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RESEARCH ARTICLE

Progress and Trends in Museum Interactive Experience Research: A Bibliometric Visualization Analysis

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ABSTRACT

As museums increasingly shift from collection-centered to visitor-centered value orientations, museum interactive experience has progressively transformed from isolated, fixed, and linear narratives to participatory, immersive, and inclusive multidimensional narratives. This study employs bibliometric visualization analysis to conduct a comprehensive review of the relevant literature on museum interactive experience within the Web of Science Core Collection database, uncovering research advancements, hotspots, and evolving trends in the field. The findings indicate a continuous increase in interest within this field, accompanied by frequent collaborations across regions. Furthermore, the development of this area has progressed through three stages: Technical Exploration and Basic Experience (before 2015), Application Deepening and Enhanced Experience (2015 to 2020), and Digitalization and In-Depth Experience (2020 to 2024). This progression underscores the ongoing optimization of visitor experiences and the exploration of new technological potentials, reflecting a visitor-centered concept. Future research trends in this field are anticipated to evolve towards highly digitalized and immersive technology-driven deep experiences. This study contributes by offering researchers a comprehensive understanding of this field and providing reference materials to support the reconstruction and innovation of knowledge in this area.

INTRODUCTION

The International Council of Museums (ICOM) defines a museum as a non-profit institution that researches, collects, conserves, interprets, and exhibits tangible and intangible heritage[1]. However, as museums increasingly shift from collection-centered to visitor-centered value orientations, new challenges and missions have emerged for museum interactive experience[2, 3]. The development of new technologies and evolving visitor expectations are driving this transition from isolated, fixed, and linear narratives to participatory, immersive, and inclusive multidimensional storytelling[4-6]. This transformation in interactive experience paradigms has enabled the dissemination of collection information to transcend the sensory limitations of static displays and traditional interactive forms, achieving digital and intelligent presentations that go beyond physical boundaries[7, 8]. Concurrently, the role of visitors has evolved from passive recipients and observers to active participants and leaders[9, 10].

The museum encourages visitors to actively explore and access information about the collections through immersive experiences and interactive narratives[11]. This approach redefines the roles of both the collection and the visitor, shifting from a traditional relationship of "viewed" and "viewer" to one that integrates entertainment, learning, and experience[10, 12]. The museum is no longer a "mausoleum of objects", and visitors are no longer "silent readers in a library"[9, 11]. Research indicates that multi-sensory interactive experiences significantly enhance visitor engagement and learning, contributing to emotional responses and long-term memory retention[10, 13-15].

Compared to basic interactions, those that leverage new technologies are more engaging and facilitate the acquisition of relevant concepts and cultural information during interactions with the exhibits[16-18]. Additionally, visitors show greater interest in immersive experiences facilitated by interactive narratives[19, 20]. Such interactive technologies can promote meaningful informal learning alongside entertainment, thereby attracting the interest of younger visitors and mitigating the negative perceptions that adult visitors may have regarding museum interactive experiences[21-23].

In recent times, the ongoing evolution of technology and concepts has significantly expanded the boundaries of knowledge in this field[24]. The innovative use of technologies like artificial intelligence (AI)[25], extended reality (XR)[26], and humanoid robots[27], along with concepts and methodologies like gamification design[28], accessibility design[29], multi-sensory experiences[30], and participatory design[31] in museums, have clearly demonstrated the vast developmental potential of this area. Despite the rapid growth in research output, there remains a notable deficiency of systematic review studies, particularly those that provide a comprehensive overview of the dynamic development processes and trends across the entire research landscape. This gap may hinder researchers and museum professionals from fully understanding the present condition and future trajectory of the field, subsequently affecting the evaluation of research priorities and trends. Furthermore, museum interactive experience research encompasses the intersection and integration of multiple disciplines and methodologies[32]. However, existing research frequently adopts a single-disciplinary perspective, which, to some extent, impedes broader academic exchange and dissemination. Consequently, bibliometric research in this domain is highly warranted.

This study aims to establish a comprehensive academic framework for museum interactive experience research through bibliometric visualization analysis. It reveals the research progress, key hotspots, and evolving trends within the discipline. Furthermore, the research seeks to bridge knowledge gaps across various fields and promote international knowledge sharing and innovative development. This interdisciplinary integration will enable researchers and museum practitioners to gain a holistic understanding of the field from a macro perspective, thereby providing robust guidance and reference for both practical applications and theoretical advancements.

2. MATERIALS AND METHODS

2.1 Data sources

The research data for this study is sourced from the Web of Science Core Collection database, which is one of the most influential and authoritative academic resources globally, and is commonly utilized for bibliometric analysis across specific knowledge domains[33]. The Web of Science Core Collection encompasses multiple disciplines and includes high-quality academic papers, thereby ensuring the authority and comprehensiveness of the research data[34]. This database offers detailed citation data, including citation frequencies and reference lists, which supports complex citation network analysis and trend studies, thereby providing essential foundational data for bibliometric analysis[35].

2.2 Data retrieval strategy

In the data collection process, a detailed structured search strategy was formulated based on the research topic and objectives. The search query employed was: TS==(museum OR museums) AND TS=("interactive experience*" OR "interaction experience*" OR "user experience*" OR "visitor experience*" OR "customer experience*" OR "digital experience*" OR "immersive experience*" OR "human-computer interaction*"). The search was conducted in English, with the timeframe restricted to publications between January 1, 1998, and June 20, 2024. The inclusion criteria focused on articles and proceeding papers relevant to the search terms, while letters, newsletters, book reviews, and similar documents were excluded. After data cleaning, organization, and analysis, duplicates and irrelevant data were removed, ensuring the accuracy and completeness of the data. This process resulted in a dataset of 683 articles related to the topic, which formed the basis for the analysis. The specific retrieval process is illustrated in Figure 1.

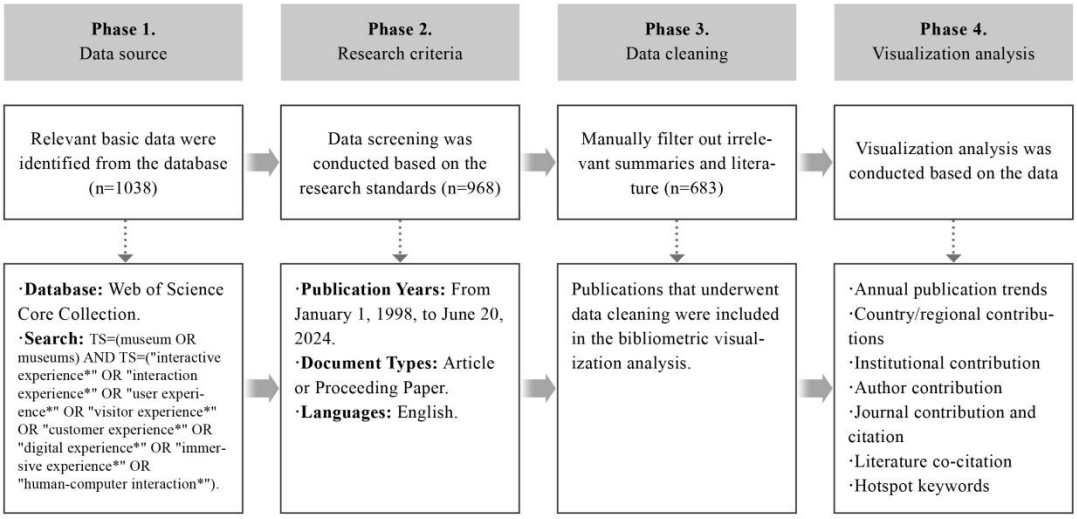

Figure 1: Retrieval process diagram.

