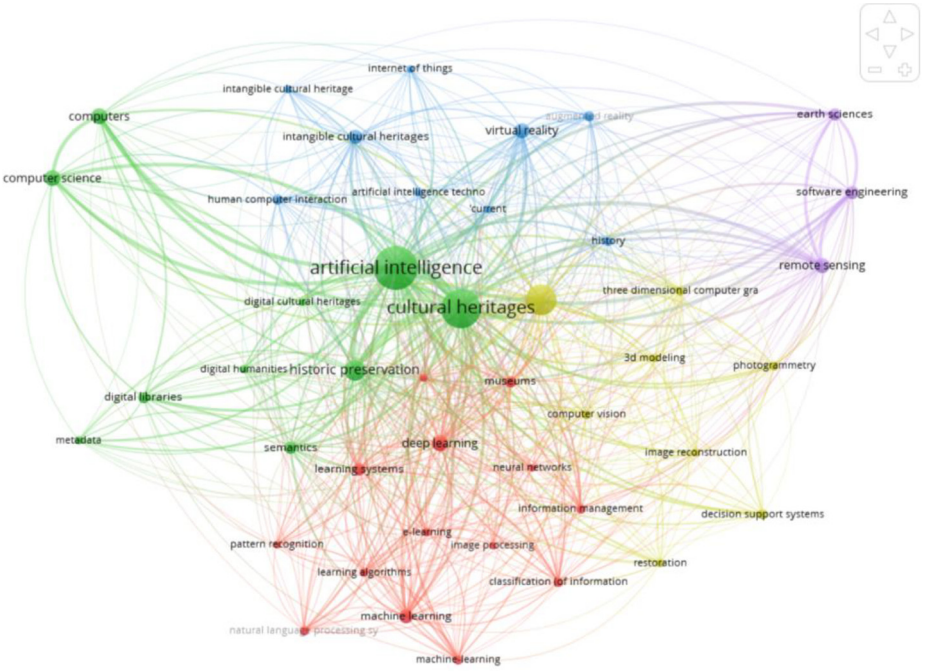

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Figure 8. Keywords occurrence on the research of AI and cultural heritage from 2001 to 2023

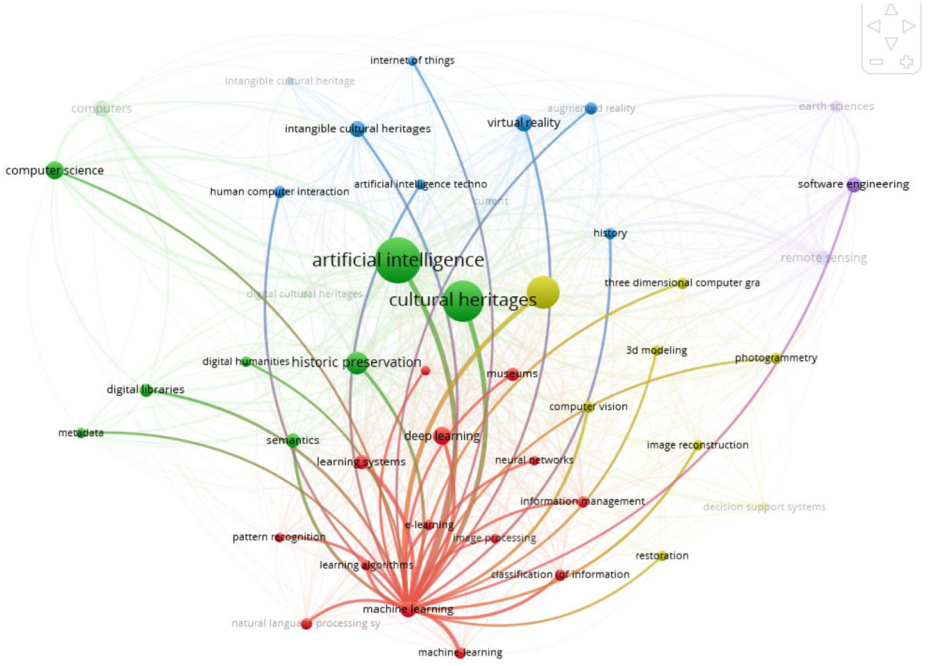

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Figure 9. Red cluster "Conservation assessment"

