Visualizing Digital Transformation Research in Museums: A Citespace Analysis

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Abstract	Article Info
Currently, advancements in digital technologies like AI, cloud computing, cloud-network integration, and 5G communication are profoundly reshaping the cultural sector, particularly museums. These innovations offer vast opportunities for upgrading and transforming digital experiences within museums. The digital economy is emerging as a pivotal driver of economic growth and a critical component of the cultural industry's evolution in this new era. Consequently, embracing digital transformation has become indispensable for museums striving towards high-quality development and relevance in today's landscape. This study delves into 432 journal articles sourced from the Web of Science (WoS) database spanning 2004 to 2024. Utilizing the bibliometric software CiteSpace, the analysis identifies research areas, lineage, and hotspots in the digital transformation of museums. Key findings highlight influential authors, institutions, and countries, revealing trends through burst detection of keywords. Since 2021, the primary research hotspots include "technology," "user experience," and "virtual tourism," with the integration of technology and user experience emerging as a prominent trend. However, challenges persist, such as disparities in research distribution and insufficient collaboration between scholars and institutions, posing hurdles for digital transformation research in museums.	

INTRODUCTION

In today's era of digital intelligence driven by technology, industry, and capital, new media technologies like augmented reality, virtual reality, and artificial intelligence are significantly impacting social and cultural development. These technologies are characterized by informatization, digitization, interactivity, immersion, and intelligence (Wang, 2024). The advancement and adoption of digital technology have not only revolutionized how people access and share culture but also opened up new avenues for preserving andn transmitting cultural heritage (Bekele et al., 2018). Museums, crucial for cultural inheritance and display, are now at a crossroads of pressure and opportunity due to digital transformation. Traditional methods of museum exhibitions and visits no longer fully satisfy audience demands, necessitating digital transformation and technological innovation to enhance exhibition effects and visitor experiences (Wang, 2023). Museums are actively embracing these changes to strengthen their role in cultural dissemination (Wang, 2024). "Plan for the Overall Layout of the Construction of Digital China" stresses the need to promote the development of cultural digitization, the in-depth implementation of China's national cultural digitization strategy, the construction of a national cultural big data system, and the formation of a Chinese cultural database. Further enhance the capacity of digital cultural services, create several comprehensive digital cultural display platforms, and accelerate the development of new cultural enterprises, cultural business forms, and cultural consumption patterns (The State Council of the CPC Central Committee, 2023). The American Alliance of Museums proposes to "develop a comprehensive digital strategy" in its 2022-2025 strategic framework (Liao, 2023); Governments and international organizations around the world are also fully supporting the digital transformation process of museums (Xu, 2023).

Digital transformation, alternatively, entails building a thoroughly aware, interconnected, scenario-driven, and intelligent digital environment by extensively deploying next-generation digital technologies. This process aims to effectively replicate and enhance business operations from the physical realm (Tu, 2023). In the context of museums, digital transformation primarily revolves around leveraging technologies such as cloud computing, AI, 5G, blockchain, Internet of Things, and big data. These technologies are instrumental in integrating and innovating museum operations such as collection management, heritage preservation, exhibition design, and social education. The ultimate goal is to explore new management, operational, and service models. To improve the management and operation efficiency, reduce the operation and maintenance costs, enhance the audience experience, etc., so that the museum can obtain greater development capacity and advantages in the interpretation of value, content construction, and innovation and transformation (Shen, 2022). The digital transformation of museums is a long-term systematic process, which embodies different characteristics and names in different technological contexts and development stages. Whether it is informatization, digitization, intellectualization, or digital intelligence, they are all united under the broad concept of "digitalization" (Lin, 2021).

This study employs descriptive research methods and bibliometric analysis using CiteSpace to examine global research publications concerning the "digital transformation of museums." The aim is to analyze the quantity, characteristics, and scope of these publications over the past two decades, identifying key trends and hotspots in digital transformation research within museum contexts. By addressing current research status and challenges in the academic community, the study aims to synthesize core insights and provide valuable references for advancing museum digital transformation practices.

LITERATURE REVIEW

RESEARCH METHODOLOGY:

2.1 Data sources

To study the research hotspots and trends in the digital transformation of museums and to conduct a bibliometric analysis of their related studies. This study analyzed journal articles published in the core collection of the Web of Science (WoS) database between 2004 - 2024 using the bibliometric software CiteSpace. A summary of the data sources and parameters is given in Table 1, and the search included " Museum digital transformation" or "digital museums" or "virtual museums*" or "smart museums" by searching for the title of the article, the abstract, and the author's keywords. This comprehensive search methodology produced an initial total of 933 articles. Subsequent screening procedures such as sifting out duplicates and low relevance literature ultimately retained a sample of 432 valid articles, all of which were strictly limited to peer-reviewed journal articles and

review articles. Conferences, editorials, and books were deliberately omitted from this exclusionary approach. In addition, publications from business journals and conferences were deliberately excluded to maintain a high level of relevance to the subject matter.

Table 1: Summary of Data Source and Parameters

Data source	WOS
Searching period	Jan.2004 to Jun.2024
Searching keywords	"Museum Digital transformation" or "digital museum" or "virtual museum" or "smart museum"
Document types	"Article"; "Review Article"
Language	English
Sample records	432

Source: Developed by the Author

2.2 Research Approach

CiteSpace, a Java-based visualization software for scientific bibliometric analysis, was created by Dr. Chaomei Chen from the School of Information Science and Technology at Redsell University, in partnership with the WISE Laboratory at Dalian University of Technology. Because of its capability to intuitively identify and present comprehensive information from extensive literature, CiteSpace has gained widespread adoption in integrative research across various disciplines in recent years (Chen & Li, 2023). Its main function is to quantitatively analyze the literature in a given field to reveal critical paths and intellectual turning points in the evolution of the discipline. The dataset for this analysis includes basic bibliographic elements such as title, author, abstract, keywords, and citations for each document. The CiteSpace software was employed for extensive analysis, encompassing tasks such as generating keyword clustering maps, national institution co-occurrence maps, tracking citation co-occurrence maps, creating keyword emergence maps, time zone maps, and visualizing the publication trends over time. This study maps the thematic evolution and developmental frontiers of digital transformation in museums (Chen et al., 2015).

