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User Experience In Digital Reality Technologies Applications In Cultural Heritage: Current State and Research Trends

Dijital Gerçeklik Teknolojilerinin Kültürel Miras Alanındaki Uygulamalarında Kullanıcı Deneyimi: Mevcut Durum ve Araştırma Eğilimleri

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ABSTRACT

This study reviews research focusing on user experience in digital reality technologies applications in cultural heritage between 1999-2024 using bibliometric methods. The results show a significant increase in studies between 2013-2017, followed by a relative slowdown during 2018-2021, with renewed momentum from 2022. The analysis reveals that the number of cultural assets in countries' UNESCO World Heritage List does not determine academic productivity in this field. The field demonstrates a multidisciplinary structure, with contributions from engineering, computer science, humanities, tourism, culture and art, indicating that the user experience dimension of digital reality technologies in cultural heritage continues to develop as a dynamic research area with a multidisciplinary approach.

JEL Codes: L86, O33, Z11, Z13

Keywords: Digital reality technologies, Cultural heritage, User experience, Resesarch trends, Technology adaptation

ÖZ

Bu çalışmada, 1999-2024 yılları arasında dijital gerçeklik teknolojilerinin kültürel miras alanındaki uygulamalarında kullanıcı deneyimine odaklanan araştırmalar bibliyometrik yöntem ile incelenmiştir. Elde edilen bulgulara göre, dijital gerçeklik teknolojilerinin kültürel miras alanındaki uygulamalarında kullanıcı deneyimine yönelik çalışmalar özellikle 2013-2017 yılları arasında önemli bir artış göstermiştir. Her ne kadar 2018-2021 döneminde yayın sayılarında görece bir yavaşlama gözlense de 2022 yılı itibariyle alandaki bilimsel üretkenlik yeniden ivme kazanmıştır. Bununla birlikte, analiz sonuçları ülkelerin UNESCO Dünya Mirası Listesi'ndeki kültürel varlık sayılarının, bu alandaki akademik üretkenlik üzerinde belirleyici bir faktör olmadığını göstermiştir. Ayrıca, çalışma alanının disipliner yapısı incelendiğinde mühendislik, bilgisayar bilimleri, beşeri bilimler, kültür ve sanat gibi birçok farklı disiplin bu alana katkı sağlamıştır. Bu durum, kültürel miras bağlamında dijital gerçeklik teknolojilerinin kullanıcı deneyimi boyutunun, multidisipliner bir yaklaşımla ele alındığını ve dinamik bir araştırma alanı olarak gelişimini sürdürdüğünü ortaya koymaktadır.

JEL Kodları: L86, O33, Z11, Z13

Anahtar Kelimeler: Dijital Gerçeklik Teknolojileri, Kültürel Miras, Kullanıcı Deneyimi, Araştırma Trendleri, Teknoloji Uyarlaması

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Introduction

Today, the enriching effect and invaluable significance of cultural heritage are becoming increasingly important. Cultural heritage is seen as a significant asset that generates economic value and contributes to the development of creative industries for both academic research and organizations (Rizzo & Herrero Prieto, 2024). Cultural heritage is the entirety of tangible assets comprising architectural works, building groups and sites with universal value from historical, artistic, scientific, aesthetic, ethnological or anthropological perspectives that form humanity's collective memory, along with social life practices such as intangible beliefs, traditions, knowledge and customs (UNESCO, 1972; Welch, 2014). As can be understood from this definition, cultural heritage is a multidimensional phenomenon encompassing economic, environmental and social factors (Pasikowska-Schnass, 2018).

When reviewing the studies in the literature and research gaps, it has been determined that there is a need for a comprehensive analysis of the current state and trends of research on user experience in digital reality technology applications in the field of cultural heritage. In this context, the aim of the study is to systematically examine the current state, development, and trends of research on user experience in the applications of these technologies in the field of cultural heritage in light of bibliometric indicators. For this purpose, academic studies included in the Web of Science database between 1999 and 2024 were reviewed. The scientific development process of the field was analyzed in a multidimensional way. The study focuses on three main factors: scientific productivity, scientific impact and scientific collaboration and interaction dynamics. This systematic analysis provides a comprehensive evaluation of the existing body of knowledge in the field and highlights possible directions for future research.

Conceptual Framework

Digital Reality Technologies

The adoption rate of digital reality technologies is increasing day by day. Digital reality technologies are an umbrella concept that encompasses technologies enabling interaction between the real world and the digital world while enriching user experience (Moses et al., 2018). Digital reality technologies enable the collection of data, its processing into meaningful information and the interactive use of this information by users. The environment and user are at the center of this process, which has a real-time and continuously repeating cyclical structure. Data is obtained from the physical environment through various tools such as sensors, cameras and the Internet of things. The collected data is presented to the user through various methods such as visual layers, audio cues and live video. Users interact with and use the data through methods such as gestures, voice commands and eye movements (Mariani et al., 2017).

