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# VIRTUAL REALITY, AUGMENTED REALITY AND EXTENDED REALITY FOR HERITAGE INTERPRETATION AND PRESENTATION: A BIBLIOMETRIC ANALYSIS

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## ABSTRACT

*Extended Reality, which includes Virtual Reality and Augmented Reality, has become an increasingly important medium for enhancing cultural interpretation, knowledge communication and user engagement in heritage contexts. However, despite growing scholarly attention, research on XR in heritage remains fragmented and lacks a consolidated understanding of its thematic development and intellectual structure. This study examines global scientific output on VR, AR and XR in heritage interpretation published between 2020 and 2024. A bibliometric analysis was conducted using the Scopus database, supported by VOSviewer and citation analysis, to identify publication trends, leading contributors, influential studies and thematic clusters. The findings show a clear growth in publications during the study period, with major contributions from China, Italy and the United States, as well as prominent institutions such as FORTH and Politecnico di Milano. Five main research clusters were identified, namely 3D modelling and historic preservation, immersive learning and virtual museums, artificial intelligence and photogrammetry, the metaverse and education and digital twins in intangible heritage. Overall, the study highlights the growing convergence between technological innovation and heritage engagement, while providing a structured reference for future research, practice and policy development in immersive heritage technologies.*

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## 1. Introduction

Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) of Extended Reality (XR) have become a breakthrough in the field of digital heritage today (Innocente et al., 2023, p. 268). Anwar et al. (2025) declared that such immersive tools ensure novel means of cultural

interpretation, helping to encounter the historical narrative and heritage places through dynamic online environments in a user-centred way (Anwar et al., 2025, p.7). Unlike traditional forms of fixed display, XR technologies encourage experiential learning and embodied cognition. This allows for substantial engagement with non-material elements in culture such as rituals, oral histories and intangible histories (Doukianou & Lalioti, 2024, p.301). As such, XR is becoming common in museums, heritage interpretation centres and conservation projects worldwide (Gatto et al., 2024, p. 321).

It was at the beginning of the 2000s that the impact of XR technologies on heritage protection emerged due to interdisciplinary innovations in the spheres of computer science, digital humanities and architecture. Correspondingly, many educational facilities have integrated the idea of immersive technology in making virtual museum constructs, building historical re-enactments and enhancing the concept of storytelling inclusively (Leonardi et al., 2023, p. 60; Yang et al., 2024, p. 226). Examples of pioneering work included the European Union (EU) funded projects INCEPTION and V-Must which highlighted the value and necessity of user-centred design of heritage VR/ AR applications and brought the industry to the participatory and educational (Del Vecchio et al., 2025, p. 2). Nevertheless, although the use of XR in heritage interpretation has advanced under these conditions, research on the implementation and effect of XR in heritage interpretation is fragmented. In addition, it is essential to provide a general bibliometric analysis of this field, which would reveal the brightest spots and thematic trends (Doukianou & Lalioti, 2024; Mudička & Kapica, 2023, p. 120).

There are several assessments that concentrate on the application of VR or AR regarding heritage, focusing on educational outcomes, usability and visualization approaches (Neamu et al., 2024, p. 5; Tsita et al., 2023, p. 4136). However, no proficient studies that summarize the scientific product and resolve the work of research productivity, theme formulation and interplanetary networks in XR-based heritage interpretation exist to date (Alviz-Meza et al., 2022, p. 3). Additionally, the usefulness and challenges of XR are associated with various scholarly opinions. On the one hand, XR is viewed as a tool for democratizing access and enhancing user experience (Shim et al., 2023, p. 1459). Conversely, it is argued to be technologically dependent, costly and leading to cultural misrepresentation (Mavrin et al., 2023, p. 289). This discussion reveals the need to establish an epistemic outline within this new field of science to develop informed progression in the future (Yoo & Yu, 2024, p. 25877).

Quantitative assessment of bibliometric analysis is a methodological procedure to study the regularities of scientific literature (Öztürk et al., 2024, p.3334). Passas (2024) stated that it is useful in identifying tendencies, authors on the rise, institutions and common themes being studied in a subject (Passas, 2024, p. 1020). Such tools as VOSviewer and Scopus analytics allow mapping the co-occurrence of the keywords, analysis of citations and locating international research collaborations (Huang et al., 2025, p. 1160). Furthermore, bibliometric analysis, in the case of XR and digital heritage, offers insights into the scholarly development, unexplored topics and emerging clusters that drive the research front (Zhang et al., 2024, p. 2).