Classification is discussed in the study by Siountri and Anagnostopoulos (2023), addressing the classification of modern Athena architecture using deep learning-based you only look once (YOLO) algorithm, contributing to digital management in urban building stocks and automatic categorization based on street scene images, enhancing tangible cultural heritage. Deep learning is explored in Iyer and Bhardwaj (2024) research, identifying the usage of AI neural networks in identifying characters from Kathakali, a sacred cultural heritage of India, through image analysis.

The yellow cluster (Figure 10) focuses on "exhibition and visualization," detailing image reconstruction, restoration, computer vision, 3D modeling and photo memory. Image recognition, as discussed in the study by Bombini *et al.* (2022), explores Artificial Intelligence for Digital Restoration for Cultural Heritage (AIRES-CH). The study emphasizes the creation of a web-cloud native application for digital restoration of artworks using computer vision technology applied to raw X-ray fluorescene (XRF) data. Restoration, as explored in the research by Jiang *et al.* (2022), centers on a novel approach to digital conservation and virtual restoration of frescoes. The process involves mural restoration with the assistance of computers combined with the actual painting process. Computer vision, as investigated by Díaz *et al.* (2020), delves into the use of new methods and technologies for image classification, captioning, object detection and more. The study, conducted within the context of the Digital Humanities ChIA project, presents an approach to testing various computer vision tools (CV) and open-source platforms (YOLO) on selected cultural food

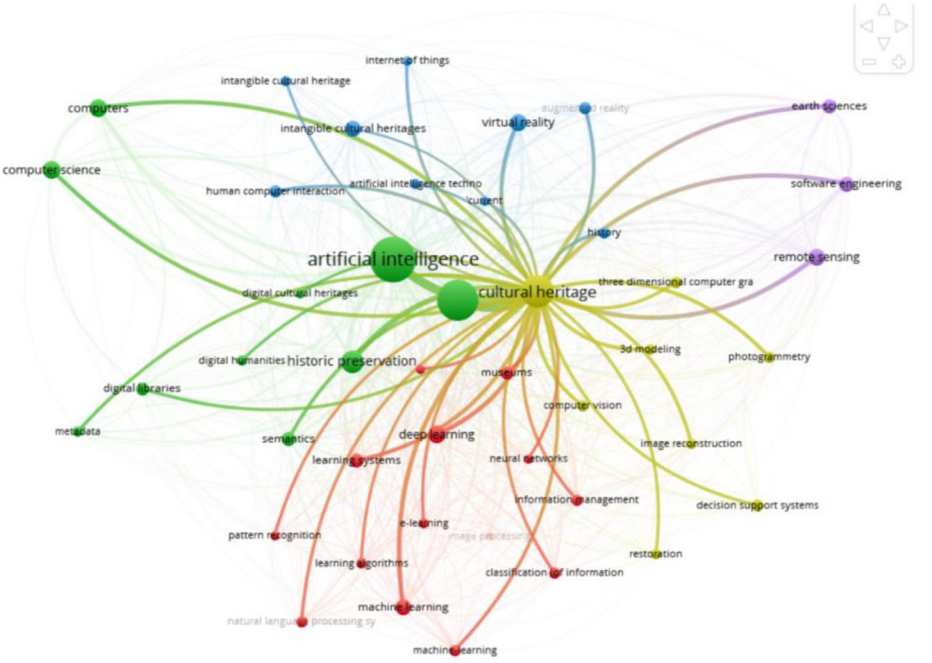

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Figure 10. Yellow cluster "Exhibition and visualization"

images. 3D modeling, as explored by Condorelli (2023), discusses the utilization of a prompt-to-image system to obtain images for subsequent reconstruction and 3D modeling. The specific application involves illustrations from Kircher's book found in the Brixen Seminary Library.