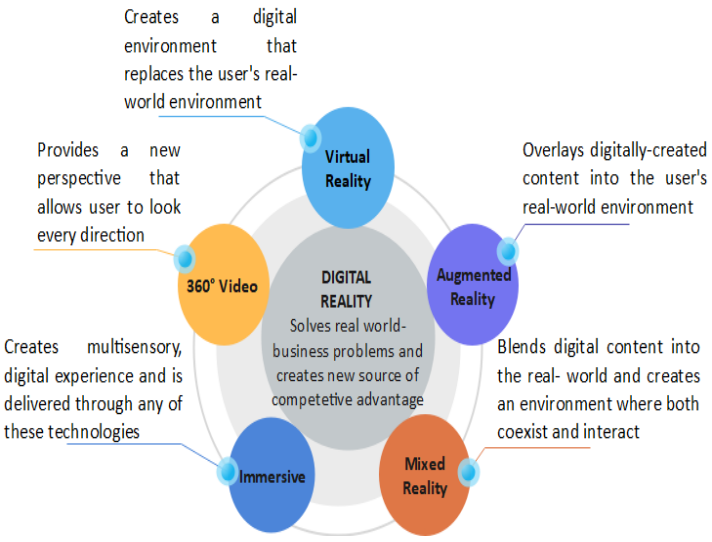
The foundations of digital reality technologies date back to panoramic paintings that emerged in the 1800s, which marked the beginning of immersive visual experiences. These large-scale paintings offered viewers different perspectives by creating perceptions that extended beyond what was visible. In 1838, Charles Wheatstone discovered the stereoscope device by modeling the working principle of the human brain, enabling the perception of images in three dimensions. Morton Heilig developed the Sensorama cinema technology, which provided a multi-sensory experience stimulating all senses and formed the foundation of today's digital reality technologies. In 1960, he designed the first head-mounted display technology offering sound and wide field of view. In 1965, Ivan Sutherland's Ultimate Display concept, consisting of a virtual interface, three-dimensional sound system, physical feedback mechanism and hardware enabling the creation of the virtual world, formed the basis of VR technologies we experience today. In 1975, the first interactive VR system was developed by Myron Krueger. Parallel to these technological developments, a scattered conceptual structure necessitated the development of a common terminological framework. For this purpose, in 1987, Jaron Lanier introduced the term virtual reality to the literature to establish a common reference point. In 2007 and 2010, geographical information was transferred to the virtual environment with Google Street View. Similarly, the development of consumer-oriented virtual reality applications with Oculus Rift became a significant turning point in the widespread adoption of virtual and augmented reality technologies. In 2018, VR devices independent of computers and mobile devices were developed. In 2019, significant progress was made in this field with the development of more interactive mixed reality technology combining virtual and real worlds (Virtual Reality Society, 2017).

Through a long historical development process, digital

reality technologies have evolved into their current multidimensional structure. As shown in Figure 1, this technological ecosystem comprises virtual reality, augmented reality, mixed reality, 360-degree technologies, and immersive technologies. (Moses et al., 2018).

Figure 1.

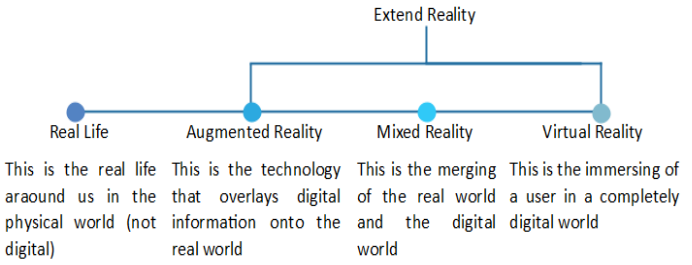
Digital Reality Ecosystem (Deloitte, 2018)



While each of these technological components performs important functions on its own, together they form the fundamental building blocks of digital reality technologies. This classification demonstrates the scope and diversity of digital reality technologies while also reflecting the maturity level reached in the technologies' development process. Within this technological ecosystem, virtual reality technology involves a computer-generated virtual environment. This virtual environment, inspired by the real world, provides sensory experiences. Augmented reality technology is a technology that enriches real-world experience by adding digital content to users' physical environment. It provides access to digital content that interacts with the real world. Mixed reality technology is an innovative technology that allows users to interact simultaneously and actively with both the real world containing physical objects and the digital environment containing virtual objects. It also offers the possibility to perform and influence both physical and virtual actions in the same environment (Horne & Shilton, 2022). 360-degree video technology is a virtual space technology that provides viewers with a panoramic field of view by enabling viewing of a scene from all angles, supported by spatial audio technology and enhances the sense of reality with its interactive features (Cinnamon & Jahiu, 2023). The gradual transition of these technologies from reality level to virtuality level and their interaction level with the real world is shown in Figure 2. The initial stage of technology consists of real life, where the physical world is directly experienced without any digital intervention. In the second stage that follows, we encounter augmented reality technology created by placing digital information such as graphics and text over the real world. The next step in development features mixed reality technology, which emerges from the interaction between the real world and the digital world. In the final stage of this process is virtual reality technology, where the user is completely immersed in a digital environment (Horne & Shilton, 202).