This investigation is designed to review the scientific development of such spheres as XR, VR and AR studies of the interpretation and presentation of heritage and historical areas. Bibliometric study consists of investigating publication trends, thematic concentrations and author contributions via analysis of indexed documents in the Scopus database over 2020-2024. The conclusions of this analysis provide an all-inclusive understanding of the applications being made of immersive technologies within the realm of heritage that researchers as well as practitioners could use in the future to streamline their work in the field with the grounded knowledge.

### **1.1 The Research Question**

The research question, which serves as the basis of this entire bibliometric analysis, presupposes the identification, collection, and analysis of data. The intended audience for the research will include scholars, heritage professionals, policymakers and technology developers interested in the adoption of XR technologies in cultural heritage. The idea is to achieve a systematic grasp of world research trends and highlight topics that should be further explored. This part presents major questions that the current study is aimed at answering:

- What has been the history of publication on XR, VR, and AR in heritage interpretation and presentation since 2020?
- What are the most comprehensive XR and heritage-related publications, and what are their qualities (e.g., indexing, impact factor)?
- What are the main thematic directions and conceptual frameworks used in studies of XR in the context of heritage settings?
- Which are the most prominent writers in this field? Which organizations and countries play the most significant roles in XR-based heritage research?
- Which are the most cited papers in this field, and how do they facilitate the advancement of heritage technologies?
- How to determine the research patterns that prevail using the keyword co-occurrence or bibliographic coupling?

The formulation of these questions is the basis of bibliographic analysis, allowing for exploring the research trends, intellectual frameworks and developing terms in the sphere of XR-driven heritage research. In essence, results will provide insightful support to the institution and real-world application of this interdisciplinary area of study which is undergoing immense development.

## **2. Materials and Methods**

The term bibliometrics (deriving in part etymologically from the prefixes bi and -metrics) was first used in 1969 by Alan Pritchard to mean the quantitative study and statistical analysis of publications. He introduced the term to summarize the scientific analysis of textual communication and means of transmission patterns in the field of information science (Donthu et al., 2021, p. 288). According to Rojas-Sánchez et al. (2023), the conceptual framework and development of scientific disciplines can be analysed with the help of bibliometric tools, which prove to be vital in their study (Rojas-Sánchez et al., 2023, p. 162). Bibliometric research helps to identify the trends of publications, working authors and themes and patterns and thus

provides an empirical basis to understand the scholarly output and influence (Mukherjee et al., 2022, p.110).

In the sphere of heritage, where the intersection of disciplines is a common phenomenon, the bibliometric study is a precise way of outlining the research area, revealing the networks of the research era and evaluating how the comparatively new technologies including XR, VR and AR are introduced to the academic community (Syahrial et al., 2024, p. 8). The proposed paper will employ a bibliometric methodological approach that analyses scientific production associated with immersive technologies as a means of heritage interpretation and presentation. It is aimed at defining the tendencies, major contributions, and fundamental groups of research that determine the current state of knowledge in this area.

This research employed a quantitative bibliometric method, focusing on data extracted from the Scopus database. Scopus was selected for its wide coverage of peer-reviewed literature and indexed conference proceedings. The search was conducted using a combination of terms related to immersive technologies and heritage applications.

A search strategy to be used was as follows:

Title: “Extended Reality” OR “Augmented Reality” OR “Virtual Reality” OR “Mixed Reality” AND “Heritage” OR “Cultural Heritage” OR “Heritage Interpretation”

DocType: Article OR Review

PubYear: 2020 to 2024

### 3. Results

This five-year period was marked by a significant increase in literature on XR, including VR, AR, and MR in cultural heritage. According to Scopus records, there are 11,126 documents on the topic between 2020 and 2024, and the output is expected to rise, resulting in 3,373 documents in 2024. The current year-on-year growth (Figure 1) illustrates an increase in the number of research papers covering the domain, surpassing the volume of published works per year by more than twofold in less than a decade. The fact that this growth has been rapid implies that the concept of immersive technology in heritage interpretation has become a prevalent area of research within the last few years.