2.3 Research methodology

Bibliometrics is a scientific discipline that systematically studies literature and related phenomena through quantitative methods. At its core, bibliometrics employs statistical and mathematical analysis techniques to elucidate the quantitative characteristics, distribution patterns, and dynamic changes in literature[36]. The primary subjects of bibliometric research encompass various types of literary resources, including journal articles, patents, and books[37]. By conducting quantitative analyses of elements such as citations, authors, institutions, and journals, bibliometrics can assess the impact of scientific research, uncover trends in the development of disciplines, identify research hotspots, and evaluate the academic performance of research institutions and individual researchers[38]. Currently, commonly used bibliometric analysis software includes VOSviewer, CiteSpace, BibExcel, HistCite, Pajek, and Gephi. These tools facilitate the management of literature data and enhance the efficiency of scientific research evaluation through quantitative analysis and visualization techniques[39].

This study employs VOSviewer 1.6.18 (Centre for Science and Technology Studies, Leiden University, The Netherlands), Scimago Graphica 1.0.35 (https://www.graphica.app/, USA), and the chorddiag R package to construct a Co-occurrence Analysis Map of Country/Region Collaboration Relationships, along with corresponding chord diagrams. Specifically, VOSviewer 1.6.18 and Pajek 64 5.16 (University of Ljubljana, Slovenia) are utilized to analyze the co-occurrence and temporal changes among countries/regions, institutions, authors, journals, and prominent keywords. In the visualizations produced by these software tools, circles and text labels denote nodes, with the size of the nodes represented by the diameter of the circles. Different colors signify distinct clusters, while the lines connecting the nodes illustrate co-occurrence relationships, with the thickness of these lines reflecting the strength of the relationships.

Additionally, this study employs CiteSpace 6.3.R1 (Chaomei Chen, China) to conduct a visualization analysis of co-cited references and keywords, generating relevant maps. In the co-citation analysis map, the CiteSpace parameters are set as follows: time slicing (1998-2024), years per slice (1), and selection criteria (k=25). Different circles represent various co-cited references, with the size of each circle proportional to the number of citations the publication has received. The lines connecting the circles indicate co-citation relationships, while the size and color of the rings within each circle reflect the number of citations and the corresponding time period. For the timeline analysis of clustered hot keyword frequencies, the CiteSpace parameters are set as follows: time slicing (1998-2024), years per slice (1), and selection criteria (k=15).

The application of these methods and tools ensures the comprehensiveness and precision of the data analysis in this study, providing a reliable basis for revealing research progress and trends in this field.

3. RESULTS

3.1 Analysis of annual publication trends

Analyzing annual publication trends is essential for understanding the developmental history and research dynamics within this field[40]. Based on an analysis of publications related to museum interactive experience from January 1, 1998, to June 20, 2024, a total of 683 papers were published, resulting in an average annual publication rate of 25.30 papers. As illustrated in Figure 2, the number of publications per year during the 1998-2024 period demonstrates cyclical fluctuations, with an overall upward trend. This publication trend can be categorized into three main phases.

Initial stage (1998-2008)

From 1998 to 2008, the annual publication volume concerning museum interactive experience remained relatively low, with no more than seven papers published each year. This period marks the nascent stage of research, during which the concepts of interaction and experience in museums were still in an exploratory phase. The academic community exhibited limited interest in this topic, and research activities were notably scattered.

Preliminary growth stage (2009-2014)

Between 2009 and 2014, there was a steady increase in the annual publication volume, which rose from 11 papers in 2009 to 21 papers in 2014. This period witnessed a growing academic interest in museum interactive experience, driven by advancements in digital media and interactive technologies. Research during this time became more systematic, and the number of academic activities and conferences related to this theme increased, further contributing to the rising prominence of this field.

Rapid development stage (2015-2024)

From 2015 to 2024, the annual publication volume on museum interactive experience experienced significant growth. Notably, the years 2017 and 2018 recorded 62 and 63 published papers, respectively, while 2023 reached a historic high with 82 papers. This period signifies the rapid expansion and maturation of the research field. The growth has been driven by the adoption of immersive technologies, such as virtual reality and augmented reality, alongside the increasing demand for interactive experiences from museum visitors. These factors have catalyzed deeper and more diverse research, fostering robust development within the field.

In terms of cumulative publication volume, the overall trend demonstrates exponential growth, represented by the trendline equation $y = 4.4759e^{0.1972x}$. The coefficient of determination, $R^2 = 0.9904$, indicates an excellent fit. This suggests that the research content on museum interactive experience has gradually expanded over time, reflecting stable and continuous development in this area.

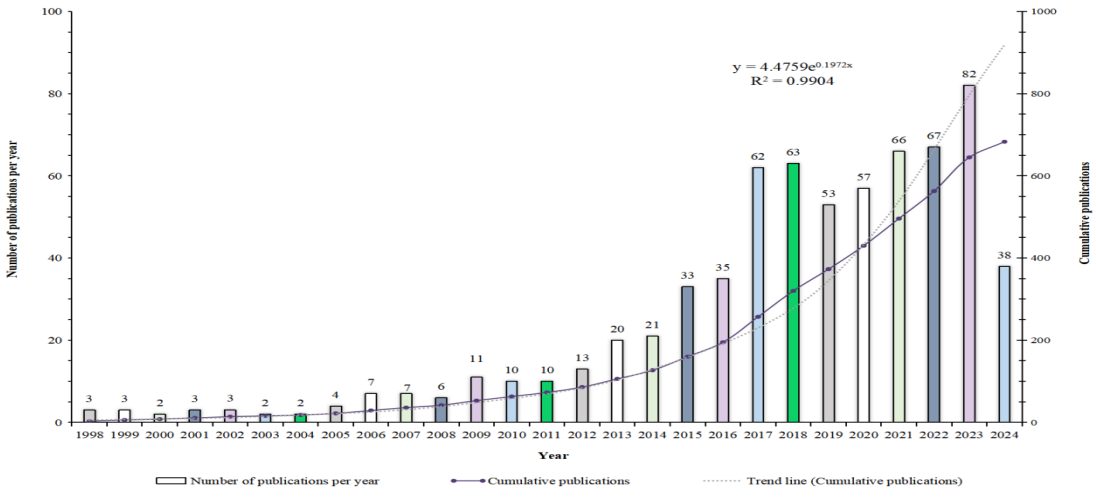

Figure 2: Trend analysis of publication volume

3.2 Analysis of country/regional contributions

Analyzing contributions by country and region enhances our understanding of geographical distribution, collaboration patterns, and evolving trends within this field, thereby providing researchers with a comprehensive international perspective[41]. Research on museum interactive experience encompasses 71 countries and regions worldwide. This study employed VOSviewer software to establish a minimum publication threshold of three papers per country or region, resulting in the global distribution map illustrated in Figure 3(A). The connections depicted in the figure represent collaborative relationships between countries, with the thickness and color of the lines denoting the strength of these collaborations. Darker colors and thicker lines indicate closer cooperative relationships.

Figure 3(A) illustrates that China leads with the highest number of published papers, totaling 149, which accounts for 21.8% of the overall publications. Following China, Italy and the United Kingdom have published 112 and 76 papers, respectively, representing 16.4% and 11.1%. These figures underscore the significant contributions of these countries to the field. The data further indicate that China, Italy, the United States, and the United Kingdom are the primary collaborators in this area. Additionally, European and Asian countries, such as Portugal and Japan, have made notable contributions and established collaborative relationships, reflecting the current landscape of international cooperation. The influence of these nations is largely attributed to their rich historical and cultural backgrounds, as well as support from national policies that promote the digital preservation of museums and cultural heritage. For instance, China's establishment of the Asian Cultural Heritage Protection Alliance in 2023 and the European Union's Horizon 2020 program have both advanced the development of museum interactive experience through sustainable development and capacity building[10, 42].