The Purple Cluster, "Software Solutions," (Figure 11) elaborates on remote sensing, decision support systems (DSS) and software engineering. Remote sensing, with the current technology based on unmanned aerial vehicles (UAVs), has gained global recognition. Due to its ability to investigate vast areas in a very short time and at very low costs, UAV-based sensing technology has found extensive applications in various contexts, including security and surveillance inspections, environmental monitoring, geology, agriculture, archaeology and cultural heritage (Noviello *et al.*, 2021).

DSS, as discussed in the study by Acampa *et al.* (2023), focuses on defining a methodology for assessing priorities among interventions at the historical center of Florence, ranging from conservation to regeneration of its heritage. A mixed-method approach is used by integrating multicriteria models, specific degradation analysis methods and parameters used for optimizing construction costs. The methodology selects areas for regeneration, evaluating different transformation alternatives through both Hierarchical Impact Assessment (HIA) and Multi-Criteria Decision Analysis (MCDA).

Next, software engineering, as described in the research by Amelio *et al.* (2020), explains that The 2nd International Workshop on Visual Pattern Extraction and Recognition for

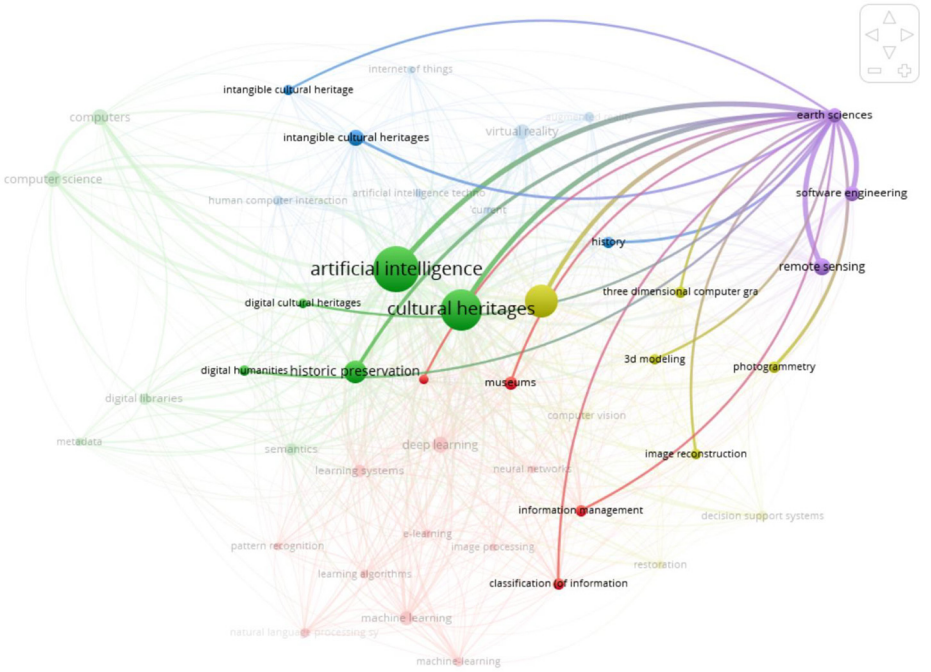

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Figure 11. Purple cluster software solutions

Cultural Heritage Understanding (VIPERC, 2020) serves as an international forum primarily aimed at presenting recent advances in research, innovative works, sustainable projects, academic insights and project reports in statistics, data mining, applied mathematics, knowledge representation, intelligent systems, information retrieval and software engineering. The workshop focuses on visual pattern extraction, analysis and recognition with the goal of preserving cultural heritage.

