International Journal of Management, Accounting, Governance and Education
2025, Volume 1, Issue 2

Evolution of Research Hotspots and Emerging Trends in Virtual Museums: A Scientometric Analysis Based on CiteSpace (2001–2025)

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ABSTRACT

Virtual museums, as an interdisciplinary field combining digital heritage, immersive technology, and cultural informatics, have expanded rapidly in recent years. However, existing research often emphasizes technical applications or case studies, with limited attention to the field's overall knowledge structure and evolution. Using 356 publications from the Web of Science Core Collection (2001–2025) and CiteSpace (6.2), this study conducts keyword co-occurrence, clustering, and burst analyses to map research trends. Results identify a three-stage evolution: an early phase focused on 3D modeling and system development, a middle phase emphasizing user interaction and narrative design, and a recent phase driven by artificial intelligence, immersive experiences, and metaverse applications. The field shows a clear shift from technology-centered approaches to user- and experience-oriented frameworks, alongside growing interdisciplinary integration. Meanwhile, international collaboration remains relatively fragmented, with regional clustering and limited cross-regional cooperation. Based on these findings, future research should prioritize intelligent curation, data interoperability, and globally coordinated empirical frameworks. This study provides a systematic understanding of the structural features and evolution of virtual museum research, offering theoretical and methodological insights for digital heritage and cultural communication studies.

Keywords: Virtual museums; immersive technologies; CiteSpace; scientometric analysis; disciplinary evolution

1.INTRODUCTION

1.1 Research Background and Significance

Virtual museums have emerged as a key medium for the digital transformation of cultural heritage and have experienced rapid global development in recent years. As innovative platforms integrating culture, technology, and education, virtual museums leverage advanced technologies such as virtual reality (VR), augmented reality (AR), 3D modeling, artificial intelligence (AI), blockchain, and Web 3.0 to extend the functions of traditional museums into digital environments. This transformation enables more immersive, interactive, and temporally flexible cultural experiences for the public. Increasingly, the focus of museum development has shifted from display-oriented approaches to experience-, education-, and participation-centered models, reflecting a broader paradigm shift in digital cultural engagement.

From a global perspective, the evolution of virtual museums can be understood as a transition from early digitization of collections to immersive and narrative-driven cultural experiences. Early initiatives in Western countries laid the groundwork for large-scale digital heritage infrastructures by promoting the integration of resources across museums, libraries, and archives. These developments not only established foundational digital repositories but also facilitated subsequent advancements in semantic interoperability and cross-platform data sharing (Yang, et al.,2025).

In comparison, although Asian countries entered the field at a later stage, they have demonstrated rapid progress in recent years, particularly in immersive exhibition design and digital heritage preservation. The development of high-resolution digitization, interactive display systems, and narrative-oriented exhibition strategies has contributed to the formation of regionally distinctive approaches to virtual museum construction (Winter, 2022). These efforts collectively highlight the growing importance of virtual museums as platforms for cultural preservation, public education, and digital communication.

Overall, the global development of virtual museums reflects a broader shift from static digital representation toward dynamic, user-centered cultural experiences. This transformation not only expands the accessibility of cultural resources but also reshapes the ways in which knowledge is produced, disseminated, and experienced in the digital age.

Despite the substantial progress achieved in the practical development of virtual museums, existing academic research remains characterized by fragmentation and methodological limitations, with insufficient theoretical depth（Yang et al.,2024）. Current studies predominantly focus on case-based applications and technological implementations, while lacking a comprehensive, macro-level analysis of the overall research landscape, knowledge evolution pathways, and interdisciplinary integration trends.

In the context of emerging technologies such as the metaverse, artificial intelligence-generated content (AIGC), and blockchain, related topics have gained increasing attention in the literature. However, much of this research remains conceptual in nature, with limited efforts devoted to developing structured and quantifiable analytical frameworks（Wang, Hong & He,2024）. For instance, following the rapid rise of the metaverse concept after 2021, a growing body of studies has explored the potential of “metaverse museums,” yet most remain at the level of conceptual discussion and future projections, without systematic empirical analysis of existing knowledge foundations or evolutionary trajectories.

Furthermore, existing visualization-based studies often rely on simple keyword frequency analysis and fail to effectively capture knowledge clustering, research trajectories, and the dynamic evolution of research hotspots. As a result, there is a clear need for systematic, knowledge-mapping approaches to better understand the intellectual structure and developmental patterns of the virtual museum research field.

1.2 Research Significance

To address these gaps, this study adopts CiteSpace (version 6.2) as a scientometric analysis tool and utilizes data from the Web of Science Core Collection, covering 356 publications on virtual museums from 2001 to 2025. By employing co-occurrence analysis, cluster analysis, burst

detection, and temporal evolution mapping, this study systematically examines the field from three perspectives: knowledge structure, research hotspots, and development trends.
Specifically, this study aims to address the following research questions:
(1) What are the structural characteristics and developmental stages of virtual museum research?
(2) How have major research clusters and keywords evolved over time?
(3) What emerging research frontiers are developing in the context of new technologies?
By visualizing and analyzing the knowledge structure of virtual museum research, this study provides theoretical insights for academic inquiry and offers practical implications for policy-making, cross-institutional collaboration, and the integration of culture and technology.

2.DATA SOURCES AND RESEARCH METHODS

2.1 Data Sources

To ensure the reliability and comprehensiveness of the dataset, this study selected the Web of Science (WoS) Core Collection as the primary data source. The WoS database, maintained by Clarivate Analytics (formerly the Institute for Scientific Information, ISI), is widely recognized for its coverage of high-quality, peer-reviewed academic publications and is commonly used in scientometric and bibliometric research.
To enhance the academic rigor of the dataset, the document types were restricted to “Article” and “Review,” while non-scholarly materials such as conference abstracts, book reviews, and news items were excluded. This filtering process ensures both the relevance and quality of the analyzed publications.
The search strategy was defined using the following topic keywords: “virtual museum” OR “online museum” OR “digital museum”. The initial search yielded 771 records. To improve data accuracy, a manual screening process was conducted to remove irrelevant publications and five retracted articles, resulting in a final dataset of 356 valid documents. The data retrieval date was August 5, 2025.