Figure 2.

Digital Reality Spectrum (Horne & Shilton, 2022)



The high-resolution visualization and interaction offered by these technologies have enabled the development of diverse applications across various fields. For example, it enhances the effectiveness of material analysis by providing sensitivity beyond human perception in detecting microscopic cracks and signs of corrosion. In medical imaging, particularly in the diagnosis of bone fractures, it offers more detailed and interactive analysis capabilities compared to traditional methods. Additionally, in psychological treatment methods, it increases the effectiveness of interventions by providing a safe and controlled virtual environment for exposure therapy used in treating phobias (Mariani et al., 2017). Similarly, it has many application areas such as enhancing learning experiences in museums through digital reality technologies (Agostinelli et al., 2023), introducing mountainous areas through digital reality-based games and laboratories (Kleftodimos et al., 2023) and using avatars with question-answer capabilities in virtual tours of cultural heritage sites (Farella et al., 2022). In recent years, applications related to digital reality technologies have been widely used particularly in the examination, preservation and presentation of cultural heritage (Bekele

et al., 2018).

User Experience (UX)

User Experience (UX) is a holistic field that lies at the heart of technology design and brings together various disciplines (Rebelo et al., 2012). Defined by the ISO as *"a person's perceptions and responses resulting from the use and/or anticipated use of a product, system, or service"* (International Standardization Organization, 2010), UX is a complex process that becomes particularly prominent in interactions with computer-based systems (Soegaard, 2020). This process presents a multidimensional structure encompassing the emotional, behavioral, and cognitive responses of users during their interaction with products (Konstantakis & Caridakis, 2020).

Today, UX design has evolved beyond basic usability features and has become a dynamic discipline shaped by the specific functionality and usage context of each product. Han et al. (2018), emphasize that successful UX design is not limited to technical specifications but requires the integration of quality features that meet users' needs and expectations. As also noted by Rebelo et al. (2012), this approach offers a holistic perspective that takes into account the psychological, emotional and behavioral characteristics of users.

The model developed by Hassenzahl (2018) provides a significant framework that systematizes this multidimensional approach. The model reveals that UX consists of a balance between pragmatic qualities (usability, efficiency) and hedonic qualities (emotional value, identity, meaning), and that it varies depending on contextual factors. This perspective emphasizes the importance of criteria such as attractiveness, pleasure and satisfaction in the evaluation of UX.

The quality of user experience plays a critical role in the adoption of digital reality technologies. Kim et al. (2020) state that to develop effective UX designs in this field, different factors such as hardware specifications, interaction models, and sensory perceptions need to be considered together in a holistic way. In cultural heritage applications, augmented reality (AR) demonstrates successful examples of this approach. Digital reality technologies not only provide tourists with museum information but also offer convenience in terms of access and transportation, while enabling immersive sensory and visual experiences of historical contexts. In terms of accessibility, digital reality technologies offer inclusive experiences by facilitating interactions between visually impaired individuals and museums (Orr et al., 2021).

An effective UX design should be shaped by a synthesis of user-centered and product-centered approaches, balancing both technical and emotional elements. Understanding users' psychological, behavioral and contextual needs forms the foundation for creating successful and meaningful experiences.

Literature Review

The current state and trends of digital reality technologies in literature have been examined by different researchers using various methods and on different subjects. Among these studies, Borda and Bowen (2017) examined the use of innovative digital tools and imaging methods in the preservation and promotion of cultural assets in different smart city applications through case studies. In a comprehensive study conducted by Bekele et al. (2018), these technologies were evaluated in terms of fundamental elements such as monitoring and recording, virtual environment modeling, presentation, input devices, interaction interfaces and systems. The researchers found that these technologies were used in various ways in cultural heritage applications and that each element significantly affected the technology's effectiveness. In the study by Ovallos-Gazabon et al. (2020), the evolution of technological tools used in museums and their effects on visitor experience were examined. Research results concluded that technologies such as interactive systems, digital games, QR codes, mobile applications, augmented reality (AR), virtual reality (VR) and gamification played an important role in personalizing and enriching experiences in museums. In a recent study by Li et al. (2023), it was determined that the use of immersive technologies in museums stood out in areas such as heritage tourism, virtual museums, interactive art education and immersive storytelling. In the study by Omran et al. (2024), virtual reality (VR) and augmented reality (AR) technologies were used to examine how they can be utilized in tourism and how they can improve tourists' travel experiences. The study adopted a hybrid approach combining bibliometric analysis with the TCCM (theory-context-characteristics-method) framework. This enabled obtaining quantitative data about the general state of the field while also examining the theoretical foundations, contexts and methods of existing research. Zhang et al. (2024), in their study, examined research related to virtual reality (VR), augmented reality (AR) and mixed reality (MR)

technologies in the cultural heritage field over the last 10 years. The study indicated that expanding future studies to include Web of Science and other databases would increase knowledge accumulation in the field and lead to more comprehensive results.