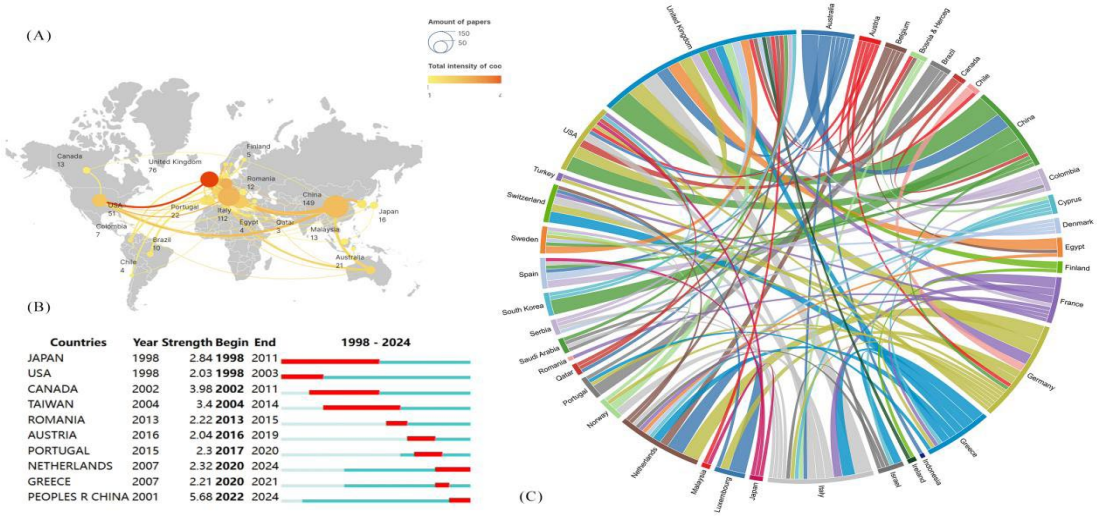

Figure 3: (A) Global distribution map of research on museum interactive experience; (B) Top 10 countries with the strongest citation bursts (blue bars indicate citation period, red bars indicate citation burst period); (C) Chord diagram of country collaborations.

Citation bursts refer to the phenomenon in which a country's academic achievements receive a significant number of citations within a specific timeframe, often reflecting that country's influence in global scientific research[43]. Figure 3(B) illustrates the top ten countries ranked by citation burst intensity from 1998 to 2024. Notably, since 2022, China has maintained a leading position with a citation burst intensity of 5.68, underscoring its substantial international influence in scientific research. This data not only enhances our understanding of the level of research activity in this field across various countries but also provides an international and dynamic perspective on museum interactive experience.

This study utilized the chorddiag R package to perform a visualization analysis of international and regional research collaborations within this field, resulting in the chord diagram presented in Figure 3(C). In the chord diagram, each segment of the outer arc represents a country or region, and the width of the connecting lines indicates the intensity of collaboration among these entities. As

illustrated in Figure 3(C), the United Kingdom exhibits the highest total link strength, indicating a strong inclination to collaborate with other countries or regions. Among all international partnerships, the collaboration between the United Kingdom and China ranks first in terms of strength, suggesting that these two countries engage in the most frequent and close collaborations. Following China, Germany and Italy demonstrate the next strongest collaborative ties with the United Kingdom.

The above analysis enhances our understanding of the international collaboration patterns in museum interactive experience research by identifying the key contributing countries and their collaborators. These findings not only illuminate the current research landscape but also offer valuable insights for promoting international cooperation and exchange.

3.3 Analysis of institutional contribution

By analyzing the collaborative relationships among various institutions, the network structure of scientific collaboration can be elucidated, enabling researchers to identify which institutions occupy central or key roles in specific research fields[43]. This study employed VOSviewer to perform a visualization analysis of the publication output from these institutions. The data indicate that a total of 780 institutions have published 683 articles pertaining to museum interactive experience. By establishing a minimum publication threshold of two articles per institution, a co-occurrence map illustrating institutional publications and collaborations was generated, as depicted in Figure 4.

As illustrated in Figure 4, the circles and accompanying text represent individual institutions, while the connecting lines between these circles indicate collaborative co-occurrences among them. The thickness of these lines reflects the strength of the collaboration. Politecnico di Milano leads the field with 16 articles, representing 2.34% of all publications. The Consiglio Nazionale delle Ricerche (CNR) follows closely, contributing 15 articles, which make up 2.20% of the total. The University of the Aegean and Zhejiang University have published 12 and 10 articles, respectively, representing 1.76% and 1.46% of the total. The active contributions of these institutions underscore their significant roles within this research domain.

The University of the Aegean exhibits the highest total link strength, signifying its strongest inclination to collaborate with other institutions. The institution with which it collaborates most frequently is the Ionian University. Among all institutional partnerships, the collaboration between Eindhoven University of Technology and the University of Luxembourg ranks first in collaboration strength, indicating the closest relationship between these two institutions. Marche Polytechnic University boasts the highest total citation count, reaching 425 citations, while Curtin University leads in average citations per paper, with 135.67 citations.

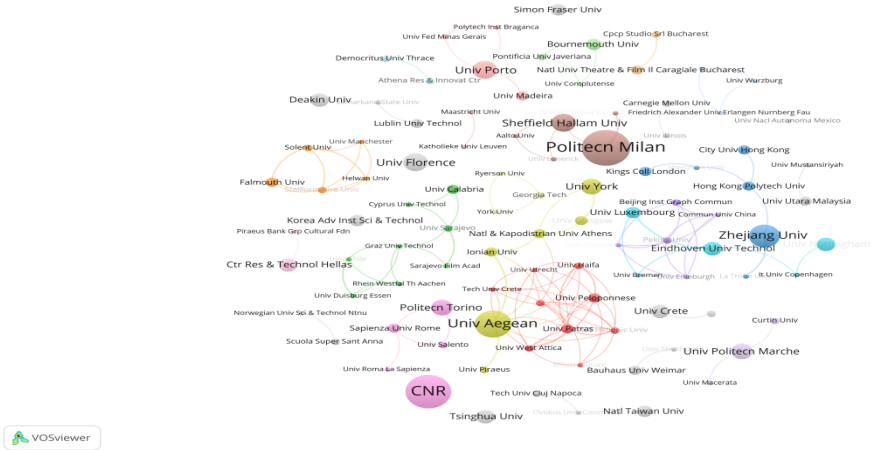

Figure 4: Institutional publication and collaboration co-occurrence.

This study employs CiteSpace to analyze the top ten institutions exhibiting the strongest citation bursts from 1998 to 2024, as illustrated in Figure 5. These institutions demonstrated a notable increase in research activity during specific periods. Leading the list is the Consiglio Nazionale delle Ricerche, which recorded a citation burst strength of 4.19 from 2014 to 2016. Following closely is the Istituto per le Tecnologie Applicate ai Beni Culturali, with a citation burst strength of 4.01 from

2014 to 2017. Ranked third is the Universidade do Porto, which achieved a citation burst strength of 3.52 from 2017 to 2019. These findings underscore the significant contributions made by these institutions in the field.