2.2 Research Methods

This study adopts a scientometric approach to analyze the research landscape of virtual museums, using CiteSpace (version 6.2.R9) as the primary analytical tool. CiteSpace, developed by Chen (Drexel University), is a widely used visualization software that integrates co-citation analysis and pathfinding algorithms to identify critical nodes, research frontiers, and evolutionary trends within a scientific domain.
The analysis was conducted with the following parameter settings: the time span was defined as 2001–2025, with a one-year time slice to ensure fine-grained temporal analysis. The threshold (Top N) was set to 50 to balance network complexity and interpretability. The node types included authors, institutions, and keywords, allowing for a multi-dimensional examination of the research structure.
Based on these settings, multiple analyses were performed, including publication trend analysis,

collaboration network analysis, keyword co-occurrence analysis, cluster analysis, and burst detection. Specifically, cluster analysis was conducted using the Louvain algorithm to identify thematic structures within the field, while burst detection was applied to identify keywords with significant increases in frequency over specific time periods, thereby capturing emerging research fronts.

In addition, descriptive statistical analysis was conducted using Microsoft Excel to supplement the visualization results, particularly in terms of publication output and citation patterns. This combined methodological framework enables a systematic exploration of the knowledge structure, research hotspots, and developmental trends in virtual museum research.

3.RESULTS AND ANALYSIS

3.1 Publication Trend Analysis

The evolution of publication output is a key indicator for assessing the level of research activity within a given field and provides important insights into the development of research hotspots over time. Based on the statistical analysis of the sampled literature, the overall number of publications on virtual museum research from 2001 to 2025 exhibits a clear trend of progression from gradual growth to rapid expansion.

More specifically, the development of this research field can be divided into three distinct phases: an initial exploratory stage (2001–2010), a steady development stage (2011–2019), and a rapid growth stage (2020–2025). This phased evolution reflects not only the increasing academic attention to virtual museums but also the broader transformation of the field in response to technological advancements and changing research paradigms.

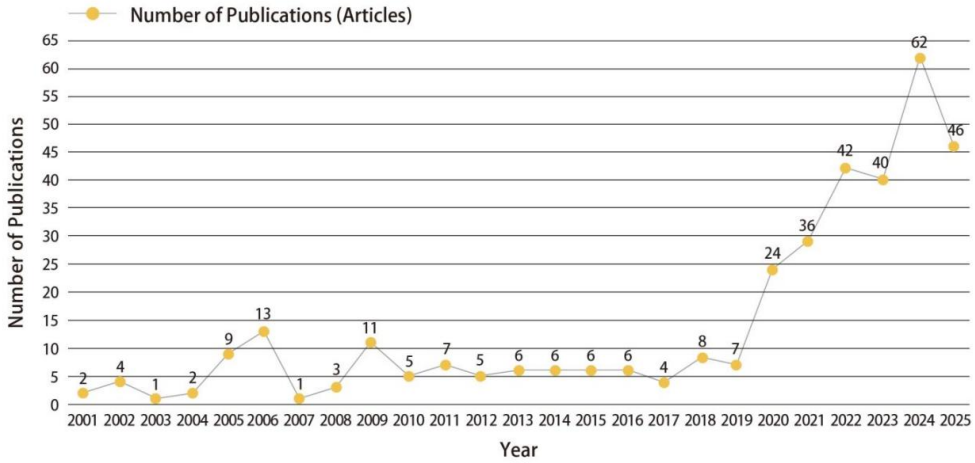

Figure 1. Annual Publication Trends in Virtual Museum Research

In the initial exploratory phase (2001–2010), research on virtual museums was still at a relatively early stage. The average annual output remained low, at around five publications, and although there were fluctuations from year to year, the overall trend showed only a gradual increase. As indicated in Figure 1, the number of publications during this period was consistently limited, generally ranging from one to ten per year. This suggests that the field had not yet developed a stable or systematic body of academic work.

Looking more closely at the yearly distribution, small peaks can be identified in 2003, 2006, and 2009. Even so, none of these exceeded ten publications, which points to a pattern of sporadic rather than sustained research activity. Toward the later years of this phase, terms such as immersive experience, cultural communication, and user participation began to appear more frequently. This shift hints at a gradual move away from a purely technical focus toward a growing interest in user-oriented perspectives. At the same time, the potential of virtual museums in areas such as distance learning and public cultural dissemination started to receive attention, suggesting their emerging relevance beyond experimental or technical contexts.

During the following period of steady development (2011–2019), publication output did not increase dramatically, but the scope of research became noticeably broader. As shown in Figure 1, the number of publications in most years still remained below ten, yet the overall trend was upward. A turning point can be observed around 2017, when annual output exceeded fifteen publications for the first time, indicating that the field was gradually gaining momentum.

More importantly, changes during this stage were reflected not only in the number of publications but also in the nature of the research itself. With the gradual maturation of virtual reality (VR) and augmented reality (AR) technologies, the focus began to shift from technical implementation toward issues such as user experience, cultural narrative, and educational integration (AlGerafi,et al.,2023). Virtual museums were increasingly approached as environments for communication and learning, rather than merely as technical systems. This change suggests a broader reorientation of the field, in which the quality of interaction and the interpretation of content became more central than technical feasibility alone.

The period from 2020 to 2025 marks a phase of rapid growth. The year 2020 stands out as a clear turning point, with publication output rising sharply from seven articles in 2019 to twenty-four in 2020. This increase continued in subsequent years, reaching forty-two publications in 2022 and peaking at sixty-two in 2024. Such a rise reflects a significant expansion of research activity, accompanied by a noticeable broadening of research themes.

From a wider perspective, virtual museum research has gradually shifted from a relatively marginal topic to a more integrated and interdisciplinary field. Contributions now come from a range of disciplines, including computer science, architecture, design, museology, and information management. Correspondingly, research topics have expanded beyond technical development to include areas such as immersive storytelling, user emotional experience, digital ethics, and AI-assisted curation (Gurel, 2025). Since 2021 in particular, there has been a marked increase in studies related to concepts such as the metaverse, digital twins, and cultural heritage reconstruction. This suggests that the field is undergoing a transformation in its underlying knowledge structure, with growing emphasis on user participation and intelligent systems.

Overall, the past two decades have seen virtual museum research evolve from a relatively nascent field into one characterized by strong technological momentum and considerable development potential. With continued support from digital cultural policies and technological innovation worldwide, it is likely that research activity in this area will continue to expand.

