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Emerging Trends and Future Directions in Artificial Intelligence for Museums: A Comprehensive Bibliometric Analysis Based on Scopus (1983-2024)

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Abstract

Artificial Intelligence is changing the future of museums, opening the door to unprecedented innovations that are revolutionising the way collections are managed and experiences are designed. This bibliometric analysis, covering four decades of research (1983-2024) from the Scopus database, explores how Artificial Intelligence is transforming museum activities — from creating personalised visitor experiences to preserving cultural treasures through advanced digitisation processes. The study shows that the number of publications on Artificial Intelligence has increased dramatically in recent years, reflecting the growing momentum in the field.

The integration of AI in museums demands careful reflection on its implications for human rights, cultural values, and social responsibility. As AI adoption accelerates, addressing ethical concerns—such as potential biases, transparency, and accountability—has become increasingly vital. Institutions are encouraged to develop robust ethical frameworks that mitigate these risks, ensuring AI does not reinforce inequalities or distort cultural representation. By embracing AI responsibly, museums can not only enhance visitor engagement and streamline operations but also uphold their commitment to inclusivity, safeguarding their role as stewards of knowledge, culture, and education.

Keywords: Artificial Intelligence; Museums; Technologies; Innovation; Ethics

1. Introduction

Artificial Intelligence (AI) is transforming the museum sector, influencing everything from collection management to visitor engagement, and reshaping how museums address conservation and accessibility challenges. Recent developments have shown that AI can enhance both the operational and experiential aspects of museums. One of its most significant contributions is the creation of personalized visitor experiences. Through machine learning algorithms and recommendation systems, AI allows museums to suggest tailored exhibition paths based on individual preferences, as exemplified by the Mauritshuis in The Hague (Britannica, 2024), which developed an AI chatbot called 'Muse' to provide personalized recommendations on artworks.

AI is also revolutionizing the digitization and accessibility of collections, making archives more easily available to researchers and the public. Using image recognition techniques, AI systems can automatically catalog artworks, identifying features and patterns that might otherwise be overlooked. The Metropolitan Museum of Art in New York has employed these tools to improve the accessibility and categorization

of its vast collection. The Rijksstudio is a platform from the Rijksmuseum that serves as an open-access digital archive, featuring high-definition, open-source images and collections organized by historical period, themes, authors, and more. Users can create a personal profile to engage in various activities on the platform, such as creating their own collections of artworks, downloading them, or making collages. Additionally, to foster creativity and interaction among museum visitors, the museum encourages users to create and publish their own material inspired by the museum's works, such as prints, jewelry, objects, etc. (Rijksmuseum, 2020).

In the field of conservation and restoration, AI offers new possibilities for monitoring the condition of artworks and predicting potential deterioration. Image analysis algorithms provide data-driven insights that support timely and precise interventions, reducing the need for extensive manual inspection. Behind the curtain, AI is revolutionising operations management. The Smithsonian, for example, uses machine learning algorithms and sensors to perform predictive maintenance on its equipment, allowing it to anticipate breakdowns and schedule repairs ahead of time. This strategy not only reduces downtime, but also optimises operating costs and ensures greater efficiency.

AI can also simulate virtual restorations, allowing experts to assess the impact of different techniques before applying them in real life.

Smart technologies, including virtual reality (VR) and augmented reality (AR), are also revolutioning visitor interactions by blending physical and virtual experiences, making cultural artifacts more accessible and understandable (Ronco, 2024). AI-generated narratives, such as scavenger hunts or interactive stories, further enrich the visitor experience, particularly for younger audiences, fostering a deeper connection to the exhibits (Hettmann et al., 2023).

Virtual reality, implemented through specific headsets or goggles, transports the visitor into a completely digital environment, stimulating them sensorily to interact with the context (Gao, 2023; LaValle, 2023). 'Mona Lisa Beyond the Glass' is the first virtual reality project created by the Louvre, based on the latest research on Da Vinci's technique and creative process (Musée du Louvre, 2021).

Furthermore, AI is enhancing the visitor experience by integrating with augmented reality (AR) to create immersive and interactive environments (Li, 2023; Samala, 2023).

'The Met Unframed', designed by the Metropolitan Museum of New York (USA) in partnership with the multidisciplinary production company Verizon Communications Inc., is an immersive augmented reality experience available for free on any mobile device. Its goal is to make the viewer feel as if they are truly inside the museum by allowing them to navigate a realistic reproduction of some of the Metropolitan's iconic spaces. The experience also offers exclusive features and content specifically designed to be enjoyed through the app, such as new galleries and artworks that come to life through a series of animations made possible by augmented reality (Metropolitan Museum of Art & Verizon, 2021). Nel 2023, the Metropolitan Museum of Art and Verizon have teamed up to introduce a

groundbreaking experience called 'Replica'. This initiative allows visitors to The Met to use augmented reality (AR) to scan artworks and digitally transfer selected elements into the immersive platform 'Roblox'. Through this innovative technology, visitors can interact with famous art pieces in new ways, bridging the physical and virtual worlds and enhancing their museum experience (Metropolitan Museum of Art & Verizon, 2023).

The AI for MUSE project, born from the collaboration between the University of Turin and the Polytechnic, uses artificial intelligence, virtual reality, and apps to enhance the museum visit experience. The I-MUSE app allows users to enrich their visit, offering personalized itineraries, suggested insights based on their preferences, and the opportunity to discover not only the exhibited works but also those stored in warehouses and archives. Thanks to I-MUSE, it is possible to expand the horizons of the visit, moving beyond the idea of separate museums and fostering dialogue between collections. Visitors can experience the heritage as if it were housed in a single, large museum.