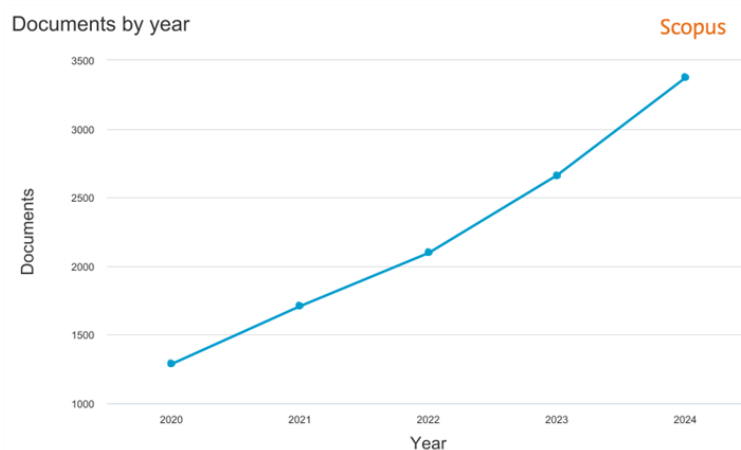


Figure 1. Annual number of Scopus-indexed documents on XR for heritage interpretation/ presentation (2020–2024)

It is a table that ranks academic journals and proceedings at conferences by the quantity of publications, including both research disciplines and geographical conditions (Table 1). The leading publication with 492 papers is Switzerland Sustainability. This is followed by the United States (US) ACM International conference proceedings series, with 333, and the third is Switzerland Applied Sciences, with 290 publications. The venues cover a wide range of topics, including environmental science, computer science, engineering, humanities, and multidisciplinary fields, with contributions from articles from countries like Switzerland, the US, Germany, and Spain. The statistics indicate that these publications vary in different performance indicators: citation profiles range from 0.8 to 6.1, with IEEE Access having the highest score. The journals occupy varied ranks: Q1 to Q4, with accompanying varying sufficiency of academic status and influence. Most quality-performing venues, such as “Conference on Human Factors in Computing Systems Proceedings,” “IEEE Access,” both assigned Q1 journals, and the Spanish journal Applied Mathematics and Nonlinear Sciences, whose performance is assigned the low number rank Q4 based on citation parameters.

We yield 11,970 keywords. The 20 most common keywords are VR, AR, Cultural Heritage, Three-Dimensional (3D) Computer Graphics, 3D Modeling, E-learning, Photogrammetry, Tourism, Immersive, Artificial Intelligence, Architectural Design, Historic Preservation, Students, Visualization, Museums, MR, Deep Learning, Human and Image Reconstruction (Figure 2).



Figure 2. Most common keywords

Finally, there are bibliometric trends that present interesting research clusters and influence patterns. This is indicated by citation analysis: there are some highly influential papers (many of which comprise an overview or framework), supplying the community with a source of reference. In the meantime, the co-word and thematic analysis selected unique groups of works. A major group of activities involves the application of AR and 3D scanning/ photogrammetry methods for the digital reconstruction of historic buildings and artifacts. The other significant cluster forms around MR and immersive storytelling related to heritage and tends to focus on intangible cultural heritage preservation as well as increasing museum visitors’ education. Significantly, scientists use AR more often than VR in such settings, capitalizing on the feature of AR to project digital content into real-life images. As the XR-for-heritage literature

continues to grow (currently numbering around 250 bibliographical entries), it appears increasingly convergent around the idea that technology-driven innovation (high-fidelity digital preservation and simulation) and user-centred design (interactive learning and user experience) approaches. Each is in balance with the other, suggesting an aging field with multiple clearly defined research directions. The following figure presents the network visualization of the keywords (Figure 3). It is possible to verify that there are five keyword clusters:

- C1: 3D modelling, cultural heritage, helmet-mounted display, historic preservation, 3D computer graphics, user experience;
- C2: AR, education, immersive, metaverse, virtual environments, virtual museum, VR;
- C3: article, deep learning, human, photogrammetry, teaching, tourism;
- C4: adversarial machine learning, artificial intelligence, contrastive learning, federated learning, machine learning, VR;
- C5: architectural heritage, digital protection, digital twin, Historic Building Information Modelling (HBIM), information management, intangible cultural heritage.