At the same time, this rapid development also raises a number of issues that require careful consideration. Technological advancement, on its own, does not necessarily ensure the realization of cultural value. In addition, as intelligent technologies become more prominent,

questions related to ethics, equity, cultural diversity, and user experience are becoming increasingly important. Future research would therefore benefit from greater attention to topics such as data interoperability, platform standardization, cross-cultural collaboration, and user participation mechanisms. These directions are essential for supporting the shift of virtual museums from display-oriented systems toward more participatory and co-creative forms.

3.2 Distribution of Core Institutions in Virtual Museum Research

The institutional collaboration network illustrates the spatial distribution of research capacity within this field. Using the institutional analysis function of CiteSpace, it is possible to gain a deeper understanding of the relationships among research institutions engaged in virtual museum studies. These network connections provide an intuitive representation of collaborative patterns and can serve as a reference for evaluating the academic influence of institutions.

Figure 2 presents the institutional collaboration network of virtual museum research after data processing. In the network, node size represents the number of publications produced by each institution, while the thickness of the links indicates the strength of collaboration between institutions.

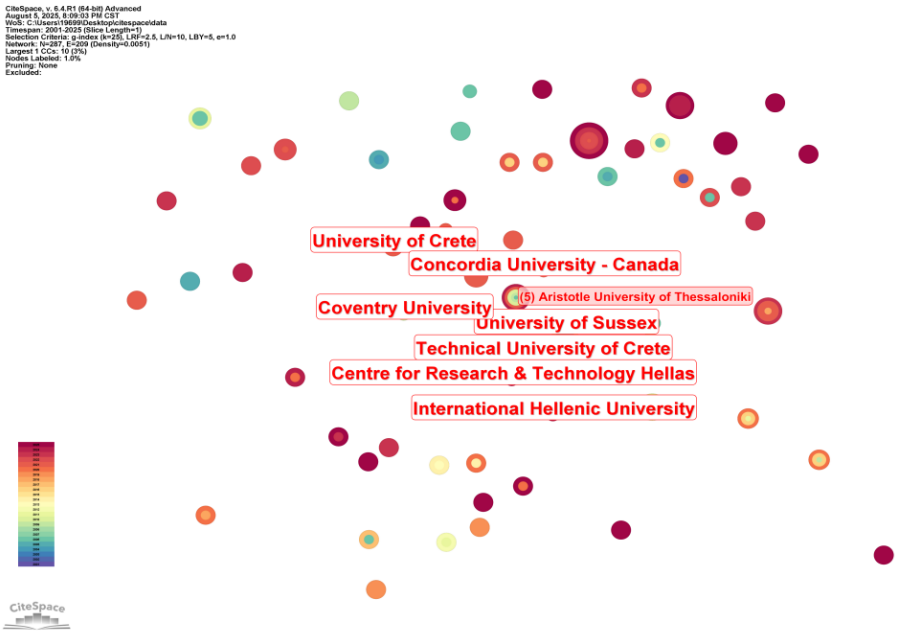

Figure 2. Institutional Collaboration Network in Virtual Museum Research (2001–2025)

The institutional collaboration network serves as a key lens for understanding the spatial distribution of research capacity and patterns of scholarly coordination within a field. From a scientometric perspective, such networks not only map interactions among knowledge-producing actors but also reflect the pathways of knowledge diffusion and the allocation of research resources. The collaboration network generated by CiteSpace includes 287 institutional nodes and 290 links, with a network density of 0.0051, indicating a sparse and weakly connected overall structure.

Structurally, the low density suggests that stable and frequent collaborations among institutions have yet to emerge, and knowledge exchange remains relatively dispersed. This type of loosely connected network is commonly observed in emerging interdisciplinary fields, where the number of participating actors continues to grow, but a cohesive core of collaboration has not yet formed. In more mature disciplines, collaboration networks often exhibit a "core–periphery" structure, in which a small number of central institutions act as hubs of knowledge production, while others engage through more peripheral connections. In contrast, research on virtual museums has not yet developed such a stable core. One possible explanation lies in its strong application-oriented nature: many studies are conducted within specific projects or practical contexts, often led by individual institutions or localized teams. As a result, the demand for cross-institutional collaboration remains relatively limited, which in turn constrains the expansion of international collaborative networks (Gurel, 2025).

From a spatial perspective, the collaboration network shows clear regional clustering, with relatively weak connections across different geographic areas. This pattern not only reflects uneven distribution of academic resources but also suggests that a highly integrated global research collaboration system has yet to take shape. Although some institutions occupy structurally central positions and play important roles in knowledge dissemination and resource coordination, their influence remains largely confined to local or regional networks and has not developed into stable cross-regional collaboration mechanisms.

Meanwhile, in certain regions, research output has increased noticeably in recent years, yet these institutions still occupy peripheral positions within the collaboration network. This imbalance between growing publication output and limited network influence points to structural inequalities within the global knowledge system. The underlying causes are multifaceted. At the institutional level, differences in research evaluation systems and incentive structures across regions may discourage international collaboration, particularly where local publication is prioritized. At the level of academic communication, language barriers and disparities in publication channels further limit the ability of some researchers to engage deeply in international collaboration (Lund, et al., 2023). In addition, cross-border collaboration typically depends on stable funding and institutional support, and uneven resource distribution further exacerbates regional disparities within the collaboration network.

With the continued development of digital cultural heritage research, cross-regional collaboration has begun to emerge more clearly. The promotion of data sharing and open access in the cultural sector has created new conditions for cooperation among institutions, while advances in digital technologies have lowered the technical barriers associated with geographically distributed collaboration, making remote cooperation increasingly feasible (Lin, Frey, & Wu,2023). At the technical level, progress in semantic computing and data interoperability has enabled cultural data to be integrated and shared in more structured forms, improving data usability and supporting collaboration across institutions (De Mello, et al., 2023). At the same time, the introduction of artificial intelligence has made knowledge discovery more data-driven, contributing to shifts in collaboration models.

Despite these developments, the evolution of collaboration networks still faces several constraints. One major issue lies in the lack of unified data standards and semantic frameworks,

which limits effective integration across systems. In addition, the sharing of cultural heritage data often involves concerns related to intellectual property and cultural sensitivity, adding institutional complexity to cross-organizational collaboration (Lee , et al., 2025). Meanwhile, as virtual museum research moves toward more immersive and intelligent forms, increasing technical complexity places greater demands on interdisciplinary cooperation. This suggests that future collaboration models will need to move beyond projects led by single actors toward multi-actor, co-creative approaches that integrate technology, content, and user experience.