Material and Methods

Today, with the increasing number and diversity of scientific studies, effective evaluation processes have become more complex for actors involved in decision-making mechanisms. The increasing volume of data and the need for systematic analysis have led to the importance of quantitative methods that use objective and measurable indicators. However, quantitative indicators alone may not be meaningful. Additional controls may be needed to ensure the accuracy of quantitative data. This can be possible through making quantitative data express a meaningful situation by combining objective criteria provided by numerical data with in-depth analyses from expert opinions. Bibliometric analysis is one of the commonly used methods in such evaluations (Pendlebury, 2008).

Bibliometrics is an objective and measurable research method that analyzes scientific productivity, impact and collaboration factors of units such as individuals, institutions and countries through statistical methods based on academic publications (Petr, 2015). Bibliometric analyses facilitate large-scale, comparable evaluations in research fields. This method enables scientific determination of developing and declining trends in scientific studies (Waltman & Ed Noyons, 2018). While bibliometric analyses guide the shaping of science policies and effective distribution of resources, they are also used in evaluating scientific competition in international circles. Furthermore, it provides an important tool for analyzing the impact of scientific research on economic growth and social development. Thus, by revealing the societal benefits of scientific activities, it contributes to directing and supporting research and development efforts (Okubo, 1997).

In the literature, numerous different parameters are examined using bibliometric methods. In this study, various metrics such as publication numbers, citation analyses, author relationships, institutional collaborations, thematic trends and keyword analyses are classified under three main parameters. These parameters were systematically evaluated within the scope of scientific productivity, scientific impact and scientific collaboration and interaction dynamics.

Scientific productivity and dissemination of knowledge are carried out through scientific outputs in various formats. These outputs include articles, conference papers, theses, books, book chapters, reviews and patents. These different types of literature play important roles in sharing research findings and academic thought. However, scientific articles play a central role due to their reliability, accessibility and continuous development of scientific knowledge through standardization, peer review, wide access and citation system (Okubo, 1997).

Scientific impact refers to the quantitative assessment of how knowledge generated through the research process accumulates and spreads within academic communities. This measurement is typically conducted using citation-based metrics, which indicate the extent to which research contributes to the scholarly discourse. Citation-based measurements provide a quantitative indication of a study's contribution to the scientific field. They do this by assessing how often the research is cited in other scientific studies. Research that receives a high number of citations is generally considered to be recognized and valued by the scientific community. Such studies are seen as making significant contributions to their respective fields. (Tsatsaronis, 2020). Citations primarily serve as a quantitative measure for evaluating the scientific performance of researchers and institutions. Additionally, citations function as an important indicator in identifying trends in research fields, monitoring the development of academic communication networks and analyzing interactions between scientific communities (Mingers & Leydesdorff, 2015).

Relationship maps are created by examining the connections between individuals, institutions and countries that produce scientific research to understand collaboration and interaction in scientific research fields. The co-authorship factor is frequently used in determining these relationships. The co-authorship factor has been used to evaluate collaboration for the past 50 years. For co-authorship to exist, a study must be written by at least two researchers. When these researchers later work with other researchers, new connections are formed. A collaboration network emerges as a result of joint studies. In this network, metrics such as the researcher's number of joint publications and the citation counts of these publications determine the researcher's position in the network. Researchers with high metric values are positioned at the center of the network, while those with lower values are positioned from the center towards the outside of the network. Researchers at the center typically serve as bridges between different research groups,

enabling the formation of indirect connections. This network structure, which is widely used in bibliometric analyses, enables the identification of key actors in the field and the analysis of collaboration clusters. Moreover, it contributes to understanding potential research communities, identifying new areas of collaboration and evaluating opportunities for joint work (Fagan et al., 2018; Ullah et al., 2022). For bibliometric analyses, Web of Science, Scopus and Google Scholar are the most commonly used general-purpose data sources. Additionally, field-specific databases such as INSPIRE, MathSciNet, PsycINFO and PubMed stand out (Waltman & Ed Noyons, 2018). The research data was obtained from the Web of Science (WoS) database, encompassing publications from 1999 through 2024. The data collection process was conducted through systematic scanning of cultural heritage, digital reality and user experience concepts, which constitute the basic terminology of the field and their variations. The study considered publications classified as journal articles, conference proceedings, review articles and book chapters.