Institutions	Year	Strength	Begin	End	1998 - 2024
Simon Fraser University	2005	2.88	2005	2011	
University of Bologna	2012	1.89	2012	2013	
Natl Univ Theatre & Film IL Caragiale Bucharest	2013	2.13	2013	2015	
Consiglio Nazionale delle Ricerche (CNR)	2000	4.19	2014	2016	
Istituto per le Tecnologie Applicate ai Beni Culturali (ITABC-CNR)	2014	4.01	2014	2017	
Universidade do Porto	2017	3.52	2017	2019	
Korea Advanced Institute of Science & Technology (KAIST)	2019	1.97	2019	2022	
University of Aegean	2007	2.82	2020	2022	
Egyptian Knowledge Bank (EKB)	2020	2.2	2020	2021	
University of Luxembourg	2022	2.04	2022	2024	

Figure 5: Top 10 institutions with the Citation Bursts.

3.4 Analysis of author contribution

Author contribution analysis is vital for identifying key researchers within a specific field. These core researchers are frequently leaders and innovators; therefore, understanding their research outputs is crucial for keeping up with the most recent advancements[44]. In the domain of museum interactive experience, a total of 2,190 authors have published 683 related research papers. By establishing a minimum publication threshold of three papers per author, a collaboration network among these authors was generated, as illustrated in Figure 6.

In Figure 6, each node consists of a circle and a text label, with different colors representing clusters of various research themes. Koutsabasis, Panayiotis exhibits the highest total link strength, indicating that this author demonstrates the strongest willingness to collaborate and the highest frequency of collaboration with other authors. The most frequent collaborator with Koutsabasis is Vosinakis, Spyros. The thickness of the lines connecting the circles represents the strength of collaboration between authors, with the partnership between Cesario, Vanessa and Nisi, Valentina being the strongest, thereby highlighting their close working relationship. The circle size directly corresponds to the number of publications by each author. Cesario, Vanessa has the highest number of publications, totaling 11 papers, while Nisi, Valentina and Pietroni, Eva are tied for second place, each with 10 papers. This analysis not only identifies key contributors in the field but also elucidates their collaboration patterns, providing empirical support for the formulation of research collaborations and future research directions.

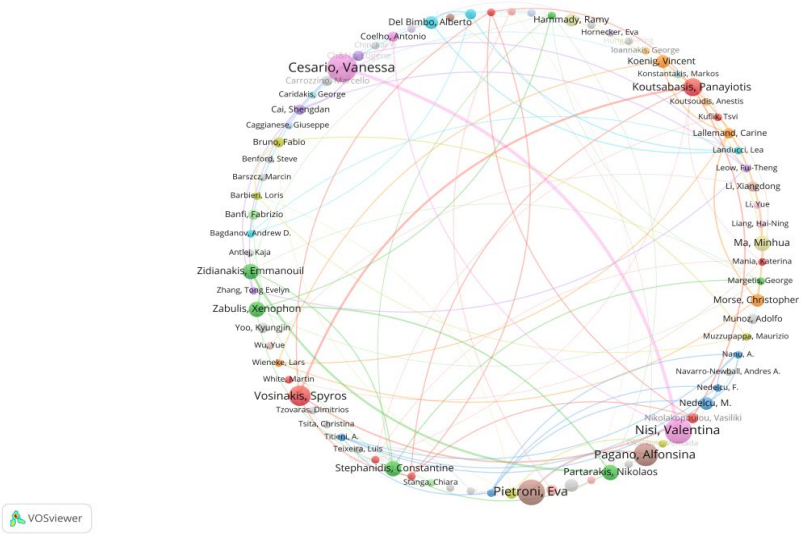

Figure 6: Author collaboration network.

Citation bursts serve as critical indicators for assessing the frequency and impact of citations within a research field. In this study, CiteSpace software was utilized to identify the top 10 authors exhibiting citation bursts, as illustrated in Figure 7. The findings reveal that Pagano, Alfonsina ranked first,

achieving a burst strength of 3.37 during the period from 2015 to 2016, which reflects the significant attention their research garnered during this timeframe. Following closely are Cesario, Vanessa and Nisi, Valentina, with burst strengths of 3.08 and 2.74, respectively, during the period from 2017 to 2019. From a temporal perspective, the majority of authors' citation bursts are concentrated after 2010, particularly Koenig, Vincent and Morse, Christopher, whose citation bursts occurred between 2022 and 2024, each demonstrating a burst strength of 2.24, which underscores the impact of their recent research.

Figure 7: Top 10 authors with the citation bursts.

3.5 Analysis of journal contribution and citation

By analyzing the contributions and citations of journals in this field, researchers can gain a clearer understanding of the current research landscape and receive guidance in selecting appropriate journals for their work. To illustrate the distribution of literature across various journals, this study constructed a journal heatmap, as depicted in Figure 8. The variations in color intensity within the heatmap represent the density of literature distribution among different journals. The results indicate that the "*ACM Journal on Computing and Cultural Heritage*" ranks first in the field with 38 related papers, accounting for 5.56% of the total publications. It is followed by "*Applied Sciences*", which contributed 16 papers, while "*Heritage*" and the "*Journal of Cultural Heritage*" published 15 and 11 papers, respectively.

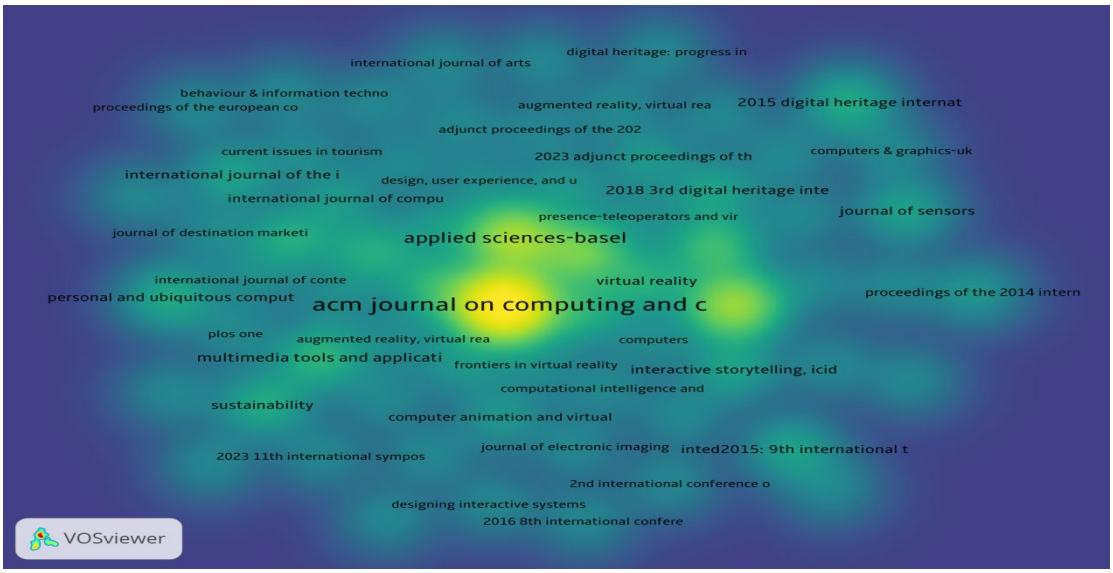

Figure 8: Journal heatmap.

This study employed CiteSpace software to identify the top 20 cited journals exhibiting citation bursts, as illustrated in Figure 9. The findings reveal that "*Communications of the ACM*" experienced the longest duration of citation bursts, achieving a burst strength of 8.02 from 2000 to 2017, which underscores its sustained and significant academic impact in the field. Furthermore, "*Sustainability*" recorded a citation burst strength of 6.83 from 2022 to 2024, indicating its recent influence within the discipline. Lastly, "*IEEE Computer Graphics and Applications*" attained a citation burst strength of 6.14 from 2010 to 2018.