Table 1. Journal information

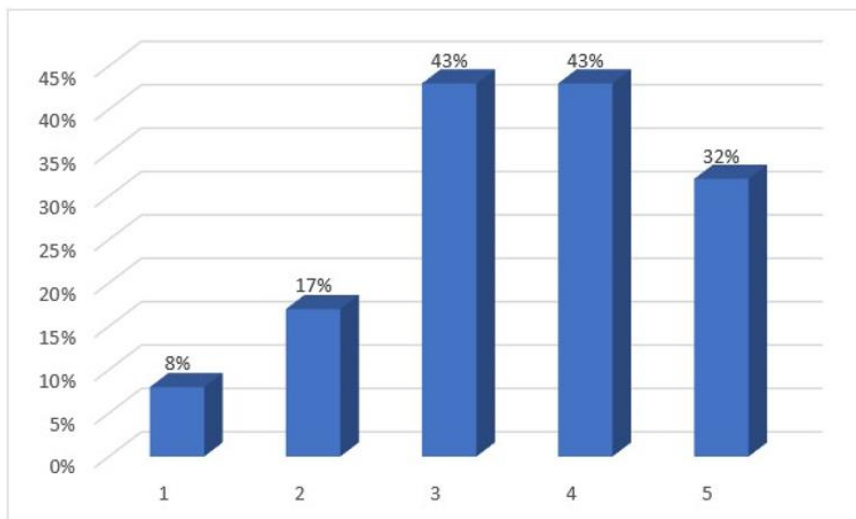
Journal	#	Country	Cite Score	SJR	SNIP	Subject (Category)	Q	H I
Sustainability (Switzerland)	492	Switzerland	5.3	0.61	1.09	Environmental Science, Energy, Social Sciences	Q2/Q3	130
ACM International Conference Proceeding Series	333	United States	0.8	0.15	0.25	Computer Science	Q4	96
Applied Sciences (Switzerland)	290	Switzerland	4.7	0.48	1.11	Engineering, Physics, Materials Science	Q2	86
International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	248	Germany	2.4	0.34	0.78	Earth & Planetary Sciences, Computer Science	Q3	50
Heritage	172	Switzerland	3.1	0.47	0.87	Arts & Humanities, Engineering	Q2	15



number of 17%. These figures provide evidence that works with three authors and those with four authors comprise 43% of the overall amount. This leads to the conclusion that small groups of collaborators as contributors to the given study direction are the most common approach. The percentage of the authors of papers reduces to 32%, which indicates that there are cases of larger teams conducting the research. However, the tendency weakens with an increase in team size. This distribution scheme depicts the conservative academic cooperation pattern. Notably, moderate research groups (3 to 4 authors) are favoured and supposedly combine the benefits of diversified knowledge and workload distribution, and the cooperation problems characteristic of large teams.

Figure 4. Number of authors

The table reveals the most prolific authors in the dataset, listing researchers who have published



17 or more articles based on the Scopus data (Table 2). Partarakis, N. leads with 30 articles, closely followed by Zabulis, X., with 23 articles. Both are members of the Institute of Computer Science at FORTH in Greece. The list also indicates a high rate of representatives from the Italian scientific community who are also researchers. This includes Pierdicca, R. of the Polytechnic University of Marche (20 works), Banfi, F. of Politecnico di Milano (19 works), and some others from the Italian universities and research centers, namely Institute of Information Science and Technologies – National Research Council (ISTI-CNR), National Research Council – Institute of Heritage Science (CNR ISPC) and Fondazione Bruno Kessler (FBK). There are also several representative institutions in Greece, FORTH and the University of the Aegean, and one representative from China, Li, Y., from the Beijing Jiaotong University. The distribution across the geography indicates that there is active cooperation on research or a common area of research in European institutions, especially in Greece and Italy. Remarkably, these hyper-prolific authors are the driving force in their respective areas of discipline.