Review Scope

Web of Science was selected as the primary database for this study. During the development of the search strategy, the literature related to the use of digital reality technologies—such as augmented reality, virtual reality, mixed reality, 360-degree video, and other immersive technologies—in the field of cultural heritage was thoroughly examined. Particular emphasis was placed on studies that explore the impact of these technologies on user experience, behavior, attitudes, interaction and practices. The search terms were developed by taking into account the variety of ways these key concepts are expressed in the literature. In this way, a strong interdisciplinary framework was established that encompasses both technological developments and user-centered approaches. These terms were determined iteratively, based on the relevance and academic quality of the samples identified during the preliminary screening process.

In the present investigation, a comprehensive analysis was conducted across a longitudinal timeframe spanning 1999 through 2024, encompassing a quarter-century period. This extensive scope was deliberately selected to facilitate the identification of evolutionary patterns and paradigmatic shifts in the domain under examination. The corpus consisted of 791 scholarly contributions, taxonomically classified as peer-reviewed journal articles, conference proceedings, systematic reviews, and book chapters. All of these works focused on the epistemological intersection of user experience methodologies and digital reality technological applications within the context of cultural heritage. To maintain methodological rigor and ensure analytical consistency, the investigation was limited exclusively to English-language publications. This approach provides a linguistically homogeneous framework for systematic literature review. At the same time, it facilitates a comprehensive assessment of the international scholarly discourse on this multidisciplinary subject.

Results

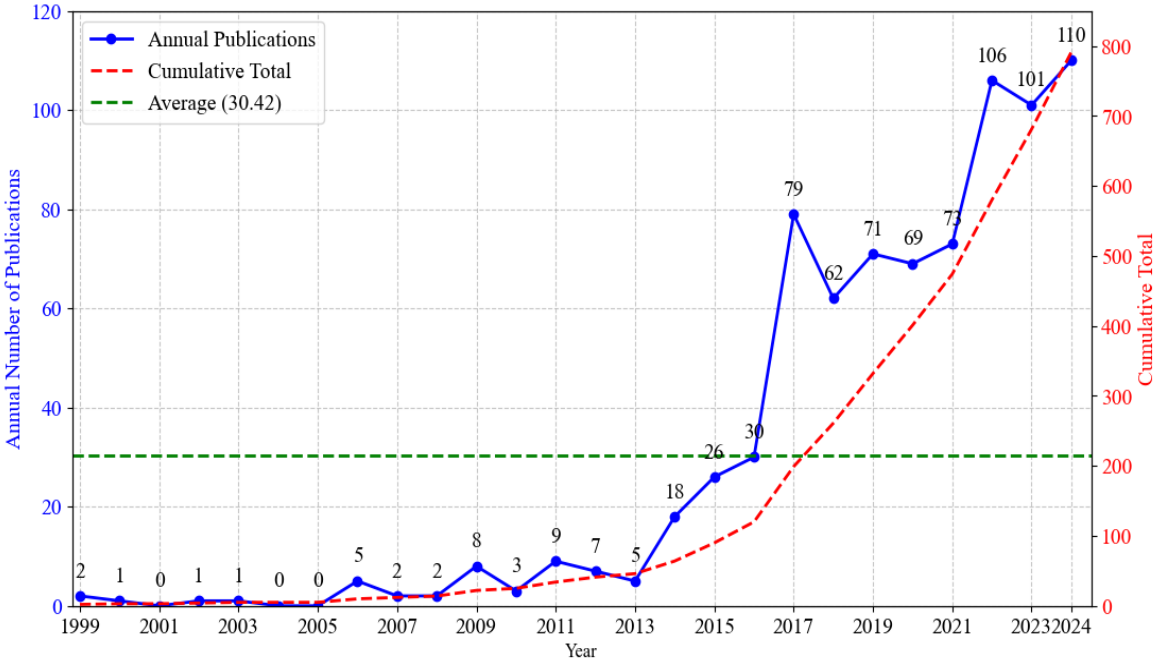
Scientific Production

The analysis of scholarly output distribution revealed that knowledge dissemination in this specialized field predominantly occurred through traditional academic channels. In particular, peer-reviewed journals and conference proceedings emerged as the primary vehicles for scholarly communication. In the analysis of scientific outputs between 1999-2024 presented in Figure 3, notable trends were observed in publication dynamics. The average annual number of publications over the examined 25-year period is visualized with a green dashed line and was realized as 31.6. When examining the distribution by years, publication numbers generally remained below average during the 1999-2016 period, however, there was a significant increase in scientific productivity starting from 2017. This increasing trend is also confirmed by the steeper rise in cumulative total values shown in the graph. This upward trend indicates that scientific interest in the field still maintains its importance.

Figure 4 illustrates annual changes in cultural properties on the UNESCO World Heritage List alongside the number of publications. The first variable shows the numerical distribution of cultural properties added to the list each year. The second variable depicts the annual number of publications on user experience in applications of digital reality technologies within the cultural heritage field.

Figure 3.