The data collected was analyzed using CiteSpace (6.3.R2.) and followed a series of key steps. Firstly, a new project entitled "Museum Digital Transformation" was created and the data was entered in plain text format, including full records and citations. Next, analysis parameters were established, such as time slices (January 2004 to June 2024, 1-year slices), term sources (title, abstract, author keywords, and keywords plus), node types (authors, institutions, countries, keywords, categories, references, cited authors, and cited journals), and selection criteria (top 10 percent), Pruning (explorer and pruning merged networks) and visualization (clustering static views and displaying merged networks). Thirdly, mapping to identify prolific authors, institutions, and countries, as well as common keywords. Calculating the frequency of keywords used in journal articles highlights the research hotspots and cutting-edge areas in the field of digital transformation in museums. Finally, the visualized knowledge graph is adjusted using the control panel to present clear, corresponding results.

RESULTS
3.1 Publications between 2004 and 2024

Figure 1 illustrates the trend in publications related to the digital transformation of museums from 2004 to 2024, based on data from the WOS core database. The number of publications shows a steady increase over this period, notably rising since 2019 and peaking at 68 in 2022. This upward trend may be influenced by the COVID-19 pandemic, which accelerated the digitalization of museums worldwide (ICOM, 2021). During the pandemic, many museums adopted a hybrid exhibition approach combining traditional and digital channels.

This shift allowed for flexible presentation of cultural artifacts, diversification of outreach channels, expansion of audience demographics, and immersive visitor experiences (Tu, 2023). The pandemic has significantly boosted the integration of digital technologies in cultural contexts like museums, influencing long-term strategies and practices in museum digitalization (Xu, 2023).

Figure 1：Number of publications each year from Jan. 2004 to Jun. 2024.
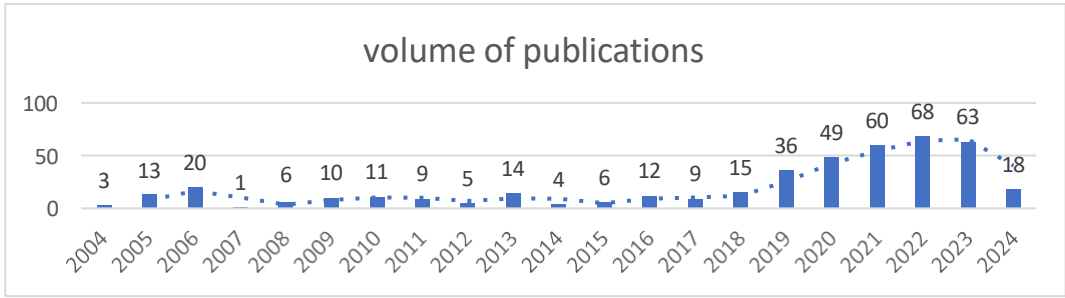
Source: Developed by the Author

3.2 Distribution and Characteristics of Research Institutions

By running Cite Space and selecting the node type as "Institution", Figure 2 shows the knowledge graph of the distribution of institutions engaged in digital transformation research in museums from 2004 to 2024, which further reveals the overall development dynamics of this field. The yellow nodes in the graph represent the source organizations of the research literature related to the digital transformation of museums; the larger the node and the font, the greater the amount of literature issued by the research organization. The connecting line between the nodes indicates that the two research organizations appear in the same article, i.e. the two research organizations have a collaborative relationship. There are a total of 347 nodes in the co-located network knowledge graph of the authors' issuing units in Figure 2, which means that the research literature on the digital transformation of museums involves 347 research institutions and generates 295 connecting lines, indicating that there are a total of 295 collaborations among these research institutions, but the network density of the connecting lines is only 0.0049, which is a relatively small value, suggesting that the network of collaborations is not obvious. It can be seen that the distribution of institutions engaged in research on the digital transformation of museums is relatively dispersed, and communication and cooperation across disciplines and geographical regions need to be strengthened.

Figure 2: Map of institutions that publish research on museums digital transformation
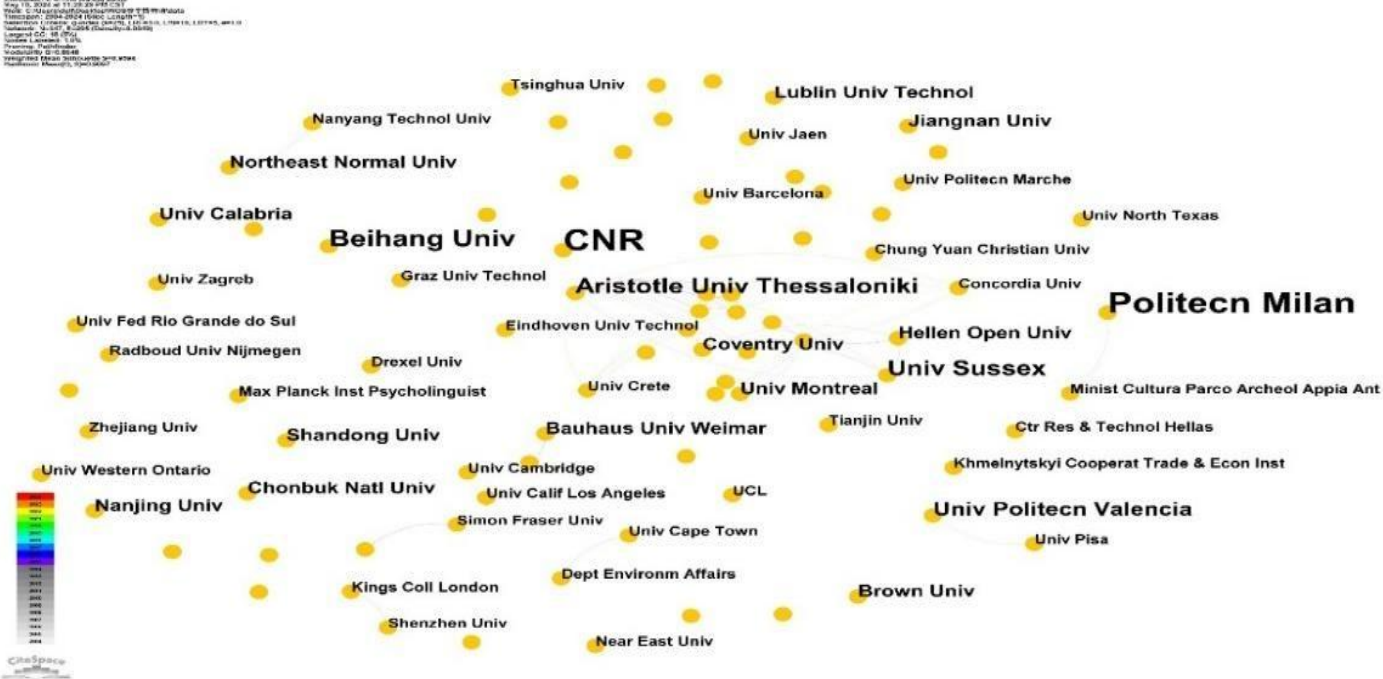