AI-based voice assistants are another key innovation, improving accessibility by providing on-demand audio descriptions for exhibited works. For instance, AI voice assistants like the one developed for the MARTA Museum guide users through virtual environments, answering questions and providing insights about artworks (Carolis et al., 2023). Similarly, IBM's Watson, used in the Pinacoteca de São Paulo, allows visitors to ask questions about specific artworks, responding with audio answers to enhance the educational experience (Fan, 2023). AIMuBot, a chatbot supporting natural language interactions, enables visitors to refine their inquiries and receive tailored information from the museum's knowledge base (Zhou et al., 2020). The Iris+ system actively engages visitors by prompting them to reflect on their experiences, fostering social interaction and informal learning (Candello et al., 2020).

AI integration in museums is revolutionizing visitor engagement and behavior analysis, enabling real-time personalization and deeper interaction. For example, AI-powered exhibits at the Wuhan Museum of Science and Technology utilize machine learning to enhance visitor engagement (Yan, 2024), while art museums offer tailored content and instant information access (Rani et al., 2023). Techniques like Faster R-CNN provide insights into visitor patterns, supporting exhibition planning (Sansonetti, 2022). Moreover, AI within the Industry 5.0 framework fosters community connections and user satisfaction (Orea-Giner et al., 2022). However, concerns around data privacy and over-reliance on technology remain challenges.

AI can track data such as time spent in front of artworks, visitor movement patterns, and interactions with digital installations. This data helps museums better understand audience preferences, optimizing exhibition layouts and improving visitor engagement. The Prado Museum in Madrid, for example, has used AI to monitor visitor behavior and enhance the organization of its exhibition spaces.

AI is also reshaping digital storytelling, enabling museums to provide audiences with more dynamic and tailored interactions. The integration of AI and digital storytelling is revolutionizing how museums engage visitors and present cultural heritage. By

leveraging advanced technologies, museums are able to design engaging, customized experiences that connect with a broad range of audiences. AI enhances the visual elements of online exhibitions, dynamically adapting content to ensure aesthetic coherence and thematic richness, as demonstrated by institutions like the British Museum and the Louvre (Zhao & Yezhova, 2024).

Furthermore, 'Advanced Interactive Digital Storytelling -A-IDS' combines narrative with gameplay to immerse visitors in historical contexts. Projects like the Trebinje Fortresses VR allow users to explore historical sites through interactive and engaging storytelling (Rizvic et al., 2024).

The integration of artificial intelligence and gamification in museums presents a significant opportunity to increase visitor engagement and revitalize the cultural experience (Plaisent et al., 2024). These technologies allow museums to attract a wider audience, especially younger generations, through interactive and personalized experiences (Bugeja & Grech, 2020). Gamification, through scavenger hunts and mini games, has proven effective in boosting visitor interest and connection with exhibits (Hettmann et al., 2023).

In conclusion, AI is driving a profound transformation in the museum world. From improving collection management and restoration efforts to enhancing visitor experiences through personalization and accessibility, AI is helping museums to navigate the challenges of the digital age while preserving their core mission as spaces of learning, cultural preservation, and public engagement.

This study seeks to investigate the evolution of the pivotal role that digital technologies, particularly artificial intelligence, have come to play in the development of a renewed, more sustainable, and inclusive cultural system. The analysis draws on publications indexed in Scopus, tracing the progression from the earliest scholarly articles on AI and museums to contemporary research.

2. Material and Methods

2.1 Tools

In this study, the Scopus database was used for the analysis. This study primarily employed two methodological approaches: the Preferred Reporting Items for Systematic Reviews and Meta-Analyses – PRISMA (Gutiérrez-Nieto et al., 2019) for the systematic review of the articles included in the analysis and the bibliometric analysis.

The bibliometric analysis was conducted in four key stages: gathering data, preprocessing the information, performing statistical calculations, and analyzing the results for application. Prior to conducting any bibliometric analysis, keywords were established as the foundational elements upon which the analysis would be predicated. To this end, authors' studies were extracted from indexed databases to annotate significant keywords. Subsequently, these keywords were employed in various combinations, culminating in the following finalized search string:

TITLE-ABS-KEY TITLE-ABS-KEY (artificial AND intelligence AND museum).

This search string initially yielded 668 documents. After applying restrictions to journal articles, conference papers, book chapters, and English language publications, the corpus was refined to 582 documents. This study represents a time-trend analysis, and the number of documents may increase over time due to ongoing publications by authors. Consequently, the study is bounded by the end date of October 11, 2024, with the earliest publication in the dataset dating back to 1983 as indexed in the Scopus database.

In the eligibility phase, the articles were checked for duplicates using their electronic identification (EID), and in the end no articles were removed.

In the next phase, the quantitative and descriptive analyses will be carried out.

The Principal Component Analysis - PCA (Jolliffe, 2016) was employed to visualize relationships between AI-related keywords in museum research. This method helps reduce the complexity of large datasets by identifying patterns and summarizing data into principal components. It allows for examination of how different AI-related keywords are connected across various studies, highlighting frequent co-occurrences and clustering around specific themes. The PCA analysis groups similar keywords, offering insights into common research themes such as technological development, digital applications in visitor engagement, and AI-driven experiences. This visualization aids in identifying key trends in AI research within museums and projecting future research directions and gaps in the literature.

In this study, the PCA results contribute significantly to understanding the evolution of AI applications in museums, highlighting major research clusters and areas of future growth.

2.2 Data analysis

The data reflects a wide range of scientific research, with a particular focus on topics related to technology and innovation, Artificial Intelligence and its applications in cultural heritage and other sectors.