The Blue cluster "Virtual exhibition" (Figure 12) describes virtual reality (VR), augmented reality (AR), Internet of Things (IoT), intangible cultural heritage and history. VR, as seen in the study by Chen and Chen (2024), explains the sustainable development of technology related to service design that will be integrated with VR technology and emotion identification technology based on convolutional neural network (CNN). AR, as discussed in the research by Espina-Romero and Guerrero-Alcedo (2022), notes that digital publications from 2018 to 2022 reveal ten fields of digitization, one of which is associated with augmented reality. IoT, according to the study by Murphy *et al.* (2022), emphasizes that the emergence of IoT has opened opportunities to enhance traditional user experiences. Intangible cultural heritage, as explored in the research by Zhang *et al.* (2023a), focuses on measuring the effectiveness of artificial intelligence technology in promoting the sustainability of intangible cultural heritage. The research context is rooted in the Attention, Interest, Search, Action and Share (AISAS) model, connecting perceived value theory and cultural identity to predict the long-term sustainability of cultural and creative products

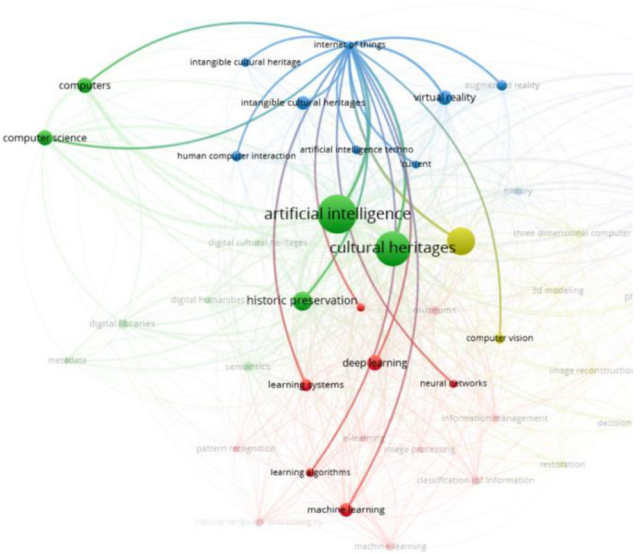

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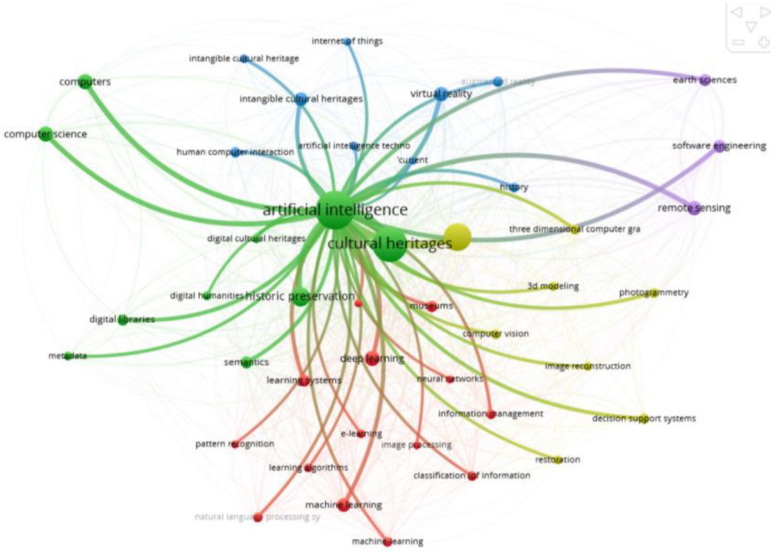
Figure 12. Blue cluster "Virtual exhibition"

produced by AI in society. Finally, history, as indicated in studies, highlights that cultural heritage has been created by people worldwide throughout history. Moreover, with the advancement of technology, AI can be used to monitor cultural heritage areas for protection purposes.