Table 2: Authors with more articles

Author	#	Organization
Partarakis, N.	30	Institute of Computer Science, FORTH, Greece
Zabulis, X.	23	Institute of Computer Science, FORTH, Greece
Pierdicca, R.	20	Polytechnic University of Marche, Italy
Banfi, F.	19	Politecnico di Milano, Italy
Zidianakis, E.	19	FORTH, Greece
Bevilacqua, A.	18	ISTI-CNR, Pisa, Italy
Li, Y.	18	Beijing Jiaotong University, China
Quattrini, R.	18	CNR ISPC, Italy
Remondino, F.	17	FBK, Italy
Sylaiou, S.	17	University of the Aegean, Greece

<sup>2</sup> Scopus

These maps illustrate the geographic and institutional powers that prevail in such a research area, and it is observed that there is a specific density among the European institutions, and they are widespread globally in pathways per country (Table 3). Italian institutions are leading at this level, with the first place being mostly Politecnico di Milano, positioned at 140 references. This is followed by Consiglio Nazionale delle Ricerche and CNRS Center National de la Recherche Scientifique (France), which are both ranked at 129 references. Other European universities with more than 80 references include Sapienza Università di Roma (91 references), Alma Mater Studiorum Università di Bologna (86 references), and Politecnico di Torino (82 references), and Greek ones such as the University of the Aegean (75 references). Meanwhile, the analysis based on country level illustrates the other trend, that the country with the largest volume of documents is China (about 2,500), then Italy (about 1,300), the US (about 1,000), and the United Kingdom (UK) (about 750 documents) (Figure 5). This implies that the single Italian and European institutions, in general, could be characterized as a centralized collection of research with a high rate of citations. Conversely, China has more institutions to incorporate the field into, considering its significant distribution in relation to the number of institutions. This density of countries can be noted in Figure 6.

Table 3: Organization with more references

Organization	References
Politecnico di Milano	140
Consiglio Nazionale delle Ricerche	129
CNRS Centre National de la Recherche Scientifique	100
Sapienza Università di Roma	91
Alma Mater Studiorum Università di Bologna	86
Politecnico di Torino	82
University of the Aegean	75
Ministry of Education of the People's Republic of China	72
Chinese Academy of Sciences	72
University College London	72