The analysis shows a clear exponential growth in the number of publications dealing with AI in cultural heritage. While there were only a few sporadic publications in the 1980s and 1990s, there has been a significant increase since 2010, peaking at 72 publications in 2023. The number is expected to rise further in 2024, as over 55 articles have already been registered.

The total number of citations for the 582 publications amounts to 4,596, with an average of about 8 citations per document. However, there is an obvious asymmetrical distribution, with a few articles receiving most citations. The most cited document is 'Interactive Museum tour robot' with 362 citations, which is an important example of the growing interest in the integration of robotics and AI into museum experiences. This suggests that certain areas, such as interactive robotics, are attracting particular interest from both academia and industry.

A substantial share of publications (approximately 73%) is not available through open access, restricting the widespread dissemination of this research. However, 155 publications are accessible via various open access models, with gold open access

being the most widespread (63 articles). This distribution reflects a general trend in scientific fields where open access is gradually gaining importance but is not yet prevalent.

Most publications in the dataset consist of conference papers (351), followed by journal articles (193). A smaller portion of the sample is made up of books and book chapters. This can be attributed to the fact that in the fields of science and technology, publications are mainly published at conferences, which offer more dynamic platforms for the exchange of new research findings.

Figure 1 shows the evolution of academic publications on AI and museums over time.

Initially there are only a few scattered publications, which indicates a limited interest or research activity in this scientific area in the early years. The number of publications has grown recently, indicating a growing academic interest and focus on the connection between AI and museum studies.

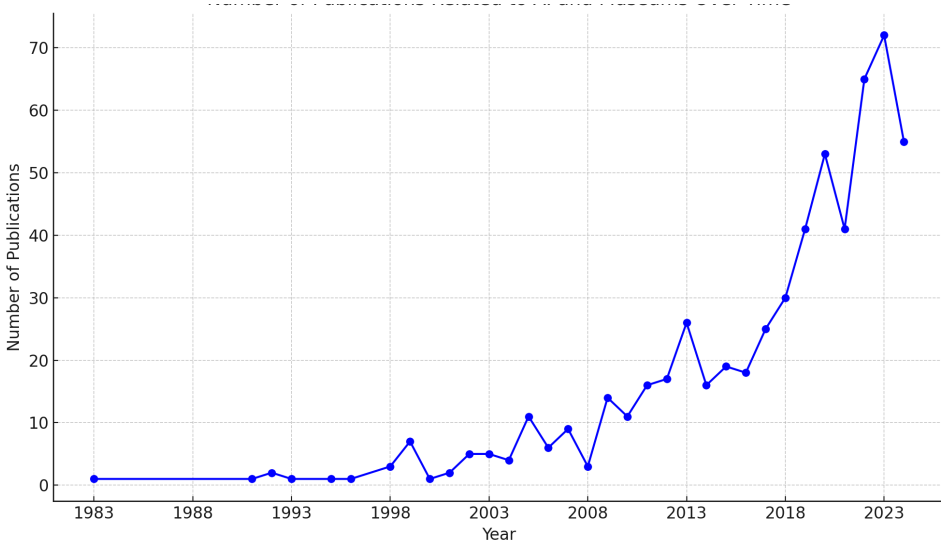

Figure 1: Publications on the topic of Artificial Intelligence and museums over time
Source: Own elaboration

This trend reflects the wider use of AI technologies in various fields, including cultural heritage and museum management. In particular, the more recent years likely show periods when technological advances stimulated new research or projects, leading to a notable increase in the number of research studies. Peaks in publication activity may coincide with specific breakthroughs in AI applications or increased funding for digital transformation initiatives in the museum sector. Research studies have been increasingly focused on the importance of AI in museums, as evidenced by the steady increase in research production over the previous decades.

The analysed dataset also sheds light on the distribution of different document types such as articles, conference papers, book chapters and books over several years (Fig. 2).

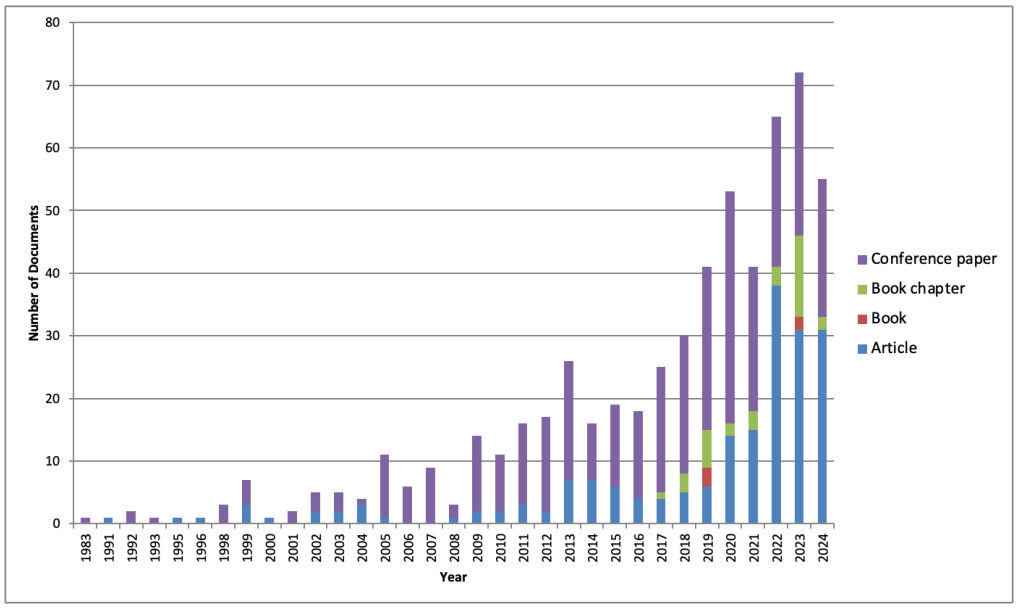

Figure 2: Distribution of Document Types per Year
Source: Own elaboration

Conference papers make up the bulk of the dataset with a total of 351 entries, followed by articles with 193, book chapters with 33 and books with 5. The dominance of conference papers suggests that a significant amount of research is shared within academic and professional conferences, indicating a focus on the rapid dissemination of results that is typical of fields that are rapidly evolving or rely on collaboration. The data spans the period from 1983 to 2024 and shows a significant increase in the number of documents over time. In particular, there is a steep increase in document production from 2019 onwards, peaking at 72 documents in 2023.