Cited Journals	Year	Strength	Begin	End	1998 - 2024
COMMUN ACM	2000	8.02	2000	2017	
IEEE COMPUT GRAPH	2002	6.14	2010	2018	
THESIS	2012	10.73	2012	2020	
2012 18TH INTERNATIONAL CONFERENCE ON VIRTUAL SYSTEMS AND MULTIMEDIA (VSMM 2012). PROCEEDINGS	2014	5.77	2014	2018	
INTERACT COMPUT	2015	5.28	2015	2021	
P SIGCHI C HUM FACT	2005	4.79	2016	2020	
MUSEUM EXPERIENCE RE	2017	4.97	2017	2019	
THE PARTICIPATORY MUSEUM	2017	4.16	2017	2019	
IDENTITY AND THE MUSEUM VISITOR EXPERIENCE	2017	4.05	2017	2019	
2015 DIGITAL HERITAGE INTERNATIONAL CONGRESS	2016	4.23	2018	2020	
MULTIMODAL TECHNOLOGIES AND INTERACTION	2019	5.03	2019	2022	
INT ARCH PHOTOGRAMM	2017	4.55	2019	2020	
CHI 2019: PROCEEDINGS OF THE 2019 CHI CONFERENCE ON HUMAN FACTORS IN COMPUTING SYSTEMS	2021	4.88	2021	2024	
INT J HUM-COMPUT INT	2018	4.2	2021	2024	
SUSTAINABILITY-BASEL	2021	6.83	2022	2024	
HERITAGE-BASEL	2021	5.44	2022	2024	
J TRAVEL RES	2022	5.01	2022	2024	
ARXIV	2022	4.91	2022	2024	
APPL SCI-BASEL	2020	4.37	2022	2024	
MULTIMODAL TECHNOLOG	2022	4.16	2022	2024	

Figure 9: Top 20 cited journals with the citation bursts.

Figure 10 illustrates the distribution of citation relationships among journals in the field through a dual-map overlay analysis. This figure consists of two components: the left side represents the citing journals, while the right side depicts the cited journals. Each point in the figure corresponds to a journal, and the connecting curves between the left and right sides reveal the citation relationships among these journals[45]. The curves not only illustrate the trajectories of cross-disciplinary citations but also enhance our understanding of the academic exchange between different fields. The analysis indicates that research published in "Psychology, Education, Health" is cited by research published in "Psychology, Education, Social."

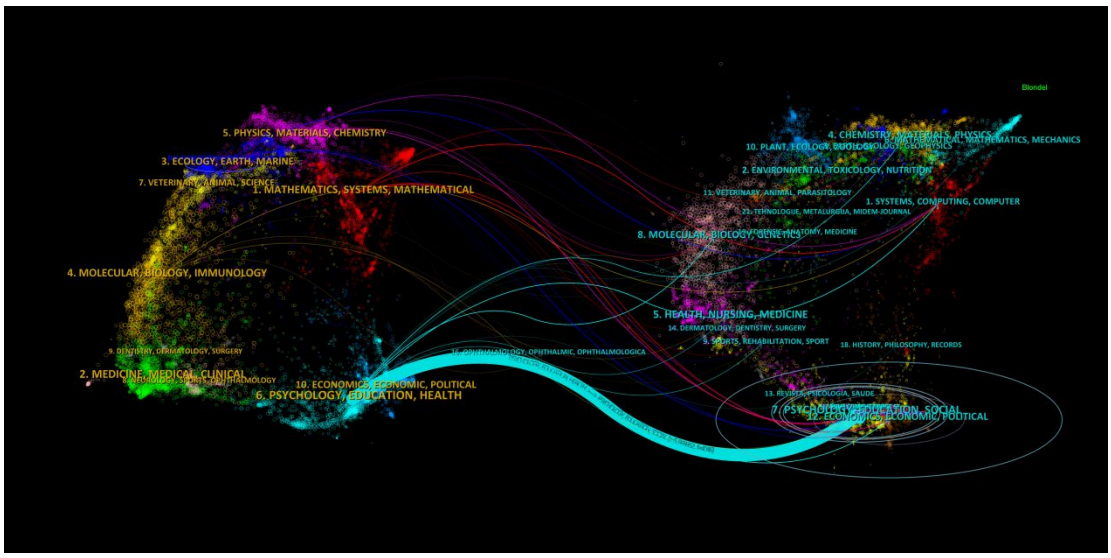

Figure 10: Dual-map overlay analysis.

3.6 Analysis of literature co-citation

Co-citation frequency is a significant metric for evaluating the academic impact of literature. When documents are frequently co-cited, it typically indicates their high academic value and substantial influence, serving as a reference point for subsequent research[46]. In this study, CiteSpace was employed to perform the co-citation analysis presented in Figure 11. In the figure, the size of the circles represents the frequency of co-citations, while the color gradient indicates the chronological order of citations. Overlapping colors suggest that the article was consistently cited over the corresponding years. The results indicate that the most frequently co-cited document is the article by Bekele MK (2018), with 46 co-citations. This is followed by the articles by Lee H (2020) and Hammady R (2020), which have 18 and 17 co-citations, respectively. These analysis results are crucial for identifying key literature with sustained impact in the field and for understanding their developmental trends.

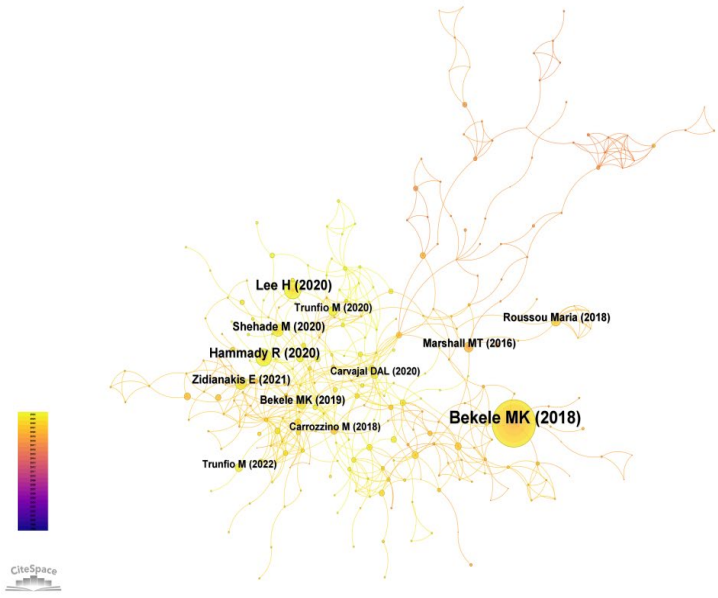

Figure 11: Analysis of literature Co-Citation.

To identify highly cited documents with significant influence in academia, this study employed CiteSpace to generate the top 20 references exhibiting citation bursts, as illustrated in Figure 12. The results indicate that Bekele MK's (2018) study demonstrated the highest citation burst strength, peaking at 12.21 during the period from 2019 to 2024. Furthermore, the findings reveal that the majority of the analyzed documents experienced notable citation bursts between 2017 and 2024, suggesting a recent surge in research activity and developmental momentum within the field of museum interactive experience.