From a developmental perspective, the collaboration network in virtual museum research is likely to evolve from its current pattern of regional clustering toward a more polycentric and coordinated structure. However, such a transition depends on the establishment of unified data standards, stable international collaboration mechanisms, and robust interdisciplinary research platforms. Future efforts to optimize collaboration networks may focus on strengthening cross-regional coordination to improve knowledge flows, advancing standardization and semantic interoperability to reduce technical barriers, and promoting interdisciplinary integration to support the joint development of technological and humanistic dimensions.

Overall, the institutional collaboration network in virtual museum research appears to be at a transitional stage, shifting from fragmented growth toward greater systemic integration. Enhancing collaboration structures and improving coordination capacity will be key to deepening research outcomes and expanding the field's international influence.

4.MAJOR RESEARCH HOTSPOTS IN THE FIELD OF VIRTUAL MUSEUMS

Keyword analysis provides an effective approach for examining the evolution of research hotspots and emerging trends in virtual museum studies. In CiteSpace, this type of analysis can be presented through keyword co-occurrence networks and temporal visualizations.

4.1 Keyword Co-occurrence Clustering Analysis of Virtual Museums

Keyword co-occurrence clustering is a key method for identifying the thematic structure of a research field and detecting emerging directions. It helps reveal the internal logic and evolutionary patterns underlying different research paradigms. Using CiteSpace, a co-occurrence analysis of keywords was conducted based on literature related to virtual museums from 2010 to 2025 in the Web of Science Core Collection. After applying modularity-based clustering (using the Louvain algorithm)（Shen & Tran, 2025）, a knowledge structure map was generated, as shown in Figure 3. The map presents 14 major clusters, each representing a distinct research theme with strong internal semantic coherence.

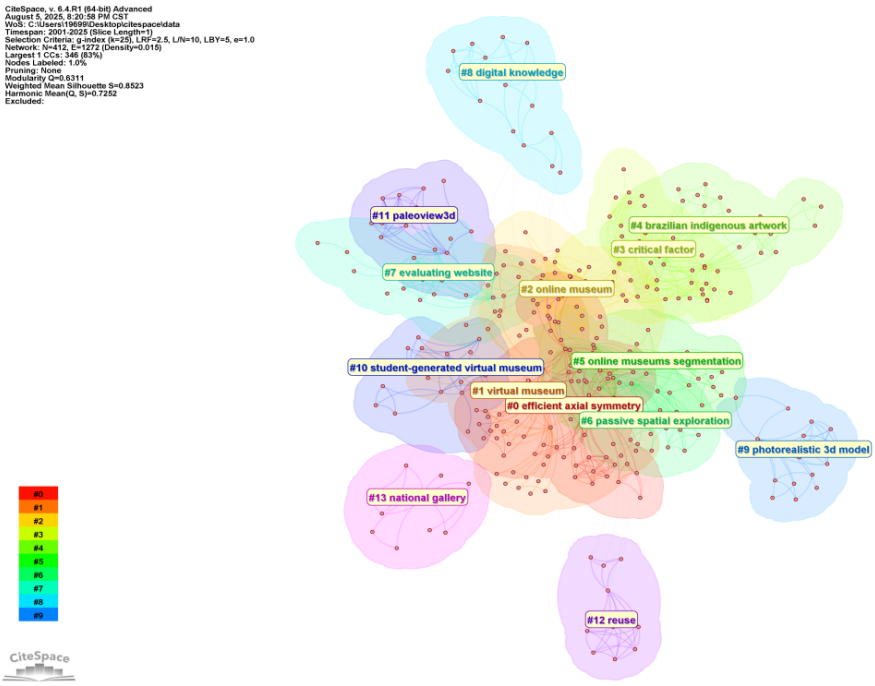

Figure 3. Keyword Co-occurrence Clustering Map of Virtual Museum Research

The overall structure of the knowledge map reveals a distinctly multi-centered and interdisciplinary pattern, indicating that virtual museum research has evolved into a multidimensional landscape encompassing technological platforms, user experience, content design, and semantic systems. The overlaps and linkages among clusters highlight both the diversity and integrative nature of research themes in this field. The main clusters can be interpreted as follows:

Cluster 0: Efficient Axial Symmetry. This is the largest cluster in the map, reflecting strong research interest in optimizing spatial symmetry in virtual museum design, as well as in building information modeling (BIM) and 3D modeling workflows. In particular, balancing structural authenticity with modeling efficiency has become a central issue in the reconstruction of historical architecture and heritage scenes (Xiong, et al., 2023). Research in this cluster is largely grounded in computer graphics and computational geometry, with applications in digital preservation and virtual reconstruction of historical buildings.

Cluster 1: Virtual Museum. As a core cluster, this group includes keywords such as "virtual reality," "digital heritage," and "interactive systems," pointing to systematic explorations of the definition, functionality, construction methods, and user engagement mechanisms of virtual museums. In recent years, virtual museums have shifted from static displays toward user-centered, dynamic experience systems, incorporating advanced technologies such as AI-driven semantic recommendation and immersive interaction (Xu & Pan, 2024). Research within this cluster forms the theoretical foundation of the field, covering conceptual frameworks, system architecture, content organization, and user behavior analysis. Notably, this cluster shows strong connections with clusters #2 and #3, underscoring the integrative nature of the

field.

Cluster 2: Online Museum. This cluster focuses on virtual exhibition environments built on internet platforms, with emphasis on cross-platform access, web-based visualization, and data sharing. It reflects the rapid evolution of virtual museums toward remote services and cloud-based curation, particularly in response to the pandemic context (Chunlan, Tengku Wook & Rosdi, 2025). Research topics include WebGL technologies, responsive design, and mobile adaptation, alongside user experience across different devices. With the widespread adoption of mobile internet, responsive design has become essential to ensure seamless access across smartphones, tablets, and desktops.

Cluster 3: Critical Factors. This cluster examines key variables influencing the effectiveness of virtual museum use, including the Technology Acceptance Model (TAM), user satisfaction, interface design, educational content, and cultural adaptability. Findings in this area are often used to develop evaluation models that support design optimization (Tao, et al., 2022). Methods such as surveys, user interviews, and usability testing are commonly employed to identify determinants of user experience, including ease of use, content appeal, and interaction intuitiveness.