This trend reflects a growing number of research papers and the dissemination of knowledge, possibly related to technological advances, increased research funding or greater academic output from institutions. In the late 1990s and early 2000s, the number of documents produced is relatively low, indicating a slower research period, followed by an acceleration after 2010. Articles and conference papers are evenly represented over the years, with conference papers being particularly dominant after 2010. This increase may reflect the increasing tendency of researchers to present preliminary results at conferences before seeking publication in a journal. Book chapters, while less numerous, are clearly present from 2017 onwards, with a peak in 2023, indicating a trend towards collaborative or interdisciplinary work. The presence of books is minimal but appears in key years

such as 019 and 2023, which could be related to large-scale research projects that result in books. The year 2023 stands out as the most productive year with 72 documents, including 31 articles, 26 conference papers, 13 book chapters and 2 books. This indicates a well-rounded year with significant contributions in various formats.

The year 2024 also reflects a strong output with 55 documents, specifically 31 articles and 22 conference papers, indicating continued research activity. Overall, the data shows a steady growth in research output, with conference papers being the most important dissemination medium. The increasing presence of book chapters in recent years indicates a shift towards more interdisciplinary or collaborative research.

The increase in articles in 2022 and 2023 could also indicate a maturing of the field, with more results being finalised and published in official journals. This analysis provides a clear picture of evolving research trends and document types over the years, which likely reflect broader academic, technological or societal change.

In terms of the number of publications for the top ten countries involved in the research (Fig. 3), China leads with the highest number of publications, followed by Italy and the United States.

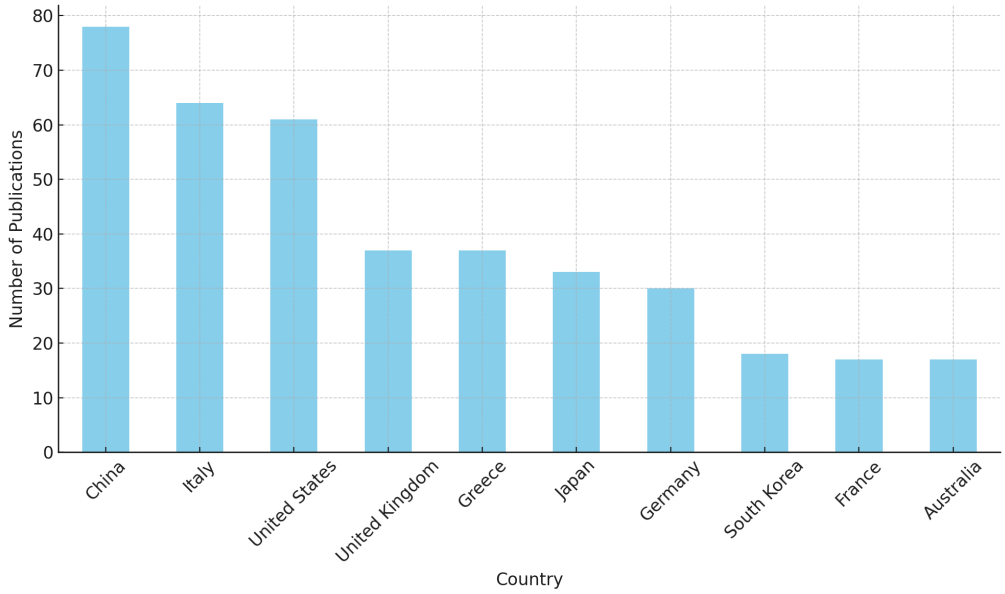

Figure 3: Top 10 Countries Involved in the Research studies [Source: Own elaboration]

Other European countries such as the United Kingdom, Greece, Germany and France are also well represented, emphasising the strong contribution of the European scientific community. However, countries such as Japan, South Korea and Australia are also strongly represented. This distribution emphasises the international nature of the research, with broad participation across several continents.

The integration of Artificial Intelligence into the cultural sector is experiencing significant growth, as demonstrated by the trends in academic publications across six distinct categories (Table 1).

Category	Description	Main Topics	Why used
AI for Technical Applications and Systems	Focuses on AI applications in technical systems, algorithms, and automation across various industries.	Neural networks, machine learning, AI-driven automation, seismic response prediction.	Groups technical and scientific papers that apply AI in system automation, neural networks, and algorithms for technical fields.
AI for Access and Visitor Experience	Enhances visitor interaction and engagement through AI-driven experiences in cultural institutions.	Virtual museum tours, personalized museum guides, AI for interactive exhibits.	Captures how AI enhances visitor engagement by offering dynamic, immersive, and personalized cultural experiences.
AI for Collection Management and Conservation	Uses AI to manage, preserve, and conserve collections in museums, libraries, and archives.	Digital archiving, artifact restoration, AI for cultural asset management.	Highlights AI's role in preserving cultural heritage, ensuring conservation and efficient management of collections.
AI for Accessibility and Inclusion	Aims to ensure accessibility and inclusion in cultural experiences for people with disabilities.	AI tools for the visually impaired, AI for inclusive museum design, accessibility tools.	Addresses AI tools that break down barriers and improve access for disabled or underrepresented groups.
AI for Marketing and Communication	AI-driven marketing, outreach, and communication to promote cultural institutions and engage audiences.	AI-powered social media marketing, chatbots for audience engagement, promotional campaigns.	Showcases AI's power to drive communication, outreach, and audience engagement strategies in cultural institutions.
AI for Historical Research and Analysis	Application of AI in historical research and analysis of cultural heritage data and archives.	AI for analyzing historical data, AI for heritage research, machine learning in archival studies.	Provides a space for research applying AI to study history, archives, and cultural heritage data.