Source: CiteSpace

Table 2 presents the top 6 research organizations based on the frequency of publications related to digital transformation research in museums. Universities dominate these institutions, showcasing a significant level of independent research without extensive collaboration between them. Leading publications are CNR (12%), Politecnico di Milano (11%), and Beihang University (6%). Following closely are Aristotle University of Thessaloniki, University of Sussex, and Universitat Politècnica de València. Currently, universities play a pivotal role in advancing digital transformation research in museums, while museums themselves contribute relatively fewer publications, indicating a need for enhanced scholarly output. Projects related to museum digital transformation primarily involve collaborations with companies and enterprises, focusing on technological integration and digital outputs, highlighting a gap in scientific research in this field.

Table 2: Top 6 Productive Institutions (Frequency ≥ 3).

No.	Frequency	Centrality	Year	Institutions
1	12	0	2010	CNR
2	11	0	2009	Politics Milan
3	6	0	2004	Beihang Univ
4	5	0	2006	Aristotle Univ Thessaloniki
5	5	0	2006	Univ Sussex
6	4	0	2019	Univ Politecn Valencia

Source: Developed by the Author

3.3 National and regional distribution of museum digital transformation research

To comprehensively analyze the current research landscape in museum digital transformation, particularly focusing on country-specific publication trends and collaboration levels, CiteSpace software was utilized. By setting the node type to "country" in the WOS core collection database, the software calculated the number of national publications and mapped the collaborative relationships among countries and regions. Figure 3 illustrates this network map, featuring 65 yellow nodes representing different countries and 54 lines indicating the extent of cooperation and information exchange between them. The network exhibits a low density of 0.026, underscoring the potential for increased research collaboration and cross-border partnerships in this field.

Figure 3: Map of countries'/regions' distribution of publications
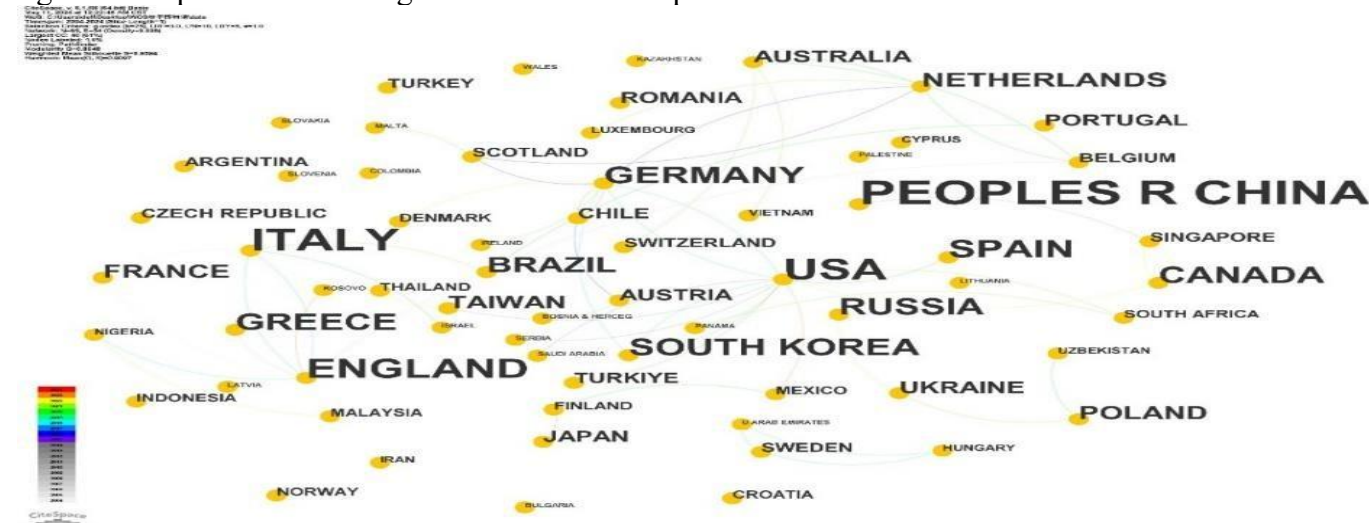
Source: CiteSpace

Based on the analysis of national and regional publication data, Table 3 presents the distribution of the top 10 countries in terms of publications related to the field. Leading publications are China, Italy, and the United

States. China leads with 77 publications, closely followed by Italy with 59, and the United States ranks third with 43 papers. Following these, the United Kingdom and Spain have 33 and 22 publications respectively, showcasing their contributions in this area of research.

Table 3: Top 10 productive regions/countries in the field of digital transformation of museums.

No.	Frequency	Centrality	Year	Country & Region
1	77	0.04	2004	CHINA
2	59	0.13	2004	ITALY
3	43	0.35	2005	USA
4	33	0.18	2004	ENGLAND
5	22	0.00	2005	SPAIN
6	19	0.20	2005	GERMANY
7	19	0.00	2005	SOUTH KOREA
8	18	0.00	2006	GREECE
9	18	0.00	2005	RUSSIA
10	17	0.01	2006	CANADA

Source: Developed by the Author

The concept of "intermediary centrality" is of particular significance in the field of national and regional network analysis. It can serve as a valuable metric for measuring the ability of nodes to connect to other nodes and as a bridge between different groups in the network. Nodes with a high intermediary centrality score, usually between 0 and 1, are particularly important in facilitating the flow of information and identifying key themes and topics in the network. Chen et al. (2010) provide a comprehensive description of this concept and its applications.