References	Year	Strength	Begin	End	1998 - 2024
vom Lehn D, 2001, SYMB INTERACT, V24, P189, DOI 10.1525/si.2001.24.2.189, DOI	2001	2.64	2004	2005	
Bruno F, 2010, J CULT HERIT, V11, P42, DOI 10.1016/j.culher.2009.02.006, DOI	2010	3.89	2014	2015	
Petrelli Daniela, 2013, INTERACTIONS, V20, P58, DOI 10.1145/2486227.2486239, DOI	2013	2.95	2017	2018	
Mortara M, 2014, J CULT HERIT, V15, P318, DOI 10.1016/j.culher.2013.04.004, DOI	2014	2.95	2017	2018	
Kersten TP, 2017, INT ARCH PHOTOGRAMM, V42-2, P361, DOI 10.5194/isprs-archives-XLII-2-W3-361-2017, DOI	2017	2.9	2017	2020	
Falk JH, 2016, MUSEUM EXPERIENCE RE, V0, P0	2016	2.78	2017	2019	
Marshall MT, 2016, PROCEEDINGS ..... INTERACTION (TEI16), V0, PP159, DOI	2016	4.45	2018	2021	
Bekele MK, 2018, ACM J COMPUT CULT HE, V11, P0, DOI 10.1145/3145534, DOI	2018	12.21	2019	2024	
Roussou Maria, 2018, MULTIMODAL TECHNOLOGIES AND INTERACTION, V2, P0, DOI 10.3390/mti2020032, DOI	2018	4.22	2020	2022	
Kiourt C, 2016, J CULT HERIT, V22, P984, DOI 10.1016/j.culher.2016.06.007, DOI	2016	3.72	2020	2021	
Carrozzino M, 2018, LECT NOTES COMPUT SC, V10851, P292, DOI 10.1007/978-3-319-95282-6, 22, DOI	2018	3.37	2020	2022	
Jung Timothy, 2016, INFORM COMMUNICATION, V0, PP621, DOI 10.1007/978-3-319-28231-245, DOI	2016	3.19	2020	2021	
Pallud J, 2017, INFORM MANAGE-AMSTER, V54, P465, DOI 10.1016/j.im.2016.10.004, DOI	2017	2.95	2020	2022	
Sylaiou S, 2018, 2018 9TH INTE ..... LIGENT SYSTEMS (IS), V0, PP595, DOI	2018	2.65	2020	2021	
Konstantakis M, 2017, 2017 12T ..... LIZATION (SMAP 2017), V0, PP90, DOI	2017	2.65	2020	2021	
Hammady R, 2020, MULTIMED TOOLS APPL, V79, P3465, DOI 10.1007/s11042-019-08026-w, DOI	2020	4.41	2021	2024	
Zidianakis E, 2021, ELECTRONICS-SWITZ, V10, P0, DOI 10.3390/electronics10030363, DOI	2021	3.1	2021	2024	
Carvajal DAL, 2020, J CULT HERIT, V45, P234, DOI 10.1016/j.culher.2020.04.013, DOI	2020	2.8	2022	2024	
Agostino D, 2020, MUS MANAGE CURATOR, V35, P362, DOI 10.1080/09647775.2020.1790029, DOI	2020	2.74	2022	2024	
Khan MA, 2021, J REAL-TIME IMAGE PR, V18, P321, DOI 10.1007/s11554-020-01038-y, DOI	2021	2.74	2022	2024	

Figure 12: Top 20 references with the citation bursts.

3.7 Analysis of hotspot keywords

Keywords represent the primary research content and core viewpoints. The co-occurrence analysis of keywords can reveal the interrelationships and potential structures among various themes within a research domain, thereby aiding in the exploration of knowledge evolution and future trends in museum interactive experience[46]. This study employed VOSviewer software to conduct a co-occurrence analysis of article keywords, selecting those that appeared at least four times. From the original dataset of 1,766 keywords, 98 were identified, and a keyword visualization map was constructed, as illustrated in Figure 13. Each node is depicted as a circle with an accompanying label. The circle's size is directly related to the keyword's frequency, while line thickness represents the strength of keyword relationships. Nodes of different colors represent distinct clusters based on the co-occurrence clustering of keywords, reflecting the similarity among them.

The red cluster represents "Museums and Digitalization," primarily encompassing keywords such as Museum, Digitalization, Visitor Experience, Museum Experience, Intangible Cultural Heritage, Education, Artificial Intelligence, and Internet of Things. This focus area is dedicated to enhancing

visitor experiences and educational functions in museums through the application of artificial intelligence, Internet of Things technologies, and digitalization. The research explores the development of intelligent guidance systems, the integration of IoT technologies, the optimization of exhibition design through data analysis, and the application of digital technologies for the presentation and preservation of intangible cultural heritage.

The green cluster represents "Virtual Museums and Gamification," primarily encompassing keywords such as Virtual Museum, Gamification, 3D Modeling, Virtual Exhibition, Edutainment, and Game-Based Learning. This area of focus is primarily concerned with leveraging internet technologies to create virtual exhibitions and online interactive experiences. The research includes the application of 3D modeling and related technologies to construct virtual museums, the adoption of gamified learning strategies to enhance visitor engagement, and the integration of multimedia and visualization technologies to offer rich learning and interactive experiences.

The blue cluster represents "Cultural Heritage and Human-Computer Interaction," primarily encompassing keywords such as Cultural Heritage, Interaction Design, Human-Computer Interaction, Mixed Reality, Interaction Techniques, Interactive Experience, and Natural Interaction. This area of focus is dedicated to optimizing the presentation and preservation of cultural heritage through the design of human-computer interactions. The research explores the application of human-computer interaction technologies to enhance audience engagement, refine user interface and navigation design, improve the usability of virtual environments, and enrich the audience's experience and understanding of cultural heritage through natural interaction methods.

The purple cluster represents "Virtual Reality and Immersion," primarily encompassing keywords such as Virtual Reality, Immersion, Interaction, Mobile Application, and Virtual Heritage. This focus area is concerned with leveraging virtual reality technology to create immersive environments that allow audiences to experience profound immersion. The research explores the application of VR technology to enhance the sense of presence and immersive experiences, the integration of VR with mobile applications to facilitate convenient interactive experiences, and the utilization of multimodal interaction and natural user interfaces to improve educational outcomes for children and informal learning.

The cyan cluster represents "Augmented Reality and Storytelling," primarily encompassing keywords such as Augmented Reality, Storytelling, User Experience, Digital Cultural Heritage, and Serious Games. This focus area is concerned with enhancing the narrative impact of artifact displays by overlaying virtual information using augmented reality technology. The research explores the application of narrative design to deepen emotional resonance with the audience, as well as the integration of AR with serious games to enhance the interactivity of digital cultural heritage displays.

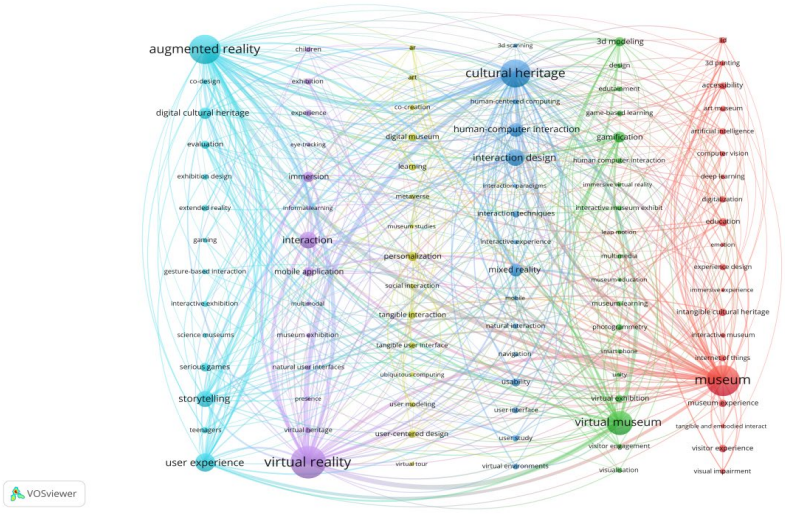

Figure 13: Keyword clustering diagram.