Table 1: Category description [Source: Own elaboration]

Overall, there is a clear increase in the number of publications over time, indicating a growing interest and adoption of AI technologies in various fields (Fig.4).
In the category of AI for Access and Visitor Experience, there has been a steady rise, suggesting an increasing focus on using AI to enhance visitor interactions within museums and cultural institutions. Similarly, AI for Collection Management and Conservation has seen a significant upward trend, driven by the use of AI for digitizing and preserving collections.
The category of AI for Accessibility and Inclusion also shows growth, reflecting the expanding role of AI in making cultural content more accessible to diverse audiences, including those with disabilities. In the case of AI for Marketing and Communication, the data points to a rise in publications, as institutions increasingly rely on AI to optimize communication strategies and engage with audiences.
AI for Technical Applications and Systems, which covers more advanced and specialized uses of AI in cultural settings, has also shown consistent growth.
Lastly, AI for Historical Research and Analysis, while growing at a slower pace, indicates that the use of AI in analysing large historical datasets is an emerging area of interest.
Together, these trends highlight the diverse ways in which AI is being integrated into cultural sectors, with varying rates of adoption across different categories.

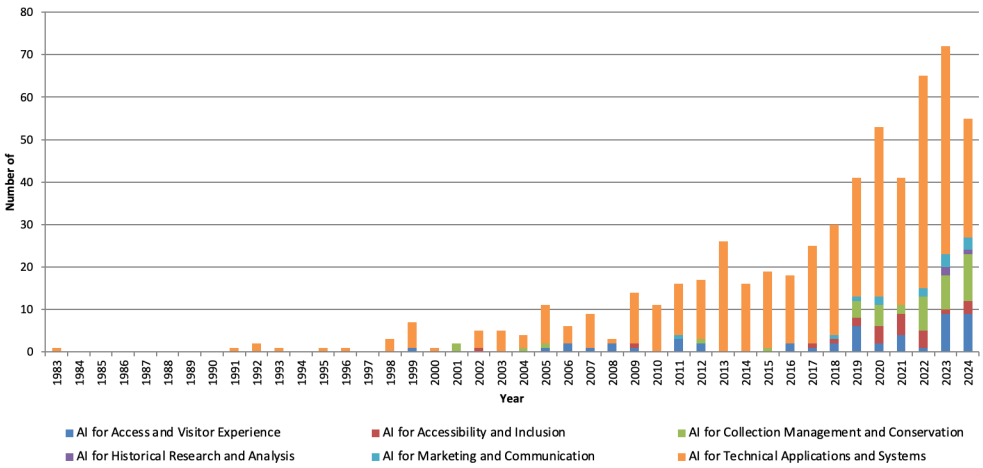

Figure 4: Trends in AI publications [Source: Own elaboration]

An analysis of the 10 most important journals dealing with AI and ML applications in museum research reveals some important findings (Table 2).

Journal	Total number of citations	Total number of publications	Publication year
Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	507	115	2024
Proceedings of the National Conference on Artificial Intelligence	408	3	2015
Virtual Reality	275	1	2010
IEEE Transactions on Pattern Analysis and Machine Intelligence	273	2	2005
Journal of the American Society for Information Science and Technology	114	2	2013
IEEE Transactions on Industrial Informatics	78	1	2019
Tourism Economics	78	1	2019
IEEE Transactions on Learning Technologies	59	1	2016
International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives	59	8	2020
Measurement: Journal of the International Measurement Confederation	59	1	2015

Table 2: The top 10 journals focusing on AI applications in museums [Source: Own elaboration]

Lecture Notes in Computer Science (LNCS) emerges as the dominant platform, leading not only in the total number of citations but also in the number of publications. This emphasises its great influence in interdisciplinary fields where AI

applications in museums are extensively researched. The 'Proceedings of the National Conference on Artificial Intelligence (AAAI)' ranks second in total citations, despite having only three publications. This emphasises the significant impact that conference papers can have in the AI research community, where even a small number of highly influential papers can shape the discourse.

The presence of virtual reality in the list, with only one publication but a high number of citations, indicates that immersive technologies play a crucial role in museums and that the application of AI in virtual reality has attracted a lot of attention. In addition, journals such as the 'IEEE Transactions on Pattern Analysis and Machine Intelligence' and the 'Journal of the American Society for Information Science and Technology', although containing older publications, continue to make an important contribution to the field, suggesting that some foundational research from earlier years is still highly relevant today.

Overall, the data shows that both academic journals and major conferences are instrumental in advancing AI and Machine Learning research in museums. While some venues publish a larger number of papers, others are characterised by the high impact of a smaller number of articles. This reflects the diverse ways in which AI is being integrated into museum research, from basic engineering studies to innovative applications in digital and immersive technologies.