Green cluster metadata and database (Figure 13). Describing computer science, computers, digital cultural heritage, digital library and metadata. Computer science, as stated by Ren *et al.* (2019), emphasizes the need for World Heritage Sites to allocate resources and implement an effective resource monitoring system. In this context, artificial intelligence techniques, particularly network algorithm calculations, are used. Additionally, theories and methods of creative computing work to integrate the tourism field with computer science. Concerning computers, Chortaras *et al.* (2018) have successfully provided a platform called WITH. This platform acts as an aggregation platform, facilitating human-computer collaboration for data annotation and enrichment. The WITH platform combines human intelligence and computer capabilities to enhance the quality of digital cultural content and its presentation, fostering new collaborative approaches between cultural organizations and their audience. Furthermore, digital cultural heritage, as explained in the research by Croce *et al.* (2023), introduces neural radiance fields (NeRF) as an advanced technology capable of applications in the cultural heritage domain. NeRF is used for the reconstruction of 3D models of real objects and multiscale image-based models, even in combination with more established photogrammetry techniques. Next, Digital Library, exemplified by EduceLab, encompasses various types of complex digital objects. This includes virtually unwrapped manuscripts relying on machine learning tools to create a digital version of invisible text, as well as 3D models consisting of 2D photos, multi- and hyperspectral images, illustrations and 3D meshes (Chapman *et al.*, 2021). Finally, metadata, as introduced in the research by



Source: Figure by author

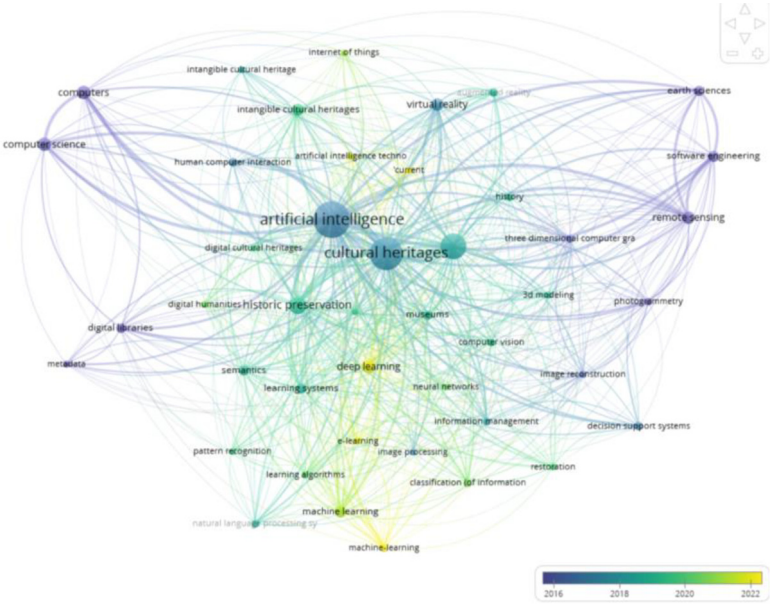
Figure 13. Green cluster "Metadata and database"

Wehmeier and Artopoulos (2023), presents MetaFraming as a contribution to a participatory methodology designed to transform extensive preliminary research notes into a richly metadata-enriched and semantically structured data set using AI processing pathways. This enables the modeling of diverse perspectives on heritage artifacts.

The research trends from 2016 to 2022 are also reflected in Figure 14, where a shift in research direction is observed. In 2016, computer science, serving as the umbrella for research themes in information technology and AI, significantly dominated. This includes the connection of computer science with its derivatives, such as the development of metadata for cultural heritage, software engineering for running various applications and the digitization of cultural heritage. Moving to 2018, VR and AR were leveraged to support the presentation of cultural heritage, including learning systems and learning algorithms for curating CH. In 2020, IoT became prominent and was used in cultural heritage, and in the latest year of 2022, there is still a significant use of deep learning and machine learning in the preservation of cultural heritage.