It is worth noting that although China ranked first in the number of papers published, it ranked fifth in intermediate centrality in the network mapping analysis of these 10 countries. The United States, on the other hand, ranked third in terms of the number of papers published but ranked first in terms of its intermediate centrality. It can be seen that although China is actively promoting research outputs in relevant areas, there may be room for improvement in its level of influence and interconnectedness in the collaborative network.

3.4 Keyword Distribution of Publications

Keywords serve as concise summaries of an author's research, reflecting the academic focus and direction of their paper, and are crucial for literature inclusion and indexing (Zhao et al., 2016). Analyzing high-frequency keywords can provide insights into research hotspots and directions. Using Citespace 6.3.R2 software, relevant literature data from 2004 to 2024 was analyzed with a yearly time interval. Nodes representing keywords were generated in Figure 4 of the museum digital transformation research literature knowledge graph, totaling 460 nodes. Node size indicates the frequency of keyword occurrence, and connecting lines between nodes signify the co-occurrence of keywords within articles.

Figure 4: Keywords network (from 2004 to 2024)
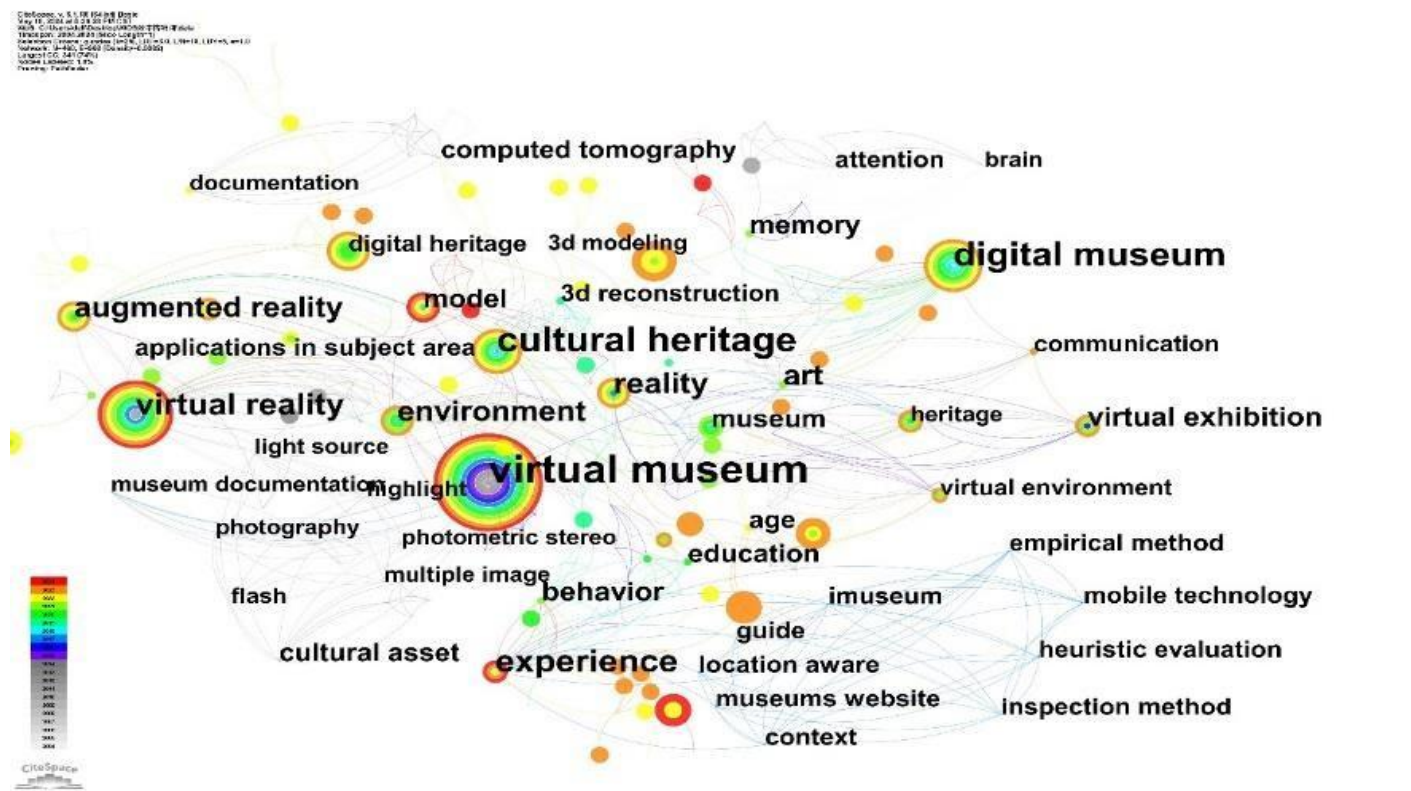
Source: CiteSpace

Keyword co-occurrence analysis identifies intrinsic correlations between keywords when they appear together in research documents, indicating their relationship strength, which grows with higher frequencies (Zhu et al., 2020). Mediated centrality in CiteSpace measures keyword importance, with larger values indicating greater significance (Liu, 2021). Table 4 presents the top 17 high-frequency keywords extracted based on frequency, highlighting those with significant intermediary centrality.

Apart from common terms like "virtual museum" and "digital museum," keywords such as "virtual reality" and "augmented reality" show notable intermediary centrality and high frequency, each appearing more than 30 times with centrality over 0.15. This underscores extensive attention and research outcomes in utilizing virtual reality and augmented reality technologies for museum digital transformation. Other prominent keywords include "cultural heritage," "environment," "digital heritage," "technology," "user experience," "model," "design," and "smart museum." These keywords reflect research hotspots centered on technological applications and user experience, emphasizing practical studies in museum digitization technology.

Table 4: Top 17 keywords in the field of digital transformation in museums.