The PCA visualisation (Fig. 5) shows the relationships between AI and museum-related keywords, with the keywords distributed across two main dimensions. These dimensions represent the underlying structures in the data and help us understand how different AI concepts are related to topics in museums.

This representation can help to identify clusters of keywords that occur frequently in publications and indicate thematic relationships.

The two dimensions resulting from the PCA represent latent components that summarise the correlations between the keywords in the data related to Artificial Intelligence and museums. These dimensions are interpreted as follows:

Dimension 1: It represents the primary component, that is, the direction in which the greatest variation is observed in the data. In this case, it reflects the association between more general concepts related to Artificial Intelligence (e.g. 'artificial intelligence',' 'deep learning',' 'AI technologies') and their application in the context of museums or cultural heritage (e.g. 'digital heritage',' 'museum'). It is more focussed on general topics of museums and cultural heritage with the influence of AI.

Dimension 2: This is the second direction of variation, orthogonal to the first. This dimension highlights more specific differences, such as practical applications of AI in museums (e.g. '3D museum',' 'virtual museum') compared to theoretical or technological aspects of Artificial Intelligence (e.g. 'AI agent',' 'convolutional neural networks'). It focuses more on digital applications and virtual interactions in the museum setting.

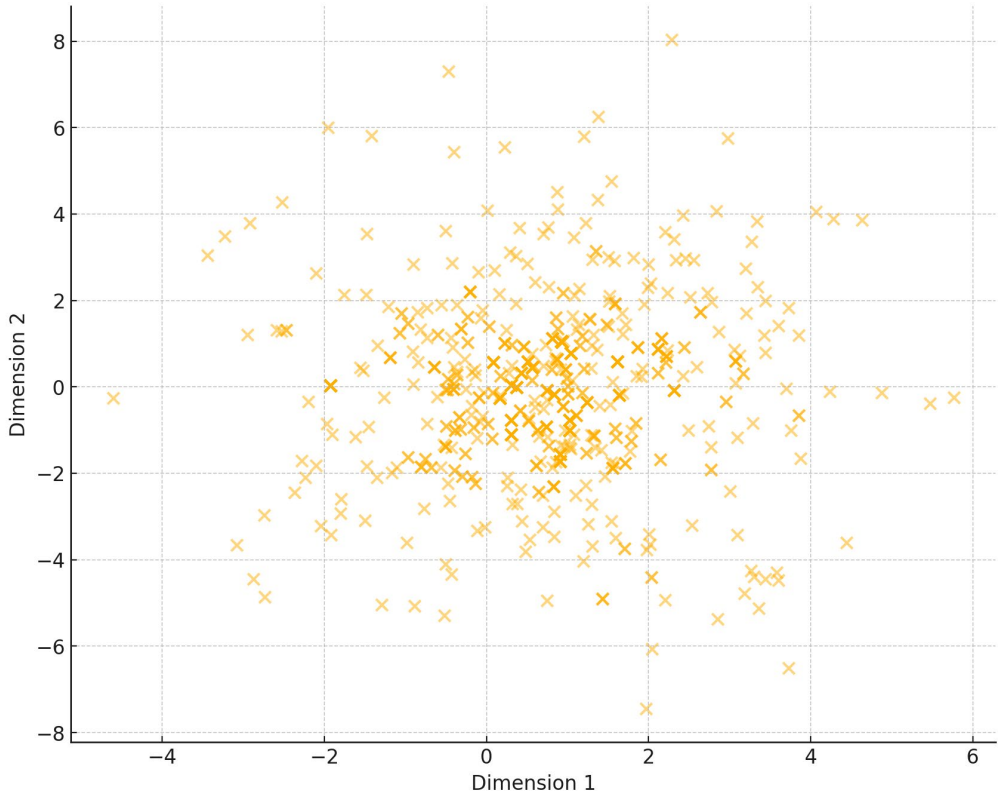

Figure 5: PCA of AI and Museum-Related Keywords [Source: Own elaboration]

Every dimension represents a 'synthesis' of the concepts addressed in the documents and allows us to visualise how the keywords relate to each other.
Keywords that are closer together in the space of the two dimensions are more closely related or more likely to occur together in the documents analysed.
Based on the PCA results, keyword clusters can be formed to identify groups of related terms that frequently occur together (Fig. 6).
One method is to apply a clustering algorithm, such as k-means clustering, to the PCA-transformed data to group similar keywords. These clusters can then be visualised on the PCA graph to obtain a better understanding of the relationships between the keywords.