Discussion

The implementation of artificial intelligence in cultural heritage can be traced back to research findings starting from the year 2001. Each year, the utilization of AI becomes increasingly apparent, as evidenced by the growing number of research outputs published in various forms such as articles, conference proceedings, book chapters, literature reviews and lecture notes. The significant increase in AI-related articles is noticeable, particularly from the years 2019 to 2023. This surge can be attributed to several factors, including the organization of numerous conferences with a focus on artificial intelligence associated with cultural heritage. One example is the "22nd International Conference of the Italian Association for Artificial



Source: Figure by author

Figure 14. Research trend from 2016 to 2022

Intelligence," featuring one of its subthemes dedicated to artificial intelligence for cultural heritage. In addition to conference outcomes, the massive development of AI is also being harnessed for the preservation of cultural heritage.

During the years 2022–2023, a considerable number of AI publications originated from China, contributing to the increased count of conference papers from the country. Italy stands out as the leading country in producing AI publications related to cultural heritage, followed by China. This is primarily due to Italy having the highest number of heritage sites, totaling 59, according to the UNESCO World Heritage List, while China has 56 heritage sites. Consequently, a substantial amount of research on the preservation of cultural heritage emanates from these two countries, along with contributions from Germany, Spain, India and the UK.

The findings from the analysis of knowledge mapping provide valuable insights into current trends at the intersection of AI and cultural heritage. The first prominent cluster revolves around the use of AI for classification and assessment in the conservation of cultural heritage. This involves applications of machine learning, deep learning and classification algorithms, as demonstrated by studies such as Deng *et al.* (2023) and Siountri and Anagnostopoulos (2023). These technologies facilitate innovative approaches to conservation assessment, bridging modern AI techniques with traditional elements. The second cluster emphasizes exhibitions and the visualization of cultural heritage through AI. This encompasses various techniques such as image reconstruction, restoration, computer vision and 3D modeling. Studies like Bombini *et al.* (2022) and Jiang *et al.* (2022) showcase the role of AI in digital restoration and virtual reconstruction, enhancing the visual representation of cultural artifacts. The third cluster focuses on software solutions, including remote sensing, DSS and software engineering. Remote sensing, particularly using UAVs, proves crucial in

various applications, including environmental, geological and archaeological utilization. DSS, as demonstrated by Acampa *et al.* (2023), aids in prioritizing interventions for historical centers, integrating multicriteria models and degradation analysis methods. Software engineering, highlighted by Amelio *et al.* (2020), plays a crucial role in developing technology for understanding and recognizing cultural heritage.

The fourth cluster discusses VR, AR, IoT, intangible cultural heritage and history. Chen *et al.* (2022) demonstrate the integration of VR technology and emotion identification for sustainable service design. Research such as Murphy *et al.* (2022) indicates that IoT enhances traditional user experiences. Furthermore, studies like Zhang *et al.* (2023b) explore AI in supporting the sustainability of intangible cultural heritage, connecting perceived value theory with cultural identity. Finally, the last cluster addresses the importance of computer science, computing, digital cultural heritage, digital libraries and metadata. This includes research by Ren *et al.* (2019), emphasizing the use of AI algorithms in managing resources for UNESCO World Heritage Sites. The integration of human and computer intelligence, such as WITH, enhances the quality of digital cultural content. The knowledge mapping findings affirm the multidisciplinary nature of AI applications in cultural heritage preservation, encompassing classification, visualization, software solutions, virtual experiences and information management. As this field continues to evolve, the identified clusters can serve as a guide for future research directions and collaborative efforts in leveraging AI for the future preservation of cultural heritage.