Cluster 4: Brazilian Indigenous Artwork. This cluster highlights the role of virtual museums in regional cultural dissemination and the preservation of indigenous and minority cultures. It reflects a broader emphasis within global digital heritage systems on local cultural representation. Research in this area explores how digital technologies can empower marginalized communities in expressing and transmitting their cultural heritage, bridging anthropology and information science (Ajani, et al.,2024). Similar efforts are observed in studies of African, Southeast Asian, and Arctic cultural heritage, demonstrating the value of virtual museums in safeguarding cultural diversity.

Cluster 5: Online Museum Segmentation. This cluster captures the trend toward specialized virtual museums tailored to different audiences, content types, and formats, such as children’s museums, science galleries, and historical memorials. These segmented forms are designed to address diverse cultural experience needs. For instance, science galleries emphasize visual knowledge representation, while historical memorials focus on emotional engagement and educational impact.

Cluster 6: Passive Spatial Exploration. This cluster centers on non-active interaction experiences, emphasizing virtual navigation, automated path generation, and seamless movement within digital environments. The goal is to better understand and optimize users’ natural behaviors in virtual spaces . Drawing on cognitive psychology and environmental behavior theory, this line of research aims to design navigation systems aligned with user cognition, such as interest-based route planning and smooth spatial transitions.

Cluster 7: Evaluating Websites. This cluster focuses on the usability, information architecture, and accessibility of virtual museum websites. Studies suggest that well-structured websites can significantly enhance users’ cognitive processing and cultural engagement (Muhmad Asri, et al., 2024). Common methods include heuristic evaluation, user testing, and eye-tracking, assessing aspects such as information organization, navigation design, and interaction feedback. Accessibility research also addresses inclusive access for users with disabilities and older

populations.

Cluster 8: Digital Knowledge. This cluster emphasizes the role of virtual museums as platforms for knowledge production and dissemination. Research topics include knowledge organization, semantic annotation, and knowledge graph construction, highlighting their potential in open education and academic sharing. Drawing from information science and knowledge management, this work aims to transform virtual museums into dynamic knowledge ecosystems, where structured semantic networks enable deeper cultural understanding.

Cluster 9: Photorealistic 3D Modelling. This cluster reflects advances in high-fidelity modeling technologies, particularly in lighting rendering, texture capture, and laser scanning, which enhance the realism of artifact representation in virtual museums. Recent progress has been driven by both hardware improvements—such as high-precision scanners and drone imaging—and algorithmic innovations, including image-based reconstruction and neural radiance fields .

Cluster 10: Student-Generated Virtual Museum. This cluster represents the extension of virtual museum practices into education, emphasizing student participation in content creation as a means of fostering interdisciplinary learning and creative expression (Li et al., 2025). This approach shifts students from passive recipients to active creators, supporting the development of digital literacy and collaborative skills while engaging with subjects such as history, art, and science.

Clusters 11-13: Specialized Subclusters . These smaller clusters cover specific tools, resource management mechanisms, and institutional case studies, further expanding the scope of virtual museum research. PaleoView3D focuses on digital reconstruction in paleontology, highlighting applications in natural sciences; Reuse addresses issues of resource reuse and copyright management in digital heritage; National Gallery examines digital transformation strategies in major cultural institutions such as the UK National Gallery.

Overall, the co-occurrence clustering map indicates that virtual museum research has transitioned from an early technology-centered phase to a more diversified and integrated stage characterized by user-centered and content-driven approaches. Future research should further strengthen cross-disciplinary collaboration and deepen the integration of semantic intelligence with cultural narrative design.

4.2 Temporal Analysis of Keywords in Virtual Museum Research

The keyword timeline map is a form of knowledge visualization that reveals the evolutionary trajectory and development patterns of research hotspots over time. Based on the timeline view generated by CiteSpace (see Figure 4), this study traces the thematic evolution of virtual museum research from 2001 to 2025. The map clearly illustrates a shift from early foundational development to more recent trends characterized by cross-media integration and intelligent interaction.

From a temporal perspective, the development of virtual museum research can be broadly divided into three main stages.