Figure 14 illustrates the temporal evolution of keywords, with changes in node size and color visually representing the development of research hotspots. Virtual Reality and Augmented Reality emerge

as the most prominent keywords, highlighting the sustained dominance of these technologies in museum interactive experience research.

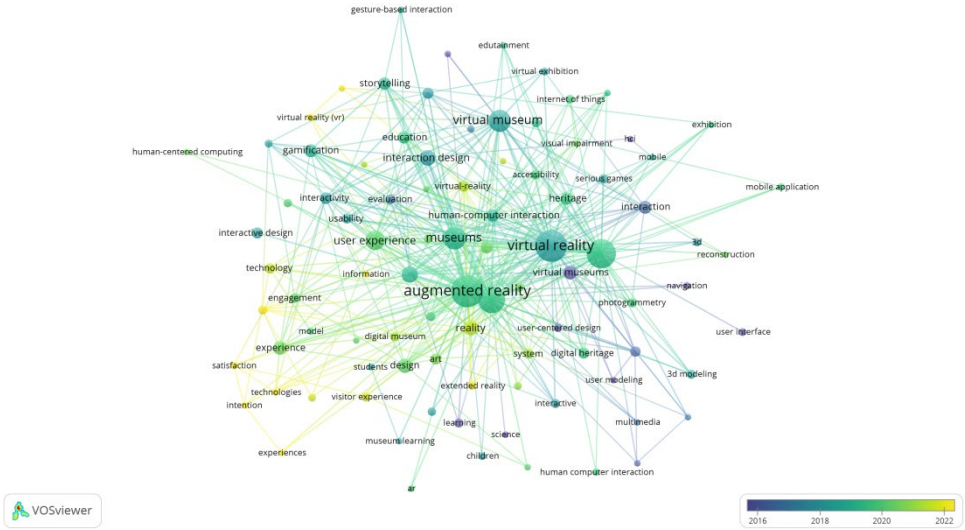

Figure 14: Keyword timeline analysis based on VOS viewer.

Figure 15 presents a clearer illustration of the temporal origins and changes in the popularity of keyword clusters. In this figure, the size of the overlapping spheres corresponds to the frequency of the keywords, with sphere size being directly proportional to the frequency of their occurrences. On the timeline, keywords within the same cluster are aligned along the same horizontal line, with the time of their initial appearance located at the top. The density of the spheres along the timeline reflects the variations in popularity of the keyword clusters over time. Additionally, the lines connecting the keywords signify their co-occurrence relationships.

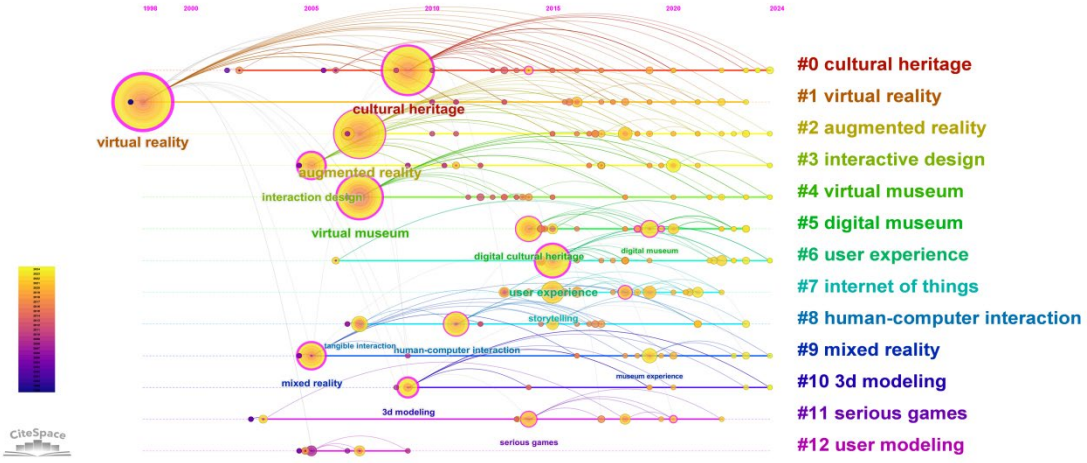

Figure 15: Keyword timeline analysis based on Cite space.

Specifically, the keywords associated with museum interactive experience research are categorized into 13 clusters on the timeline: cultural heritage, virtual reality, augmented reality, interactive design, virtual museum, digital museum, user experience, Internet of Things, human-computer interaction, mixed reality, 3D modeling, serious games, and user modeling. Among these themes, research on virtual reality and augmented reality occupies a dominant position, emerging prior to 2000 and after 2005, respectively. The spheres representing these keywords on the timeline exhibit a notable density between 2015 and 2020, suggesting that their popularity peaked during this period and has continued to garner interest beyond 2020. Cultural heritage, as a primary application scenario for museum interactive experience research, saw related studies emerge in 2002, with its popularity beginning to rise from 2013 to the present.

From the perspective of research trends, the evolution of museum interactive experience research can be categorized into three stages: Technical Exploration and Basic Experience (before 2015), Application Deepening and Enhanced Experience (2015 to 2020), and Digitalization and In-Depth Experience (2020 to 2024).

Stage 1. Technical exploration and basic experience (before 2015).

Research during this stage primarily focused on cultural heritage, interactive design, user modeling, and virtual museums. These areas laid a theoretical foundation for the interaction between museums and audiences, fostering innovations in presentation methods.

Stage 2. Application deepening and enhanced experience (2015 to 2020).

During this stage, the focus of research shifted towards the application of new technologies and formats, such as virtual reality, augmented reality, and serious games, which significantly enhanced audience engagement and learning experiences. Virtual reality facilitated the creation of immersive environments, while augmented reality increased exhibition interactivity through real-time information overlays. Furthermore, serious games enriched the audience's learning experience by integrating educational content with entertainment.

Stage 3. Digitalization and In-depth experience (2020 to 2024).

Research during this stage focuses on mixed reality, digital museums, and the Internet of Things. These technologies offer innovative support for personalized in-depth experiences within museums, enabling audiences to interact with exhibitions through smart devices and receive tailored information. Furthermore, the emergence of digital museums and the application of mixed reality have facilitated the digital transformation of museums, allowing them to more effectively meet the needs of modern audiences.

Overall, research on museum interactive experience emphasizes the continuous optimization of visitor experiences and the exploration of new technological potentials, reflecting a visitor-centered concept. It is anticipated that future research trends in this field will likely evolve towards highly digitalized and immersive technology-driven deep experiences.

Figure 16 displays the top 20 keywords ranked by citation bursts, providing a clear indication of the future research hotspots in this field. "Virtual museums" ranks first, exhibiting both the highest citation burst value (5.48) and the earliest citation burst period (2007 to 2015), which underscores its sustained research prominence within this domain. Furthermore, keywords such as "Technology," "Experience," "Digital museum," "Digital cultural heritage," and "Extended reality" show citation burst periods from 2022 to 2024, suggesting that these related topics may emerge as future research hotspots in this field.