No.	Frequency	Centrality	Year	Keywords
1	119	0.47	2005	virtual museum
2	52	0.18	2009	virtual reality
3	39	0.22	2006	digital museum
4	33	0.3	2006	augmented reality
5	31	0.24	2006	cultural heritage
6	23	0.21	2009	reality
7	15	0.09	2009	environment

8	14	0.11	2020	digital heritage
9	14	0.04	2021	technology
10	13	0.14	2017	experience
11	13	0.07	2006	model
12	10	0.03	2015	museum
13	10	0.09	2009	virtual exhibition
14	10	0.01	2021	user experience
15	9	0.01	2017	heritage
16	8	0.01	2022	design
17	7	0.06	2021	smart museum

Source: Developed by the Author

Through keyword clustering, Figure 5 depicts the keyword clustering knowledge graph, comprising 460 nodes and 868 connecting lines, with a network density of 0.0082. The clustering module value (Q-value) for this graph is 0.9097, indicating a significant clustering structure—typically, Q > 0.3 suggests strong clustering. Additionally, the average silhouette value (S-value) for the clusters is 0.9594. A silhouette value above 0.7 is considered convincing, while above 0.5 indicates reasonable clustering. Hence, the clustering results are deemed both reasonable and valid (Li & Chen, 2016).

Figure 4: Keyword clustering map
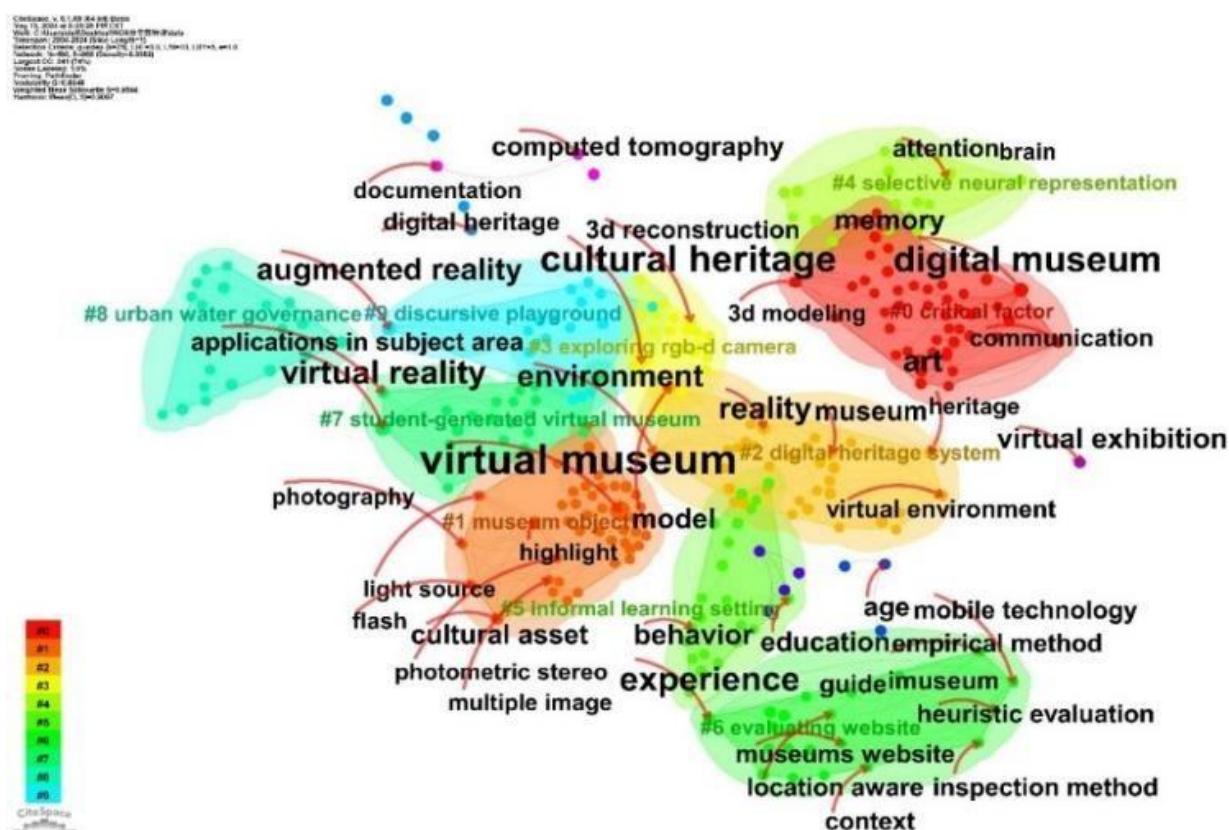
Source: CiteSpace

The clustering labels of the study were extracted in CiteSpace software using the TF* IDF weighting algorithm based on the default auto-tagged words and a timeline mapping of the keywords was generated in the form of a timeline as shown in Fig. 5 for the years 2004 to 2024. To show the characteristics of the distribution of museum digital transformation research over time and the variation and evolution of research themes.