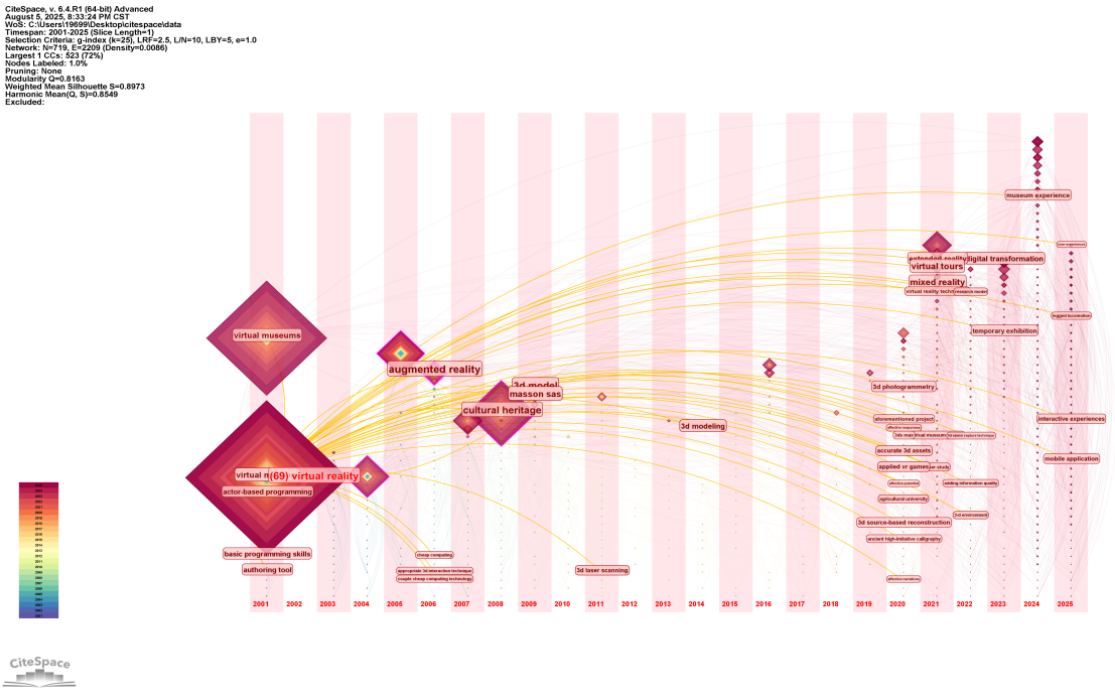

Figure 4. Keyword Timeline Map of Virtual Museum Research

Stage 1 (2001–2010): Technology Development and System Design

During this phase, keywords were dominated by technology-oriented terms such as "virtual reality," "virtual museum," "actor-based programming," and "authoring tool." Research primarily focused on the development of virtual exhibition platforms, 3D modeling, programming tools, and human–computer interaction interfaces (Zhao & Dou, 2023). Most studies were grounded in computer graphics and interaction technologies, with an emphasis on building functional virtual exhibition systems that could support the visualization of digital cultural heritage. In terms of technological evolution, this period saw a transition from web-based 3D visualization using VRML to desktop virtual reality systems developed with C++ and OpenGL. Key challenges included efficient compression and transmission of 3D data over networks, optimization of real-time rendering performance, and improving the naturalness and intuitiveness of user interaction. Representative outcomes included experimental virtual museum prototypes developed by research institutions, such as the virtual museum platform at the University of Crete in Greece and virtual reconstruction projects of historical architecture at Coventry University in the UK.

Stage 2 (2011–2019): Expansion toward Interactive Experience and Cultural Context

As technologies matured, the research focus gradually shifted from technical feasibility to the integration of user experience and cultural context. Keywords such as "augmented reality," "cultural heritage," "3D modelling," and "photogrammetry" became increasingly prominent, reflecting growing attention to cultural visualization, digital reconstruction, and artifact restoration (Pietroni & Ferdani, 2021). Research during this stage emphasized immersion, authenticity, and contextualized historical representation, placing greater importance on the educational role and cultural communication value of virtual museums (Zhang, Zhu & Hu,2025).

The advancement of augmented reality enabled the integration of digital content with physical spaces, allowing users to access layered information through mobile devices within museum environments. At the same time, improvements in photogrammetry significantly reduced the cost and technical barriers of 3D modeling, enabling more small and medium-sized museums to engage in digitization efforts. Studies in this period also began to explore educational applications, with empirical evidence showing that virtual museums can enhance learning outcomes and stimulate user engagement.

Stage 3 (2020–Present): Intelligence-Driven and Multimodal Integration

Since 2020, the global push toward digital transformation—accelerated by the pandemic—has led to a significant increase in research on virtual museums. The frequent emergence of keywords such as "virtual tours," "mixed reality," "digital transformation," "interactive experiences," and "mobile applications" indicates a shift from exhibition-centered approaches toward multimodal cultural communication characterized by deep participation, immersive experience, and intelligent recommendation . Notably, emerging terms such as "digital twin," "AI-driven curation," and "semantic metadata" suggest an early-stage integration of artificial intelligence and data-driven technologies into virtual museum research, opening up new directions for future development. Digital twin technology enables virtual museums not only to display 3D representations of artifacts but also to simulate their lifecycle, usage contexts, and historical settings. AI-based curation systems can generate personalized exhibition content and navigation paths based on user preferences and behaviors. Meanwhile, the use of semantic metadata allows museum content to be machine-readable, supporting applications such as intelligent recommendation and knowledge discovery.

The appearance of later keywords such as "temporary exhibition" and "museum experience" indicates a growing interest in replicating the fluidity and immediacy of physical exhibitions within virtual environments. This trend also highlights the transformative impact of mixed reality technologies on traditional museum models (Kneppers, 2024). Digitizing temporary exhibitions presents particular challenges due to their short duration and rapid turnover, requiring efficient and flexible digital workflows. At the same time, terms such as "interactive storytelling," "smart navigation," and "user personalization," although not yet forming large clusters, are emerging as potential frontier topics. Interactive storytelling emphasizes user participation in constructing narratives rather than passively receiving curated content. Smart navigation applies machine learning to predict user interests and dynamically optimize visiting routes, while user personalization focuses on tailoring cultural experiences based on individual characteristics and behavioral data.

Overall, the timeline map outlines an evolutionary trajectory in virtual museum research from "platform–content–experience–intelligence." It reflects the increasing integration of technological foundations with humanistic concerns, forming a more layered and multi-centered research landscape. This trend aligns with the broader global movement toward the digital transformation of cultural heritage, suggesting that virtual museums are advancing toward more intelligent, narrative-driven, and human-centered forms of cultural communication.

5.Conclusion and Future Directions

5.1 Research Conclusions

This study draws on 356 publications on virtual museums indexed in the Web of Science Core Collection from 2010 to 2025 and employs CiteSpace 6.2 to conduct a systematic scientometric analysis and visualization. From multiple dimensions — including publication trends, institutional collaboration networks, keyword co-occurrence clustering, and burst term evolution—it outlines the developmental trajectory and key characteristics of the field.

First, from a temporal perspective, virtual museum research has evolved from steady growth to rapid expansion over the past fifteen years. Since the outbreak of the COVID-19 pandemic in 2020, virtual museums have gained global attention as alternative spaces for cultural communication and public education, leading to a sharp increase in publications within a short period (Giannini & Bowen, 2022). Research topics have expanded from an early focus on technical implementation—such as 3D modeling and digital exhibition systems—to broader concerns including cultural experience, emotional storytelling, and digital participation (Lian & Xie, 2024). This shift indicates a transition from a technology-centered paradigm to a human-centered one, with increasing integration of theories from cultural heritage studies, interaction design, communication studies, and artificial intelligence. This transformation is also reflected in methodological evolution—from early-stage prototype development and usability testing to more diversified and rigorous mixed-method approaches combining surveys, interviews, and user behavior analysis.

Second, in terms of international collaboration, the field exhibits a multi-centered structure dominated by European institutions, with contributions from North America and Asia. Institutions such as the University of Crete, Technical University of Crete, Coventry University, and Concordia University occupy central positions in both research output and collaboration networks (Bekele & Raj, 2025). However, overall collaboration density remains low, with limited intercontinental cooperation and evident regional fragmentation (Ozden, 2022). This suggests that while several mature academic communities have formed, structural barriers still exist in global knowledge sharing, standard harmonization, and multilingual research communication. Strengthening international collaboration through joint projects, global conferences, and open-access platforms will be essential for enhancing knowledge exchange and innovation.