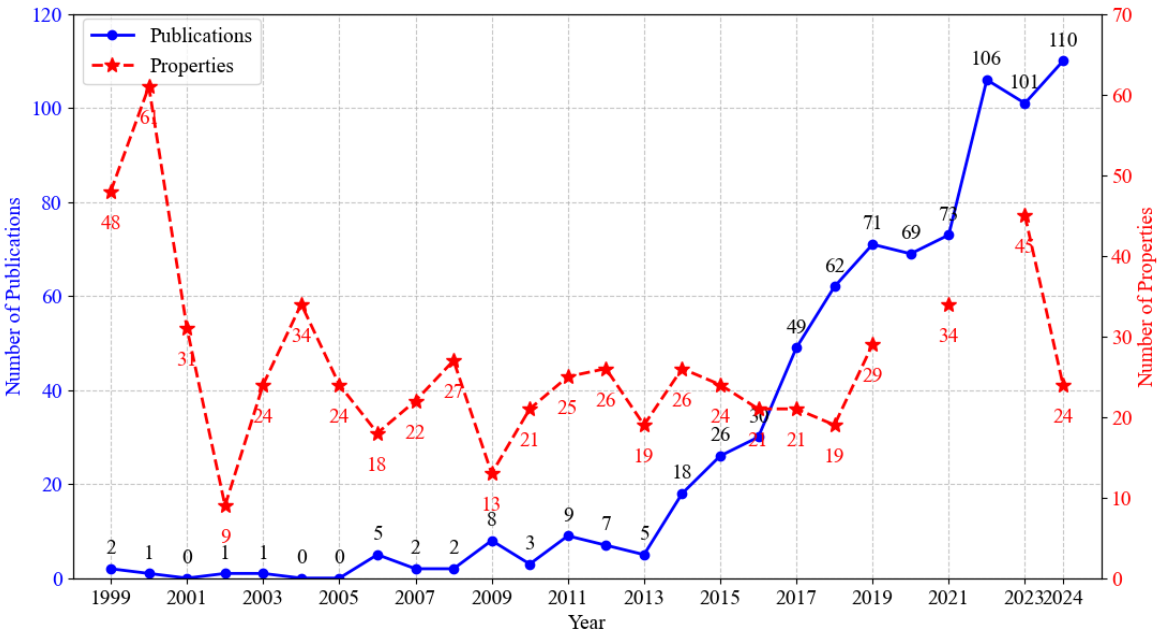
Number of Publications and Cumulative Total by year



According to Figure 4, the number of cultural properties added annually to the UNESCO list shows a fluctuating pattern. In contrast, the number of academic publications has shown a continuous increasing trend since 2013. The analysis shows no significant correlation between the number of UNESCO World Heritage List additions and academic interest in digital reality technologies for cultural heritage (Pearson correlation coefficient: 0.123). These results indicate that the growth in cultural heritage publications is not directly influenced by UNESCO's listing of new properties. This situation reveals that the transformation created by digital technologies in the cultural heritage field and the research potential in this area are developing with their own dynamics independent of cultural heritage properties.

Figure 4.

Annual Changes in Cultural Properties on UNESCO World Heritage List and Publication Number