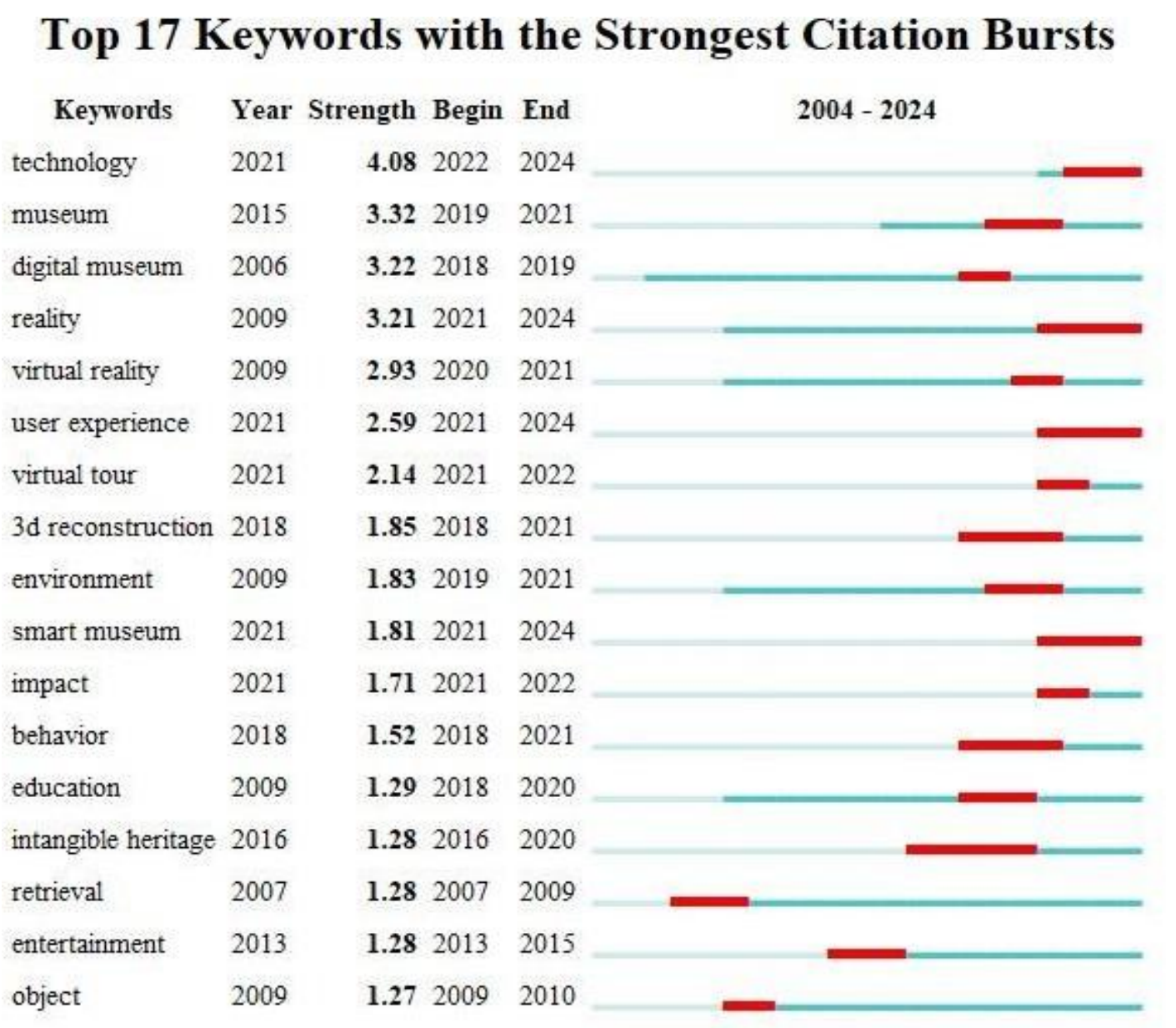Figure 5: Keywords timeline mapping
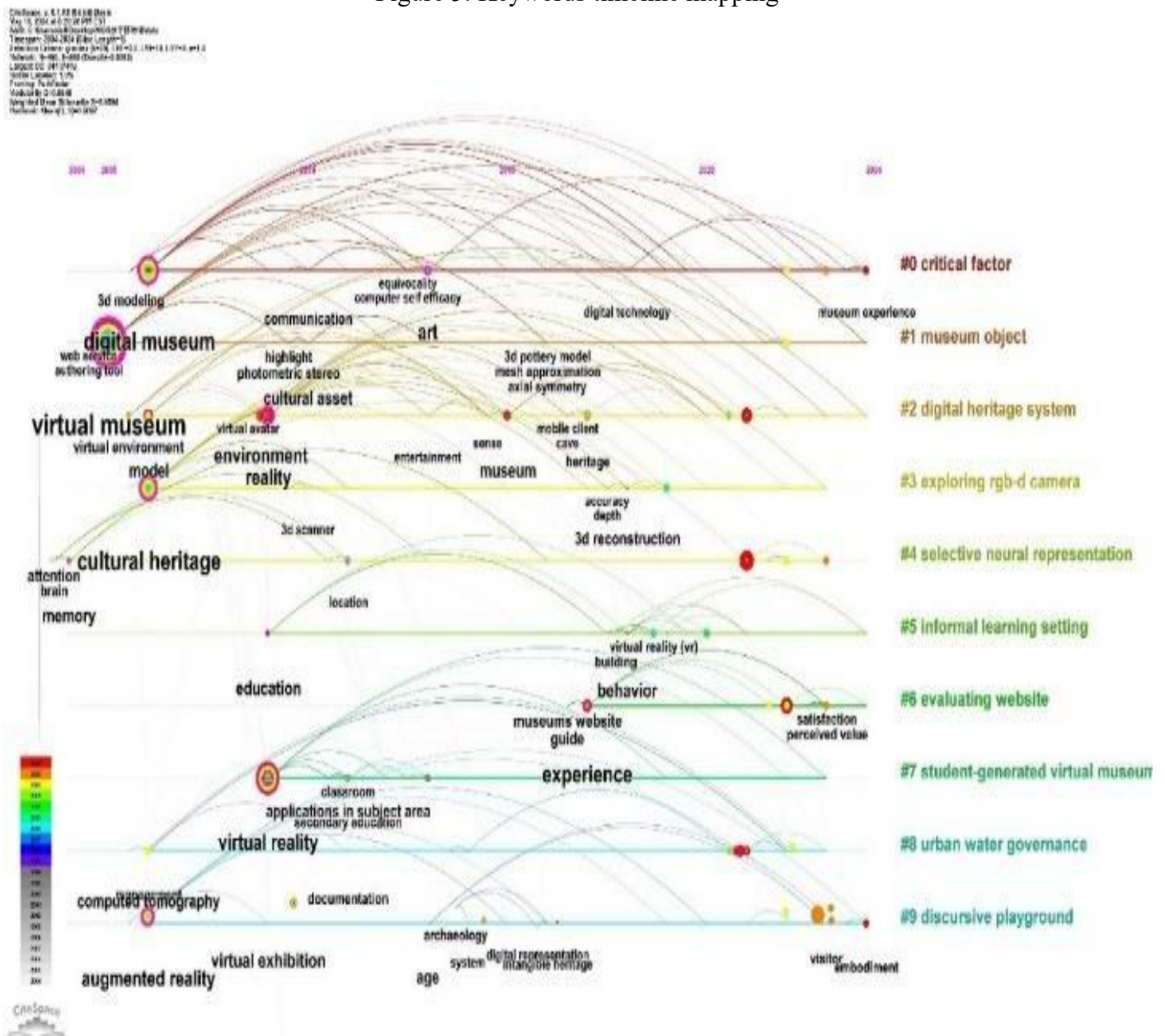
Source: CiteSpace

The emergent word analysis is a visual analysis of sudden outbreaks of hotspots in the research literature, where the appearance of an emergent word means that the keyword has suddenly appeared in large numbers over some time (Li & Chen, 2016). Analyzing emergent words enables us to track shifts in hot topics within the research field over time. By identifying key turning points and new concepts that emerge in specific years, we gain insights into the evolving research trends, prominent issues, and cutting-edge topics in the field (Chen et al., 2023).