Third, based on keyword clustering and burst analysis, the thematic evolution of virtual museum research can be summarized as a progression from “technical visualization” to “semantic experience” and then to “intelligent integration.” Early-stage keywords were predominantly technical—such as “3D modelling,” “virtual reality,” and “augmented reality” —whereas recent years have seen the emergence of concepts like“interactive storytelling ,” “AI curation,” “digital twins,” and “semantic metadata” (Song & Evans, 2024). This shift signals the entry of the field into a new phase characterized by the integration of semantic intelligence and cultural narrative. Emerging technologies—including artificial intelligence, knowledge graphs, and mixed reality—are reshaping curatorial practices and audience interaction models. The temporal distribution of clusters further supports this trajectory: technology-oriented clusters (e.g., #0 Efficient Axial Symmetry, #9 Photorealistic 3D Modelling) appear earlier, while

experience- and intelligence-oriented clusters (e.g., #1 Virtual Museum, #8 Digital Knowledge) remain active in later stages.

Overall, virtual museum research has evolved from a focus on 3D reconstruction and digital display to a new stage characterized by cultural experience, user co-creation, and intelligent curation. The field demonstrates strong interdisciplinary integration, combining technological innovation from information science and computer vision with theoretical contributions from cultural heritage, education, and communication studies (Lian & Xie, 2024). While this interdisciplinarity enriches the field, it also raises higher demands on researchers, who increasingly need to balance technical expertise with humanistic understanding.

5.2 Future Directions

Based on keyword burst analysis and clustering structures, several key directions for future research can be identified:

First, strengthening interdisciplinary integration. The complexity of virtual museums requires bridging the gap between technology and the humanities. Future studies should promote collaboration among information science, educational technology, communication studies, and cognitive psychology to better understand immersive learning and digital cultural experiences. For instance, emotional responses and cultural acceptance in virtual environments have been shown to be closely related (Pedroli et al.,2021). Integrating neurocognitive methods—such as eye-tracking, EEG, and physiological measurements—could provide more objective insights into user attention, emotional states, and cognitive load, thereby informing design optimization. The incorporation of educational and communication theories can further clarify how virtual museums function in both formal and informal learning contexts and how they shape public cultural understanding and identity.

Second, developing intelligent curation systems. With advances in artificial intelligence and knowledge graph technologies, curatorial practices are shifting from manual decision-making to algorithm-driven processes. AI-based semantic recommendation and image recognition can support personalized exhibition generation and adaptive narrative design (Cai, Zhang & Pan, 2023). However, attention must be paid to issues such as algorithmic bias, ethical concerns, and system transparency. Future intelligent curation systems should not only recommend content but also function as interactive agents that guide users through cultural exploration while maintaining diversity and inclusivity.

Third, exploring metaverse-based virtual exhibitions. The development of metaverse technologies offers new possibilities for virtual museums, including virtual guides, co-created spaces, and digital twin exhibitions (Serhal, 2024). These environments enable immersive and socially interactive experiences, particularly valuable in education and public cultural services. By allowing users to navigate 3D spaces through avatars and engage in real-time interaction, metaverse museums may attract broader audiences, especially younger users. However, challenges remain in terms of high technical thresholds, development costs, and device accessibility.

Fourth, advancing data standardization and governance mechanisms. Virtual museums currently face issues such as fragmented data and lack of unified standards. Future efforts

should focus on metadata standardization, cross-institutional interoperability, and the development of open knowledge-sharing platforms. Initiatives led by organizations such as Europeana and UNESCO provide important references for global cultural data governance (Kwiecien, Chansanam & Tuamsuk, 2025). Beyond technical standards, governance also involves copyright management, quality control, and sustainable development models, requiring coordinated efforts across governments, academia, cultural institutions, and industry.

Fifth, building global empirical research frameworks. This study highlights the current lack of large-scale, cross-cultural empirical research in virtual museum studies. Future work should promote international, comparative research projects to examine user acceptance, behavior, and cultural experiences across different contexts. Such efforts would enhance the generalizability of existing theories and help identify cultural differences that influence design and usage. Moreover, standardized methodologies would improve comparability across studies and accelerate knowledge accumulation.

In sum, virtual museum research is at a critical turning point, shifting from technology-driven development to intelligence-enabled innovation. Strengthening international collaboration, establishing ethical frameworks, and advancing data standardization will be essential for transforming virtual museums from digital display platforms into key hubs for cultural memory preservation, educational innovation, and cross-cultural dialogue (Pioli, 2024). This study, through visualization-based analysis, provides both an empirical overview and methodological reference for advancing theoretical development and internationalization in this field.

ACKNOWLEDGEMENTS

This thesis brings to an end a period that was, at times, uncertain and slow, but also quietly meaningful. More than a finished piece of work, it records a process of hesitation, revision, and gradual understanding. Along the way, I have not been alone.

My deepest thanks go to my supervisors, Dr. Hamidah and Dr. Chcok. There were many moments when I felt stuck, unsure how to move forward, and it was often through their guidance that things became clearer again. They never rushed the process, but instead allowed me to find my own way while offering support at the right time. I am especially grateful to Dr. Chcok for her patience in helping us navigate research software and for creating spaces where we could learn together. What stays with me most is not only what they taught, but how they approached research—with care, consistency, and quiet dedication.

I also want to thank the lecturers in the Education program at UNIRAZAK. Slowly, through classes and everyday conversations, my understanding of research started to change. I stopped seeing it as something to get done fast, and started realizing it's something that takes time to truly understand.

I would like to thank my classmate, Zhang Zelin. His willingness to share his experience and walk me through the technical details, step by step, made many difficult parts of this process manageable. Those moments of help were more important than they may seem.

I am also grateful for the tools and resources, such as Web of Science and CiteSpace, which made this research possible in a practical sense.

Finally, to my family—thank you. There were times when progress felt slow and frustrating, but knowing that you were there, quietly supporting me, made it easier to keep going. That sense of stability meant more than I can fully express.

Looking back, this thesis is far from perfect. But it is honest. It reflects where I am at this moment, and the effort I was able to give. For that, and for everyone who has been part of this journey, I am truly grateful.

REFERENCES

AlGerafi, M. A., Zhou, Y., Oubibi, M., & Wijaya, T. T. (2023). Unlocking the potential: A comprehensive evaluation of augmented reality and virtual reality in education. Electronics, 12(18), 3953.