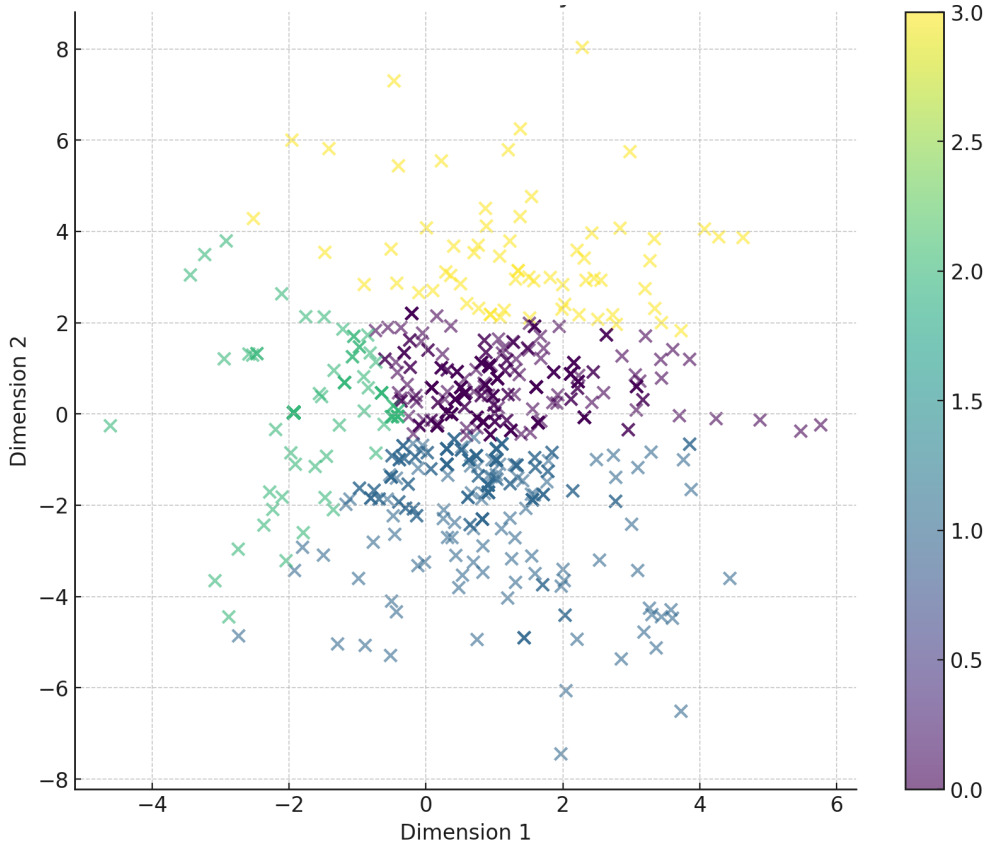

Figure 6: PCA of AI and Museum-Related Keywords with Clusters [Source: Own elaboration]

The PCA representation now shows clusters of keywords that are colour coded based on the k-means clustering algorithm. The clusters highlight different topics in the intersection of AI and museum research, from technical AI methods to cultural heritage applications and theoretical discourses.

The first cluster, represented by purple in the plot (with values close to 0 on the colour scale), focuses heavily on AI technologies and computational methods, particularly on terms such as 'neural network,' 'deep learning,' and 'AI.' This group reflects research that focuses on the technical aspects of AI and emphasizes the development and application of machine learning algorithms. In this context, AI serves as a powerful tool for processing large amounts of data, automating tasks, and performing analyses in museums. Researchers in this cluster are expected to investigate how cutting-edge computing technologies can support museum activities, such as cataloguing collections or analysing visitor interactions with exhibits.

The second cluster, shown in teal/green (with values ranging from 0.5 to 1.5 on the colour scale), revolves around the practical application of AI in preservation, with the use of digital technologies and analysis of physical artefacts. Keywords such as '3D printing,' 'cat mummy,' and 'computed tomography' indicate that this group is

concerned with technological tools for the study and preservation of cultural heritage. This cluster reflects a more practical approach to AI in museums and focuses on the use of technology to reconstruct, preserve, and digitally analysed artefacts. For example, 3D printing and imaging techniques are used to create detailed replicas or models of museum objects, while AI algorithms can be used to analyse these models for research or conservation purposes. This area of research is crucial for preserving historical objects that are too fragile to handle, enabling museums to provide access to their collections in new and innovative ways.

The third group, represented by light blue in the plot (with values between 1 and 2), has a more theoretical focus, with keywords such as 'artificial intelligence,' 'consciousness,' and 'Damasio' indicating a connection to cognitive sciences and philosophical discussions. This group is likely to investigate the impact of AI on the understanding of human cognition and perception, possibly in relation to the way visitors experience museums. By linking AI to concepts such as consciousness, this group may be exploring how AI systems can simulate or interact with human mental processes. It proposes an interdisciplinary approach that combines AI with cognitive theories and raises broader questions about the role of AI in interpreting, enhancing, or even replicating aspects of human cognition.

The last set of topics, marked by yellow in the plot (with values around 2 to 3), is focused on immersive and interactive technologies in museums. Keywords like 'extended reality,' 'large-scale language models,' and 'virtual museum' indicate that this group is dedicated to transforming and enriching visitor experiences through the implementation of AI-based solutions. This cluster highlights the growing use of Augmented Reality (AR), Virtual Reality (VR), and AI-driven systems to deliver more engaging, personalized, and immersive museum experiences. These innovations allow museums to break through the constraints of physical boundaries and offer virtual tours and interactive exhibitions that can be accessed from anywhere in the world. In addition, large-scale language modelling could be used to create AI-powered guides or interactive narratives that increase visitor engagement and enable more meaningful interactions with museum content.

Overall, the clustering of keywords shows that AI research in museums covers a broad spectrum, ranging from highly technical and algorithmic work to practical applications in digital preservation and theoretical explorations of cognition. The diverse topics represented in these clusters show that AI has a multifaceted role to play in improving museum operations and stimulating new research into how technology can interact with cultural heritage and visitor experiences. These results highlight the increasing significance of AI in defining the future of museums, serving not only to enhance operational efficiency and accessibility but also as a powerful instrument for expanding our insights into human culture and cognition through innovative technological solutions.

3. Discussion

The article discusses the application of Artificial Intelligence (AI) in museums based on a bibliometric analysis of scientific publications and shows how research in this field has grown exponentially in recent decades. Initially, in the 1980s and 1990s, the use of AI in museums was limited, but since 2010 researchers have significantly increased the number of publications and articles about AI-enabled cyber risks., peaking in 2023, with prospects for further growth in 2024. This demonstrates the rising interest in utilizing innovative technologies to enhance and collection management, particularly through advances in AI and digital technologies. Most publications originate from academic conferences, underlining the trend in this field to disseminate scientific discoveries quickly. This approach, typical of rapidly evolving technological fields, suggests that AI in museums is an ever-evolving area where timely sharing of results is critical to development. Geographically, the main research contributions come from China, Italy and the United States, with other European countries such as the United Kingdom, Greece and Germany strongly represented.