Citespace and burst detection algorithms provide the accuracy to identify key terms that experience significant frequency bursts. By scrutinizing these contingencies across the various components of the literature, it is possible to generate insights into the evolving landscape of the research topic, pinpointing noteworthy developments and foci in academic discourse. This nuanced exploration contributes to a more informed

discussion of research trajectories in the area under study. Citespace 6.3.R2. software with a burst detection algorithm (Kleinberg, 2002) was used in this study. This method helps in the clustering of specialized terms, which show a sudden increase in frequency across different literature components (including titles, keywords, abstracts, and other identifiers).

For generalization, this study exclusively considers 432 English papers from the WOS core database for keyword extraction and analysis. Synonymous keyword nodes were merged using a minimum period of 2 years, a state transition value of 0.5, and a state difference ratio of 2. The study identifies the top 17 keywords with the highest highlighting intensity based on these criteria. Figure 6 illustrates the temporal distribution of 17 highlighted keywords spanning from 2004 to 2024, indicating their appearance and duration over time. Among these keywords, "technology" stands out with an intensity of 4.08, maintaining its prominence as a pivotal term in museum digital transformation from 2021 onwards. The concept of "Digital museum" emerged in 2006 and remained a research focus in 2018-2019. "Virtual reality," introduced in 2009, has been a significant research topic since 2020. Similarly, "user experience," noted for its strength of 2.59, continues to be a critical research trend in museum digital transformation from 2021 to the present.

Figure 6 : Top 17 keywords with the strongest citation bursts (from 2004 to 2024)

Top 17 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2004 - 2024
technology	2021	4.08	2022	2024	
museum	2015	3.32	2019	2021	
digital museum	2006	3.22	2018	2019	
reality	2009	3.21	2021	2024	
virtual reality	2009	2.93	2020	2021	
user experience	2021	2.59	2021	2024	
virtual tour	2021	2.14	2021	2022	
3d reconstruction	2018	1.85	2018	2021	
environment	2009	1.83	2019	2021	
smart museum	2021	1.81	2021	2024	
impact	2021	1.71	2021	2022	
behavior	2018	1.52	2018	2021	
education	2009	1.29	2018	2020	
intangible heritage	2016	1.28	2016	2020	
retrieval	2007	1.28	2007	2009	
entertainment	2013	1.28	2013	2015	
object	2009	1.27	2009	2010	

Source: CiteSpace

3.5 Co-authorship network

To gain deeper insights into authors Analysis of knowledge graphs like keyword co-occurrence, timeline, and keyword emergence reveals that research on the digital transformation of museums continues to emphasize the adoption of digital technologies such as virtual reality and augmented reality. However, there is a noticeable shift in focus from technology to enhancing user experience. Future research is anticipated to explore more convenient and human-centered forms of interaction, indicating a new trend in this field (Chen et al., 2023). who have made significant contributions and impact in the digital transformation of museums, correlation analysis among authors was conducted using CiteSpace software. Figure 7 presents the results of the authors' co-citation analysis, depicting 457 nodes and 536 connecting lines with a network density of 0.0051. Each node and font size corresponds to the author's level of activity and publication volume while connecting lines represent collaborative relationships between authors. This visualization allows examination of each author's total publication output, annual publication rate, strength of collaborative ties, and years of collaboration with other authors. As can be seen from Table 5, in recent years, scholars centered on Chen, XW have been remarkably active and productive, with several publications of 5; and Banfi & Fabrizio have published 4 papers. Both in terms of the visual presentation of the maps and in terms of network density, inter-authorship collaboration and frequency of publication show a weak characterization. Only a limited number of simple closed or linear structures are evident, making it challenging to form complex network patterns. Most museum digital transformation researchers engage in independent research, and academics have yet to establish a broad and stable academic research collaboration mechanism, with less sharing and mobility of theoretical and practical results (Liu, 2021).

Figure 7: Co-authorship network
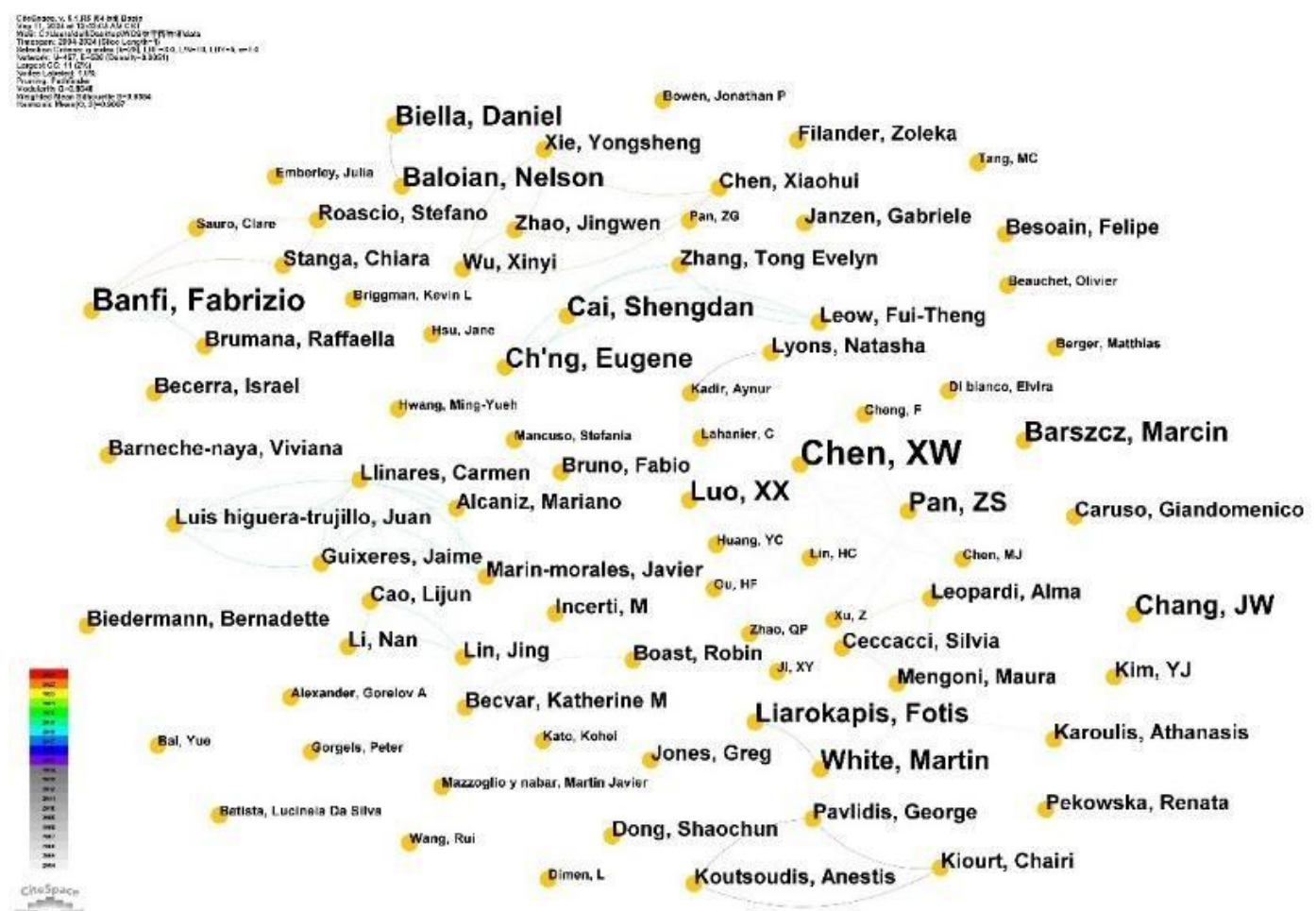
Source: CiteSpace