Ajani, Y. A., Oladokun, B. D., Olarongbe, S. A., Amaechi, M. N., Rabiu, N., & Bashorun, M. T. (2024). Revitalizing indigenous knowledge systems via digital media technologies for sustainability of indigenous languages. Preservation, digital technology & culture, 53(1), 35-44.

Bekele, H., & Raj, S. (2025). Digitalization and digital transformation in the tourism industry: a bibliometric review and research agenda. Tourism Review, 80(4), 894-913.

Cai, P., Zhang, K., & Pan, Y. (2023). Application of AI interactive device based on database management system in multidimensional design of museum exhibition content.

Chunlan, Y., Tengku Wook, T. S. M., & Rosdi, F. (2025). Advancing cultural heritage: a decadal review of digital transformation in Chinese museums. NPJ Heritage Science, 13(1), 189.

De Mello, B. H., Rigo, S. J., Da Costa, C. A., da Rosa Righi, R., Donida, B., Bez, M. R., & Schunke, L. C. (2022). Semantic interoperability in health records standards: a systematic literature review. Health and technology, 12(2), 255-272.

Gurel, E. (2025). AI-driven experiences in cultural and creative industries: a review of literature and development of a multifaceted framework. The Service Industries Journal, 1-40.

Giannini, T., & Bowen, J. P. (2022). Museums and digital culture: From reality to digitality in the age of COVID-19. Heritage, 5(1), 192-214.

Kneppers, T. (2024). User Interaction in the Online Curation of Digital Collections (Doctoral dissertation, London South Bank University).

Kwiecien, K., Chansanam, W., & Tuamsuk, K. (2025, September). Digital Cultural Heritage in Southeast Asia: Knowledge Structures and Resources in GLAM Institutions. In Informatics (Vol. 12, No. 3, p. 96). MDPI.

Lee, C. W., Sohn, D. G., Sang, M. G., & Lee, C. (2025). Empirical analysis of barriers to collaborative information sharing in maritime logistics using fuzzy AHP approach. Sustainability, 17(4), 1721.

Lund, B. D., Wang, T., Shamsi, A., Abdullahi, J., Awojobi, E. A., Borgohain, D. J., ... & Yusuf, A. O. (2023). Barriers to scholarly publishing among library and information science researchers: International perspectives. Information Development, 39(2), 376-389.

Lin, Y., Frey, C. B., & Wu, L. (2023). Remote collaboration fuses fewer breakthrough ideas. Nature, 623(7989), 987-991.

Lian, Y., & Xie, J. (2024). The evolution of digital cultural heritage research: Identifying key trends, hotspots, and challenges through bibliometric analysis. Sustainability, 16(16), 7125.

Li, X., Tang, X., Zheng, X., Huang, Y., & Tu, Y. (2025). Exploring the AIGC-driven co-creation model in art and design education: insights from a student workshop and exhibition. International Journal of Technology and Design Education, 1-31.
Muhmad Asri, F. H., Singh, D., Mansor, Z., & Norman, H. (2024). A Review of Cross-Cultural Design to Improve User Engagement for Learning Management System. KSII Transactions on Internet & Information Systems, 18(2).
Ozden, H. U. (2022). Reshaping the past: Contemporary art museum's potential to reshape the art history. UNIMUSEUM, 5(1), 37-43.
Pedroli, E., Serino, S., Pallavicini, F., Cipresso, P., & Riva, G. (2021). Exploring virtual reality for the assessment and rehabilitation of executive functions. In Research Anthology on Rehabilitation Practices and Therapy (pp. 866-884). IGI Global.
Pietroni, E., & Ferdani, D. (2021). Virtual restoration and virtual reconstruction in cultural heritage: terminology, methodologies, visual representation techniques and cognitive models. Information, 12(4), 167.
Pioli, M. (2024). Museums of the future: Digitalisation as a new form of communication.
Serhal, S. (2024). User experience in virtual worlds: an interaction design analytical framework.
Shen, C. W., & Tran, P. P. (2025). An assessment of blockchain academia and news developments: a bibliometric and text-mining analysis. Library Hi Tech, 43(1), 326-352.
Song, Z., & Evans, L. (2024). The museum of digital things: extended reality and museum practices. Frontiers in Virtual Reality, 5, 1396280.
Tao, D., Fu, P., Wang, Y., Zhang, T., & Qu, X. (2022). Key characteristics in designing massive open online courses (MOOCs) for user acceptance: An application of the extended technology acceptance model. Interactive Learning Environments, 30(5), 882-895.
Turner, R., Cotton, D., Morrison, D., & Kneale, P. (2024). Embedding interdisciplinary learning into the first-year undergraduate curriculum: drivers and barriers in a cross-institutional enhancement project. Teaching in Higher Education, 29(4), 1092-1108.
Wang, X., Hong, Y., & He, X. (2024). Exploring artificial intelligence generated content (AIGC) applications in the metaverse: Challenges, solutions, and future directions. IET Blockchain, 4(4), 365-378.
Winter, T. (2022). Geocultural power and the digital Silk Roads. Environment and Planning D: Society and Space, 40(5), 923-940.
Xiong, X., Wang, Y., Ma, C., & Chi, Y. (2023). Ensuring the authenticity of the conservation and reuse of modern industrial heritage architecture: a case study of the large machine factory, China. Buildings, 13(2), 534.
Xu, J., & Pan, Y. (2024). The Future Museum: Integrating Augmented Reality (AR) and Virtual-text with AI-enhanced Information Systems. J. Wirel. Mob. Networks Ubiquitous Comput. Dependable Appl., 15(3), 373-394.
Yang, L., Cheng, N., Jiang, P., & Noriega, P. (2024, June). Virtual museums: State of the art, trends, and challenges. In International Conference on Human-Computer Interaction (pp. 226-237). Cham: Springer Nature Switzerland.
Yang, L., Ni, S. T., Wang, Y., Yu, A., Lee, J. A., & Hui, P. (2025). Interoperability of the metaverse: A digital ecosystem perspective review. IEEE Engineering Management Review.

Zhao, W., Su, L., & Dou, F. (2023). Designing virtual reality based 3D modeling and interaction technologies for museums. Heliyon, 9(6).
Zhang, J., Zhu, T., & Hu, C. (2025). Application model of museum cultural heritage educational game based on embodied cognition and immerse experience. ACM Journal on Computing and Cultural Heritage, 18(2), 1-17.