<sup>3</sup> Scopus

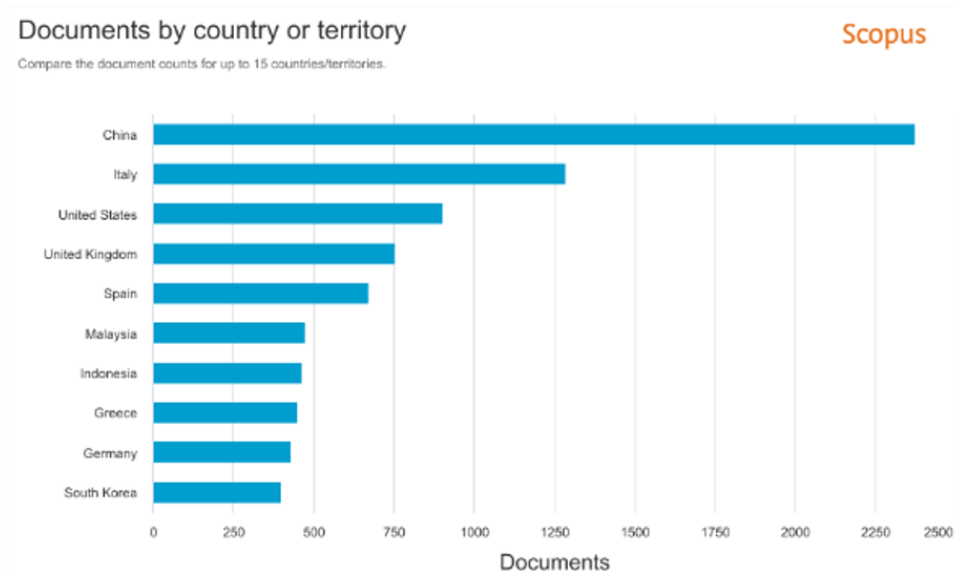


Figure 5. Top 10 contributing countries

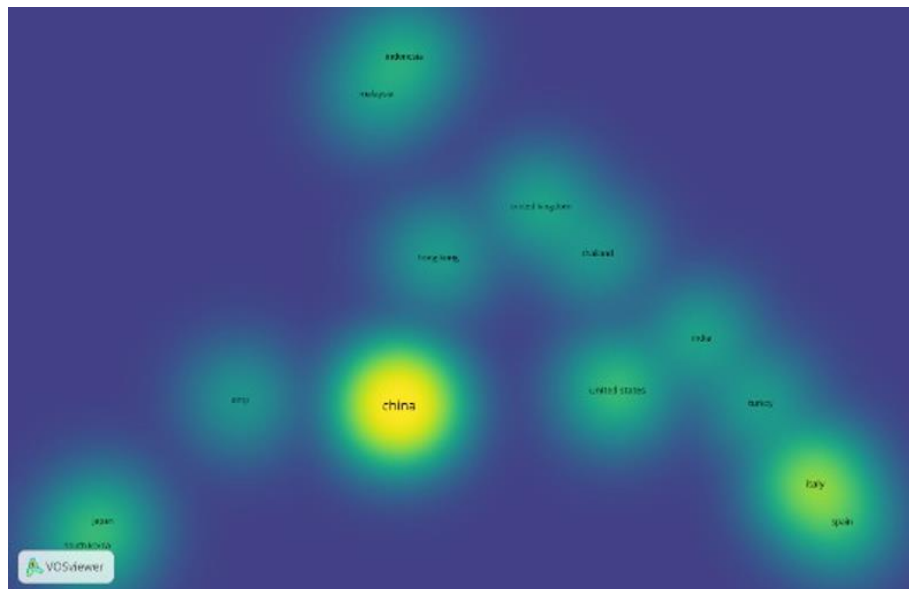


Figure 6. Density visualization, countries

Table 4: Most cited papers

Author	Year	Title	Journal	Times
M.K. Bekele	2018	A survey of augmented, virtual, and mixed reality for cultural heritage	Journal on Computing and Cultural Heritage	706
N. Chung	2015	Tourists' intention to visit a destination: The role of	Computers in Human Behavior	472

augmented reality (AR)  
 application for a heritage site

M.C. tom Dieck	2018	A theoretical model of mobile augmented reality acceptance in urban heritage tourism	Current Issues in Tourism	352
N. Chung	2018	The Role of Augmented Reality for Experience-Influenced Environments: The Case of Cultural Heritage Tourism in Korea	Journal of Travel Research	304
M.C. tom Dieck	2017	Value of augmented reality at cultural heritage sites: A stakeholder approach	Journal of Destination Marketing and Management	257
T.H. Jung	2017	Augmented reality, virtual reality, and 3D printing for the co-creation of value for the visitor experience at cultural heritage places	Journal of Place Management and Development	245
Y.L. Chang	2015	Apply an augmented reality in a mobile guidance to increase the sense of place for heritage places	Educational Technology and Society	226
A.C. Haugstvedt	2012	Mobile augmented reality for cultural heritage: A technology acceptance study	Ismar 2012 11th IEEE International Symposium on Mixed and Augmented Reality 2012 Science and Technology Papers	223
D.I. Han	2018	User experience model for augmented reality applications in urban heritage tourism	Journal of Heritage Tourism	215
T.H. Jung	2018	Cross-cultural differences in adopting mobile augmented reality at cultural heritage tourism sites	International Journal of Contemporary Hospitality Management	214

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The presented table outlines the most frequently cited articles in the research area that are related to AR implementation in cultural heritage and tourism, with the number of citations ranging from 214 to 706 (Table 4). The survey by M.K. Bekele in 2018 on AR, VR, and MR in cultural heritage, published in the *Journal of Computing and Cultural Heritage*, has a leading citation list of 706 citations. The period in the research is between 2012 and 2018, and there are several prolific authors recurring, such as N. Chung, M.C. tom Dieck, and T.H. Jung. This suggests that they are great contributors to the subject area. Furthermore, most of the paper discussions revolve around the themes of tourist behaviour, AR adoption within a heritage

attraction, mobile AR use in a heritage attraction, the use of stakeholders in heritage tourism, and differences between cultures in the adoption of technology. In addition, the articles are presented in a wide variety of journals such as tourism-oriented ones (Current Issues in Tourism, Journal of Travel Research), technology journals (Educational Technology and Society), and dedicated journals about heritage fields (Journal of Computing and Cultural Heritage, Journal of Heritage Tourism). This is indicative of the interdisciplinary nature of AR scholarship on cultural heritage applications. Accordingly, the endorsement by the academic community is even more evident by the fact that the number of citations of research on digital technologies integration in the context of culture preservation and tourism promotion remains relatively high.