Comparison with previous research reveals the evolution and development in the use of AI to preserve cultural heritage. Previous bibliometric studies have outlined trends and patterns in research on AI and cultural heritage. For instance, Bozkurt *et al.* (2022) discuss research contributions carried out by Italy and Spain related to cultural heritage, cultural tourism, digital heritage and AR. Another study by Prados-Peña *et al.* (2023) examined research trends from 1993 to 2021, based on data from the Scopus database, revealing an increase in publications in the fields of cultural heritage and AI. It further indicates that machines and AI are increasingly being used as powerful pattern recognition methods across various scientific domains, particularly in cultural heritage conservation.

Alviz-Meza *et al.* (2022) research presents research trends derived from the Scopus database and WoS, showing increasing interest from institutions, journals, researchers, countries and funding agencies in studying cultural heritage related to the use of tools and technology provided by industry 4.0. Additionally, research by Zhao *et al.* (2020) highlights research trends based on data from the WoS database, focusing on keyword maps and clusters related to big data, cultural heritage, AI, museums and machine learning. The results suggest that big data is more prominently associated with cultural heritage than AI, indicating a need for further research to bridge this gap.

By considering the contributions of previous research, this study confirms the evolution and development in the use of AI to preserve cultural heritage. The science mapping analysis in this research provides deeper insights by highlighting the main clusters that describe the application of AI in various aspects of cultural heritage preservation. This study thus not only enriches understanding of current trends but also provides deeper insight into how AI can be integrated more effectively into cultural heritage preservation efforts in the future.

Future direction of AI usage to support cultural heritage preservation

Referring to the results of science mapping analysis that indicate five main clusters of AI utilization in cultural heritage, here are some AI applications that can be developed by scientists and practitioners to support cultural heritage. For future use, AI can be designed to be as comfortable and user-friendly as possible so that users can apply it quickly:

- The utilization of drones for archaeological site documentation or historical landscapes in hard-to-reach locations.
- The use of blockchain to ensure the authenticity of objects containing cultural heritage in the curation process.
- 3D printing and virtual replication can be used to reconstruct historical objects with precision and high similarity.
- The use of extended reality, which combines VR, AR and mixed reality (MR) for the visualization and presentation of cultural heritage, as well as providing interactive experiences for users.
- Robotics and IoT for conservation, maintenance and tasks related to human safety and security.

Conclusion

The use of AI brings many significant contributions to cultural heritage preservation. For instance, it is easier to identify the ancient coin using deep learning that can process the data just like human beings, and to reconstruct the 3D historical object using 3D modeling, to build a virtual museum, using neural network to scan the textual, voice and object, and many more. The intensive use of artificial intelligence will be increasing in the future, so it is necessary for information organizations and information professionals to learn, adopt and take advantage of artificial intelligence in terms of cultural heritage preservation activity.

The research also addresses a significant gap in the understanding of AI performance in relation to cultural heritage. The research findings provide a comprehensive assessment of the research landscape, filling important knowledge gaps, and laying a strong foundation for future efforts in the integration of AI and cultural heritage preservation. Furthermore, the second significant implication of this research lies in its contribution to the development of a synergistic concept between cultural heritage and AI. Through in-depth analysis of the findings, this research not only identifies current practices but also aids in shaping a conceptual framework. The development of this concept plays a crucial role in guiding research, policymaking and practical implementation, enriching the discourse on the integration of cultural heritage and artificial intelligence.

Practically, its implications are highly significant. Institutions managing cultural heritage can use insights from this study to formulate strategic plans for AI-based curation, preservation and preventive activities. This research also provides information on AI technologies that can support cultural heritage, offering practical guidelines for implementation. Additionally, researchers gain valuable insights and a deeper understanding, identifying emerging trends and interdisciplinary aspects of AI and cultural heritage. In conclusion, the pace of artificial intelligence in cultural heritage preservation marks a transformative era. Alongside the evolution of AI, this study not only addresses current knowledge gaps but also lays the groundwork for theoretical exploration and practical applications in the future, promoting a collaborative and informed approach to the integration of AI in cultural heritage preservation efforts.

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