China in particular has invested heavily in AI and new technologies and has sought to position itself as a global leader in this field. This commitment is also reflected in the cultural applications of AI, with a strong push towards innovation and modernisation of museums.

Italy, thanks to its rich cultural and artistic heritage, has developed a strong interest in integrating technologies such as AI to preserve, manage and make its collections more accessible. Italian institutions have invested in innovative digitisation and preservation projects in collaboration with the technology sector, making AI an important tool to preserve the rich cultural heritage. The United States, which has a strong technological and academic ecosystem, has also used AI in museums to improve both the visitor experience and the management of collections.

The United Kingdom, Greece and Germany are also strongly represented in the digital humanities due to their first-class academic and museum institutions and a long tradition of innovation. These European countries have managed to harmonise their cultural heritage with technological development, putting their museums at the forefront of testing and implementing AI-based solutions.

The analysis of emerging topics reveals four main areas at the intersection of AI and museums: AI technologies and algorithms, practical applications for the preservation and analysis of artefacts, theoretical approaches to cognition and human experience in museums, and immersive technologies such as augmented and virtual reality. These topics demonstrate the highly interdisciplinary nature of the research, which encompasses areas such as computer science, cultural heritage preservation, cognitive science and human-computer interaction.

The ethical issues on the use of AI in museums remain manifold and are often not sufficiently considered despite the increasing adoption of advanced technologies in the cultural sector. One of the principal critical issues relates to cultural representation and the risk of bias. AI that relies on big data can perpetuate or

reinforce stereotypes if the data it relies on is distorted or reflects cultural biases. This is particularly relevant in museums focused on the representation of minorities or non-Western cultures, where sensitive storytelling is crucial to avoid mystification.

Another issue is accessibility and inclusion. Although AI can facilitate access to museum content, for example through automatic translations or audio descriptions for the visually impaired, there is a risk that some visitor groups may not have access to the necessary technology or feel uncomfortable using it, creating new barriers rather than breaking them down. Intellectual property is also a complex issue, as the use of AI to create or curate exhibitions raises the question of who owns the rights to the works created. If AI creates digital content or reconstructions, how will copyright be handled and who is the rightful owner?

Equally important is the issue of data transparency and control. Museums implementing AI to study visitor behaviour or recommend content must be transparent about their data collection practices. It is essential for visitors to have control over the personal information they provide and to be fully informed about how that data is utilized to improve their experience within the museum. On the workforce side, automation through the use of AI could lead to staff reductions in certain areas, such as tour guides or exhibition curators, raising concerns about job losses and the value of human expertise in a cultural context.

Finally, one of the most sensitive issues is the authenticity of the museum experience. Although AI can be used to recreate historical environments or create interactive exhibits, there is a risk that these artificial reconstructions will gradually replace the direct experience of original works or historical artefacts. This could undermine the uniqueness of the relationship between the visitor and the cultural heritage and reduce the museum to a technologically mediated experience rather than a place of direct contact with art and history.

Museum professionals must thoughtfully address these concerns to ensure that the use of Artificial Intelligence aligns with the ethical principles that underpin the educational, inclusive, and cultural mission of museums.

4. Conclusion

Artificial intelligence is profoundly transforming the museum sector, redefining the relationship between institutions and the public, and offering new ways to experience and manage collections (Bareither, 2023). This revolution is pushing museums towards a more dynamic, inclusive, and sustainable future. However, alongside AI's vast potential, critical issues arise, including privacy, algorithmic bias, and ethical responsibility (Pragya, 2024; Singh & Shah, 2024). The adoption of AI requires careful reflection on how these technologies might impact human rights, dignity, and cultural values within museums.

The intersection of AI and ethics has become an increasingly important topic, especially as museums are adopting AI technologies at a growing pace. The 'AI: A Museum Planning Toolkit' emphasizes the importance of developing ethically robust AI projects, urging institutions to consider the moral and social implications of these applications (Murphy, Villaespesa, 2020). Ethical frameworks are essential to navigate challenges related to bias and accountability, particularly in museum contexts where cultural representation plays a vital role (Maeno, 2021). Museums must also carefully assess the socio-technical aspects of AI to ensure that these technologies do not reinforce existing inequalities or biases (Salo-Pöntinen, 2021).

The responsible adoption of artificial intelligence can not only increase visitor engagement and optimize internal processes, but also ensure that cultural institutions remain relevant and innovative in an increasingly digitalized world. However, to achieve these goals, it is essential that AI use is ethical and effective, preserving the central role of museums as custodians of knowledge and promoters of social inclusion. Ultimately, while AI integration offers exciting opportunities for engagement and education, it necessitates a careful examination of ethical practices to safeguard human dignity and cultural integrity.

Limitations and Further Considerations

Although this study has thoroughly analysed the available literature, the author acknowledges certain limitations.

Firstly, although the bibliometric approach used in this study is widely recognised in the academic field, it may have certain limitations. Although the methodology chosen was appropriate for the aims of this study, other techniques, such as quantitative and qualitative methods, systematic reviews or meta-analyses, could provide a more thorough exploration of the topic.

In addition, Scopus was chosen as the primary database for this study. Although it is considered appropriate for the purpose of the study, further research could benefit from utilising a wider range of sources to improve the overall results.

Finally, the study focussed on research articles, chapters and reviews published in English. Future studies could also examine other types of publications and include articles in other languages to broaden the scope of the research.

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