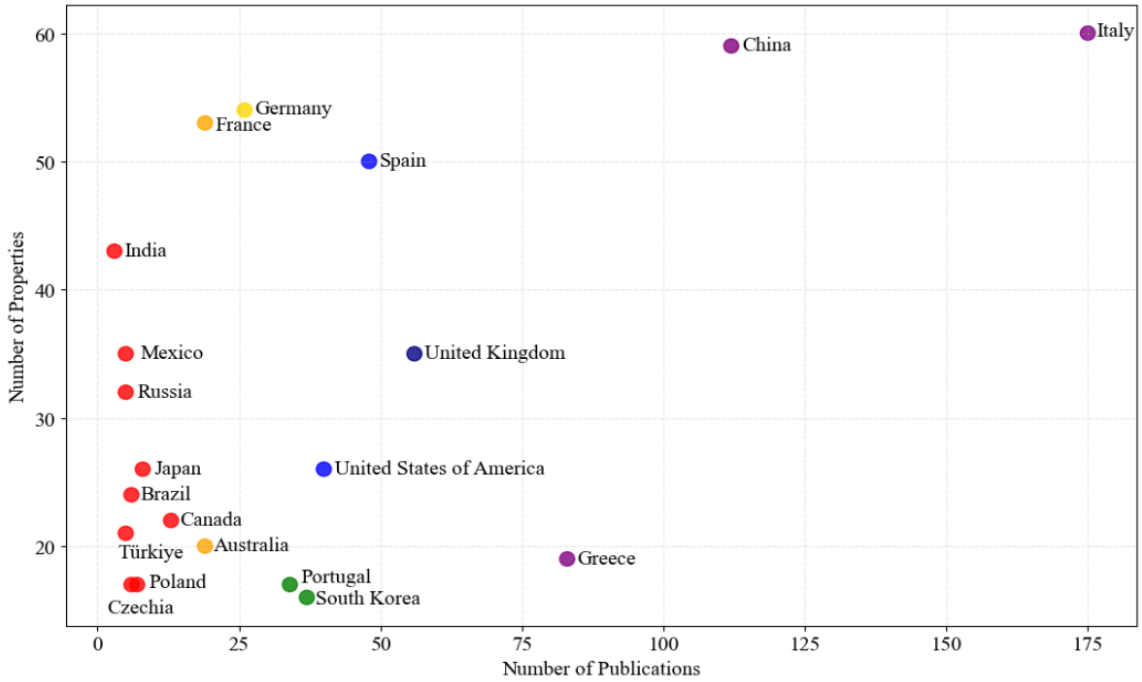


The relationship between the number of cultural properties a country has on the UNESCO World Heritage List and its academic publication output is shown in Figure 5. The findings reveal that Italy and China hold a clear leading position in terms of both publication output and cultural heritage assets. Spain, France, and Germany stand out with a high level of cultural heritage despite producing relatively fewer publications. In contrast, the United Kingdom and the United States demonstrate strong performance in publication output, yet their number of cultural heritage sites remains comparatively lower. Countries such as India, Mexico and Russia possess significant cultural heritage potential but lag behind in terms of academic production. Greece, on the other hand, attracts attention with a high level of publication performance despite having a limited number of heritage sites, thereby presenting a distinct balance between heritage and publication. Meanwhile, countries such as Turkey, Poland, Czechia, Canada, South Korea, Portugal and Australia rank at relatively lower levels in both indicators. Additionally, Japan and Brazil possess a moderate level of cultural heritage assets yet exhibit low levels of academic output. This reflects the diversity among countries in the relationship between cultural heritage and scholarly production.

The relationship between countries' scientific productivity and their cultural property wealth is analyzed from different perspectives in Figures 4 and 5. Findings from both analyses reveal that there is not always a direct correlation between a country's cultural property wealth and the number of academic studies conducted in this field.

Figure 5.

The Distribution of Countries' Cultural Property Numbers on the UNESCO World Heritage List and Academic Publication Counts



Findings related to scientific productivity have been examined from the perspectives of researchers, institutions, countries, academic publication outlets and disciplinary fields. In this context, when examining Figure 6, which shows the scientific output of researchers, De Paolis and Pierdicca stand out as the most productive researchers with 11 publications each. They are followed by Frontoni with 9 publications. This indicates that these researchers have been pioneers in identifying gaps in the field and defining new research areas.

According to Figure 7, which shows scientific output at the institutional level, universities in Italy and Greece hold significant weight in this field. The University of the Aegean is the most productive institution, followed by the Polytechnic University of Marche and the Polytechnic of Milan. These three institutions have played a leading role in research in this field.

Figure 6.
Top Researchers by Scientific Output

Author	Publication Counts
De Paolis, Luciotommaso	11
Pierdicca, Roberto	11
Frontoni, Emanuele	9
Bruno, Fabio	8
Koutsabasis, Panayiotis	8
Quattrini, Ramona	8
Rizvic, Selma	8
Carrozzino, Marcello	7
Stephanidis, Constantine	7
Elini, Paolo	7

Figure 7.
Top Institutions by Research Output

Organizations	Publication Counts
University of the Aegean	18
Polytechnic University of Marche	17
Polytechnic of Milan	15
University of Patras	12
University of Salento	12
Manchester Metropolitan University	11
University of Calabria	11
Cyprus University of Technology	11
University of Crete	11
University of Sarajevo	10

In Figure 8, which shows the outlets where scientific studies are published, Lecture Notes in Computer Science (LNCS) is the most prominent scientific outlet, publishing the highest number of works in this field. The ACM Journal on Computing and Cultural Heritage ranks second, followed by the International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences in third place. This indicates that scientific studies are predominantly published in computer science and technically oriented outlets. However, studies have been also featured in journals from specialized fields such as remote sensing and photogrammetry, as well as from different disciplines like cultural heritage and sustainability.

Figure 8.

The Distribution of the Number of Articles Published in Scientific Sources

Scientific Sources	Publication Counts
Lecture Notes in Computer Science	90
ACM Journal On Computing and Cultural Heritage	31
International Archives of the Photogrammetry RemoteSensing and Spatial Information Sciences	26
Applied Sciences Basel	24
Heritage	20
Sustainability	20
Communications in Computer and Information Science	19
Heritage Science	12
Journal of Cultural Heritage	12
International Journal of Human Computer Interaction	11

It is important to analyze academic fields and keyword networks to understand the flow of information and evaluate the directions of scientific progress in this area. These analyses help to understand which areas the studies are concentrated in, the key concepts used and the thematic connections. Figure 9 illustrates the distribution of academic publications across various disciplines. The figure reveals that research on user experience in the applications of digital reality technologies in the field of cultural heritage has a multidisciplinary nature.