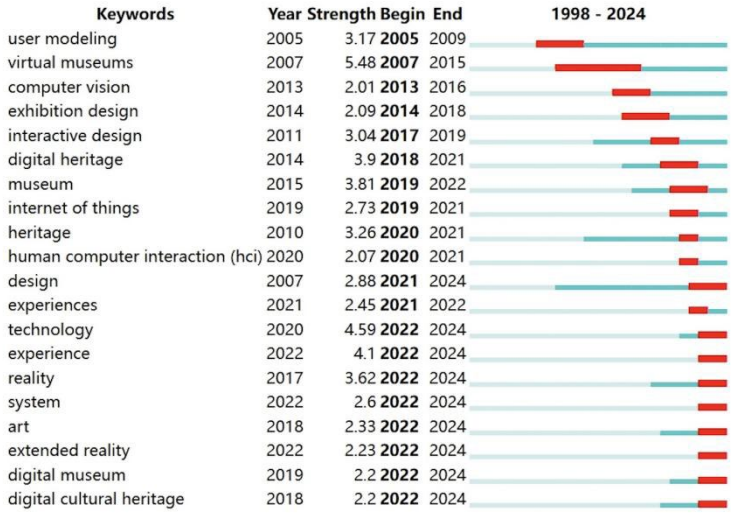

Figure 16: Top 20 keywords with the strongest citation bursts.

4. DISCUSSION

4.1 Knowledge framework

To comprehensively present the progress in this field, this study constructed a knowledge framework for museum interactive experience research based on the analysis results. The framework is shown in Figure 17.

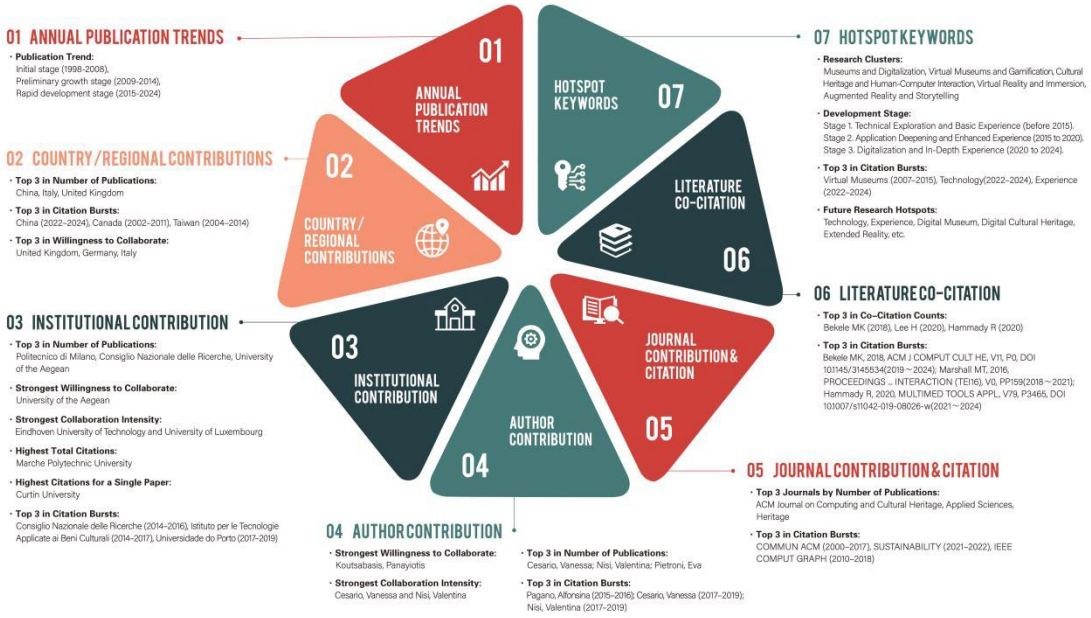

Figure 17: Knowledge framework of museum interactive experience research.

4.2 Research outlook

Museum interactive experience has consistently evolved to enhance visitor engagement and enrich the depth of experience, ranging from static displays and multimedia guides to digital transformation and mobile applications, as well as the application of immersive and intelligent technologies. This field is dedicated to offering increasingly diverse, personalized, and intelligent interactive experiences. Drawing from a comprehensive analysis of relevant research, this study presents the following outlook for the future of this discipline.

(1) Future research will place greater emphasis on interdisciplinary collaboration. By integrating theories and methods from various disciplines, the research and practice of museum interactive experience will be enriched and broadened. Interdisciplinary research can leverage educational theories to enhance visitors' learning experiences and utilize insights from sociology and psychology to gain a deeper understanding of visitor needs, thereby designing interactive experiences that align more closely with those needs[47, 48]. For instance, psychological research can optimize exhibition design by considering visitors' emotional responses during interactive experiences, thereby improving their engagement and satisfaction[49].

(2) Future research will incorporate advanced technologies that are at the forefront of innovation. Technologies including Artificial Intelligence (AI), Extended Reality (XR), and the Internet of Things (IoT) are poised to be the driving forces behind new interactive paradigms in museums. The integration of AI, VR, and AR will facilitate the development of virtual and digital museums, thereby enhancing visitor engagement through immersive experiences and dynamic intelligent interactions[50, 51]. XR technologies can further enrich visitors' immersion and emotional connection by constructing intricate historical and cultural contexts[26, 52]. Additionally, the incorporation of multisensory interactions—utilizing stimuli such as touch, sound, and smell—will unveil new possibilities for interactive experiences[53, 54].

(3) Future research will place a stronger emphasis on the visitor-centered concept. As the roles of museum collections and visitors evolve, the focus of research will increasingly center on the accessibility and inclusivity of interactive experiences, highlighting the importance of visitor-centered personalized design and barrier-free access. Special attention will be devoted to

ensuring that diverse groups, including youth, the elderly, and individuals with disabilities, can equally benefit from museum resources[55, 56]. By leveraging Artificial Intelligence and big data analysis, museums will be able to deliver interactive content in real-time, tailored with varying depths and styles to meet the needs of different demographic groups[57]. Additionally, research will investigate how interactive experiences can foster community engagement, strengthen social connections among visitors, and enhance the social value of museums as public spaces[58].

5. CONCLUSION

This study employs bibliometric methods to perform a comprehensive visualization analysis of museum interactive experience research. The analysis revealed the current research status, hotspots, and evolutionary trends in this field, thereby providing support for researchers and museum practitioners to gain a dynamic and holistic understanding of this research area. Additionally, it offers reference material to promote the reconstruction and innovation of knowledge within this domain.

The conclusions of this study are as follows: (1) Research activity in this field has been steadily increasing, with its importance and influence within academia continually expanding. The distribution of research outcomes across various disciplinary journals underscores the interdisciplinary nature and diverse developmental trends characteristic of this field. (2) This field has attracted widespread attention in Europe, Asia, and the Americas, with close international collaboration reflecting extensive global participation and varied development. Europe, in particular, has established a robust collaborative network and exerts significant influence in the field. (3) The development of this field is divided into three stages: Technical Exploration and Basic Experience (before 2015), Application Deepening and Enhanced Experience (2015 to 2020), and Digitalization and In-Depth Experience (2020 to 2024). This progression emphasizes the continuous optimization of visitor experiences and the exploration of new technological potentials, reflecting a visitor-centered concept. (4) Future research trends in this field are anticipated to evolve towards highly digitalized and immersive technology-driven deep experiences. Notable research hotspots include digital museums, digital cultural heritage, and extended reality.

This study has several limitations. First, our literature retrieval was restricted to the Web of Science Core Collection database. While this database is highly regarded, it does not include all research outputs. Second, due to time constraints during our search, literature published in 2024 may not yet be fully indexed. Third, our study exclusively included literature published in English, thereby neglecting research published in other languages, which restricts a comprehensive understanding of global research contributions. Future research plans involve expanding the database, extending the time frame, and incorporating literature in other languages to draw more comprehensive and in-depth conclusions.

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