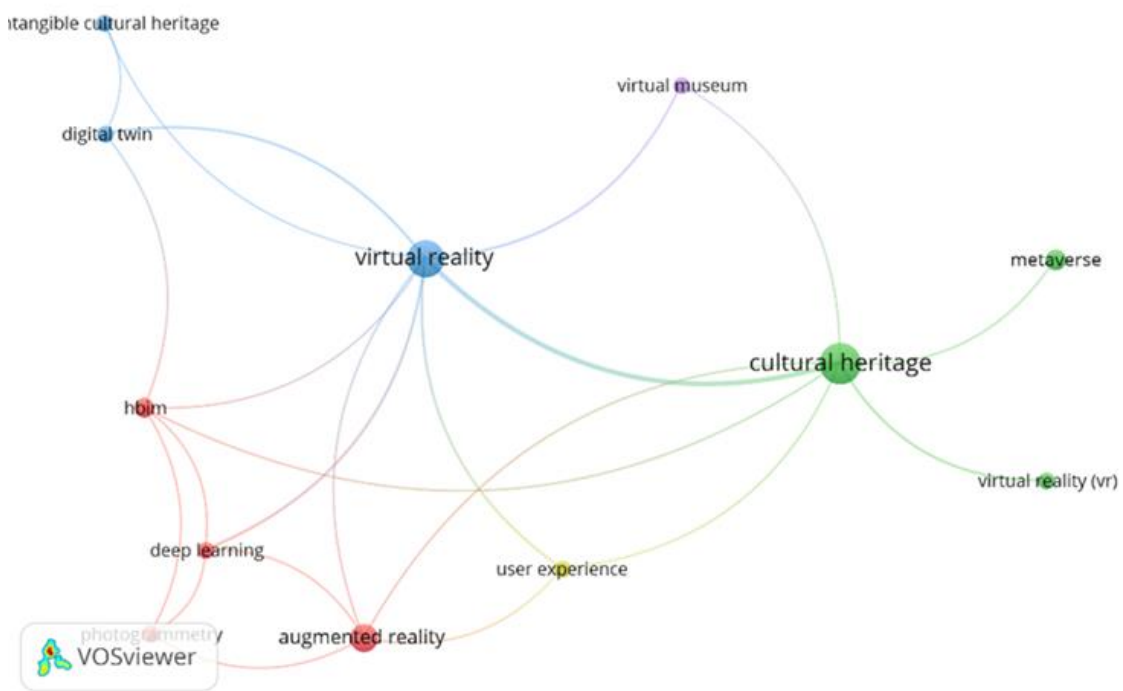


Figure 7. Keywords co-occurrence network

This map is used to demonstrate how clusters of commonly used words in the literature have a group of words that occur together in a significant way. The key nodes, like VR, AR and cultural heritage, are in proximity to each other, implying areas of main concern. Such associated terms as the digital twin, deep learning, virtual museum, and metaverse indicate the directions of the future of immersive heritage technologies and interdisciplinary innovation (Figure 7).