Table 5: Top 12 Productive authors (Frequency ≥ 3).

No.	Frequency	Year	Author
1	5	2004	Chen, XW
2	4	2019	Banfi, Fabrizio
3	3	2004	Pan, ZS
4	3	2021	Barszcz, Marcin
5	3	2019	Ch'ng, Eugene
6	3	2019	Cai, Shengdan
7	3	2016	Baloian, Nelson
8	3	2004	Luo, XX
9	3	2006	White, Martin
10	3	2016	Biella, Daniel
11	3	2009	Liarokapis, Fotis
12	3	2005	Chang, JW

Source: Developed by the Author

CONCLUSION

In this study, CiteSpace was used to analyze the current status and emerging trends in museum digital transformation research, with a total of 432 papers published between 2004 - 2024. The most productive institutions, countries/regions were identified through time distribution, institution, country, keyword, and author co-citation analysis. In addition, the current research hotspots and cutting-edge trends in the field were identified by generating a keyword network. Based on the econometric analysis of the research literature related to digital transformation in museums, the following findings were made:

First, in the field of digital transformation in museums, the volume of relevant literature from 2004- 2024 shows a general trend of growth, with an overall tendency towards a research peak from 2019 to the present. This trend may be influenced by COVID-19, where the continuous acceleration of museum informatization has further contributed to the digital transformation of museums (ICOM, 2021). The acceleration of the epidemic, the external environment, the maturity of technology, and the accumulation of experience have made digital transformation a general trend and an imminent, and inevitable choice for all museums to face the problem of survival and development (Liao, 2023).

Second, there is a critical need to enhance cooperation and exchanges among countries, regions, and institutions. Analysis reveals that significant research activity in the digital transformation of museums is concentrated in China, Italy, the United States, and the United Kingdom, with the United States notably leading in international collaborations. Research institutions primarily consist of universities, with interactions largely limited to national and regional boundaries or neighboring countries. International exchanges with other institutions are relatively sparse.Museums themselves, as both subjects and objects of digital exploration, often collaborate with enterprises rather than establishing dedicated research teams. There is minimal investment in building scientific research capabilities, with a predominant focus on technical implementation and project outcomes. Looking forward, museums can leverage their unique characteristics to enhance comprehensive planning for digitization projects, increase investment in scientific research capabilities, and establish

professional academic platforms. These efforts aim to foster deeper and broader academic exchanges in museum digitization (Kong & Pei, 2020).

Third, Explore the field of humanization while delving into technical research. In addition to the search terms "virtual museum" and "digital museum", the keywords that appear more frequently are "virtual reality" and "augmented reality"."technology" has continued to be a high-frequency emergent word in the digital transformation of museums since 2021. After analyzing the high-frequency words, emergent words, and highly cited literature, it can be concluded that the research hotspot of digital transformation of museums is dominated by technological research, which is more inclined to the in-depth excavation and enhancement of technology, and at the same time pays attention to the combination of it with other technologies (Liu, 2021), which is the main focus of digital transformation of museums. This includes the diversified integration of augmented reality with virtual reality, mixed reality, 3D modeling, and other technological fields (Chen et al., 2023). Since 2021, the digital transformation of museums has gradually begun to explore the field of "user experience" as the center of human nature, gradually combining technology and user experience, and to a certain extent, reflecting the development trend of this research field, research hot issues.

Fourth, in recent years there has been a proliferation of scholarly activity, with a significant number of authors actively engaged in research in related fields, but most of these are mainly independent studies. Communication and cooperation between authors is also sparse, with no extensive and stable academic research cooperation mechanism established, and less sharing and mobility of theoretical and practical results (Liu, 2021).

The digital transformation of museums has become an inevitable trend for the future development of museums, based on the full digitization of museums, combined with new technologies such as big data, Internet +, artificial intelligence, augmented reality, and other new technologies to achieve the functions of virtual museums and the intelligent protection of collections and digital management of museums (Wang, 2024). At the same time, it combines the digital service function of the museum and the interactive experience of the audience, with the ultimate goal of realizing people-centered public cultural services (Liu, 2021). Combining user experience theory and new digital technology, it enhances the user sensory experience, simplifies the user operation process, and explores the value of museum content, thus realizing efficient dissemination of museum exhibition information and personalized experience (Chen et al., 2023).

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