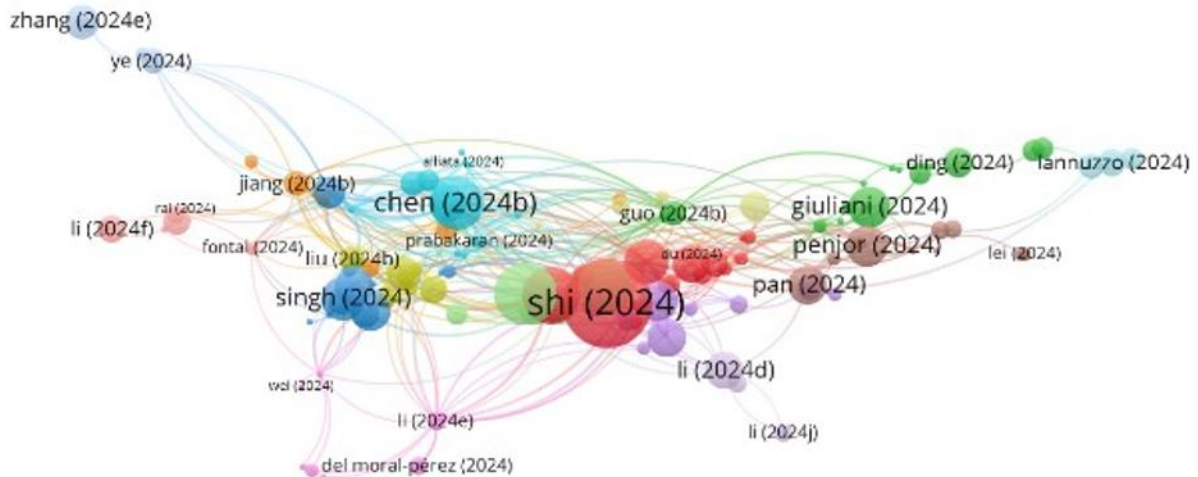


Figure 8. Author bibliographic coupling network

The network displays the intensity of common references among authors, which implies thematic correspondences and discursive similarity. The size of nodes (e.g., Shi, Chen, Singh) reflects the high bibliographic connectivity of the authors, whereas the links represent the degree of co-citation. The grouping implies the presence of various research communities that imply potential collaborations and major scholarly groups in the field (Figure 8).

#### 4. Discussion

The purpose of this paper is to analyse the research landscape of XR, VR, and AR in heritage interpretation by mapping trends, identifying key contributors, and highlighting emerging themes in Scopus-indexed publications from 2020 to 2024. The sample was composed of 11,127 articles and reviews in total. The following section addresses the research questions:

- What has been the history of publication on XR, VR and AR in heritage interpretation and presentation since 2020?  
 From 2020 to 2024, there has been a significant surge in publications, exceeding 11,000 indexed papers, reflecting an escalating interest in immersive technologies for heritage interpretation.
- What are the most comprehensive XR and heritage-related publications, and what are their qualities (e.g., indexing, impact factor)?  
 Among the leading are Sustainability (Switzerland), ACM International conference Proceedings and Applied Science, among other areas that are ranked differently in terms of quality (Q1-Q4), and content of citation that ranges in IEEE Access to the high point of 6.1.
- What are the main thematic directions and conceptual frameworks used in studies of XR in the context of heritage settings?  
 Main themes in the field are virtual museums, digital storytelling, photogrammetry, immersive learning, user experience and intangible cultural heritage, whose general

principle is participatory and user-centred design.

- Which are the most prominent writers in this field? Which organizations and countries play the most significant roles in XR-based heritage research?  
Leading authors are Partarakis N. and Zabulis X. of FORTH, Greece. Politecnico di Milano and CNR (Italy) are the most contributing institutions, whereas the two most productive countries are China and Italy, along with the US.
- Which are the most cited papers in this field, and how do they facilitate the advancement of heritage technologies?  
Bekele et al. (2018) is the most cited paper, with 706 citations, and followed by works by Chung and Tom Dieck. These works of literature emphasize the AR adoption and use, and mobile AR in tourism, which contributes to the development of future research directions.
- How to determine the research patterns that prevail using the keyword co-occurrence or bibliographic coupling?  
Five thematic clusters can be observed in keyword co-occurrence maps (e.g., 3D modelling, immersive learning, AI). Bibliographic coupling suggests author groups and collaboration patterns in Europe and Asia.

## 5. Conclusion

In this work, the bibliometric scenario of XR, VR, and AR in heritage interpretation and presentation was examined based on the calculation of publication trends, the most active authors, and thematic changes between 2020 and 2024. The results indicated that there was indeed a significant increase in academic production, more than 11,000 scholarly works that were indexed by Scopus, and the overall growth was steady year on year. The research was published mainly in Sustainability, IEEE Access and Applied Sciences, which all represent broad popularity among technologies that focus on immersive heritage. Furthermore, the analysis of keywords and thematic clustering identified five large research vectors: 3D modelling, immersive narration, integration of artificial intelligence, photogrammetry and digital twins. These themes demonstrate an increasing focus on user-centred design and technological change in heritage experience.

In addition, top scholars and organizations were identified, including Partarakis N. and Zabulis X. of FORTH (Greece), and Politecnico di Milano (Italy), and China has become the most productive nation. At the same time, the articles of Bekele, Chung, and Tom Dieck have received many citations and highlight the need to utilize the AR application in the context of cultural tourism and user experience design. Meanwhile, the analysis of the bibliographic coupling indicated that the collaboration structures were significant in Europe and Asia, which indicates a budding global research community. In general, this bibliometric examination provides scholars, researchers, and policymakers with essential information that would help perceive existing advances, uncovered knowledge gaps, and future studies on XR applications in digital heritage.

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