Figure 9.
Distribution of Publications Across Academic Disciplines

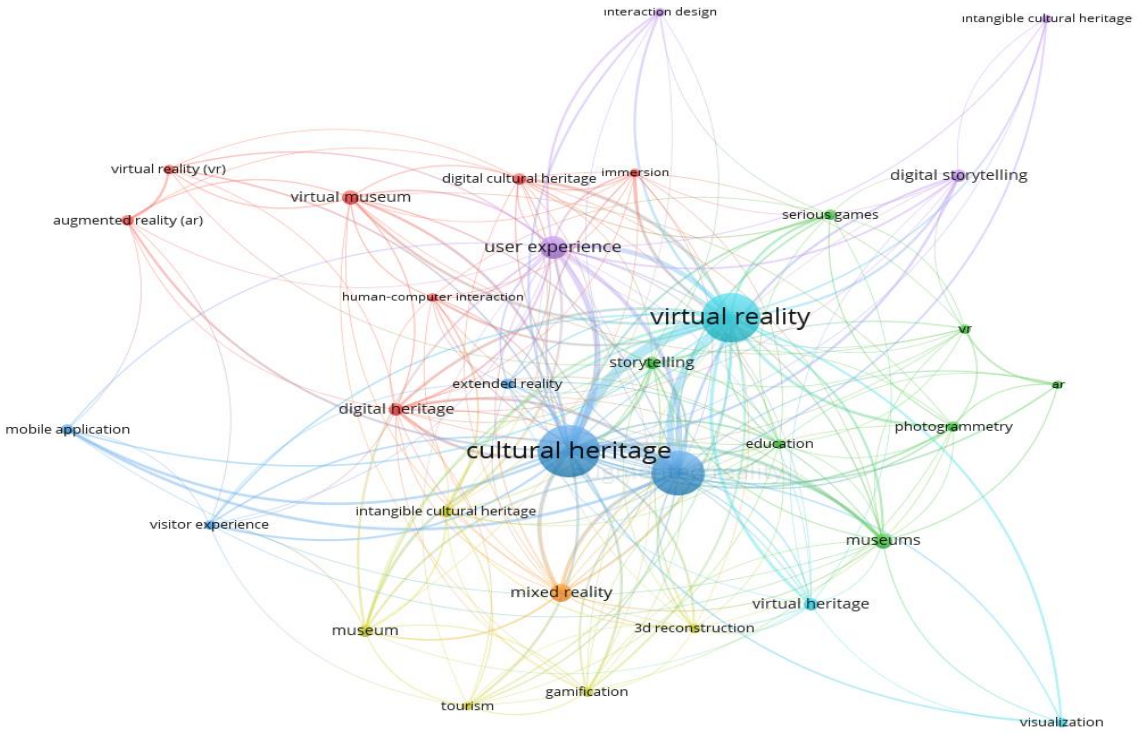
Academic Field	Counts
Computer science interdisciplinary	209
Computer science theory methods	152
Computer science information systems	124
Computer science cybernetics	103
Humanities multidisciplinary	98
Computer science software engineering	92
Computer science artificial intelligence	88
Imaging science photographic technology	69
Engineering electrical electronic	66
Materials science multidisciplinary	55

In the network map in Figure 10, the distance between words represents the degree of their relationship. As the distance shortens, the relationship between the words strengthens. The size of the nodes on the map represents the frequency of the words' usage. Larger nodes indicate that the related word is used more frequently. According to the network map, virtual reality, augmented reality and mixed reality technologies are the most commonly used technologies in cultural heritage applications. Virtual reality technology occupies a central position and has

emerged as a key technology in the digitization of cultural heritage. This central position also reflects the strong interaction of virtual reality with other technologies and its critical role. Applications such as virtual museums, digital storytelling, gamification and three-dimensional reconstruction, clustered around these technologies, enrich the user experience and ensure the effective transmission of cultural heritage in digital environments. The network map also shows that digital technologies are strongly interconnected with disciplines such as art, history, technology, education, tourism and design. Especially the digitization of intangible cultural heritage elements, alongside tangible cultural assets and their transmission through methods like digital storytelling, create an important application area for digital reality technologies.

Figure 10.

Network of Co-Occurrence of Keywords and Thematic Clusters



When the distribution of academic fields in Figure 9 is evaluated together with the findings of the keyword co-occurrence network in Figure 10, a clear pattern emerges. These results indicate that research on user experience in applications of digital reality technologies within the cultural heritage field demonstrates substantial interdisciplinary interaction.

Scientific Impact

The scientific impact of researchers was assessed based on citations per publication, as illustrated in Figure 11. According to this analysis, Sanchez-Vives and Slater emerge as the most cited authors.

Figure 11.

Top Ten Researchers with Highest Citations per Publication

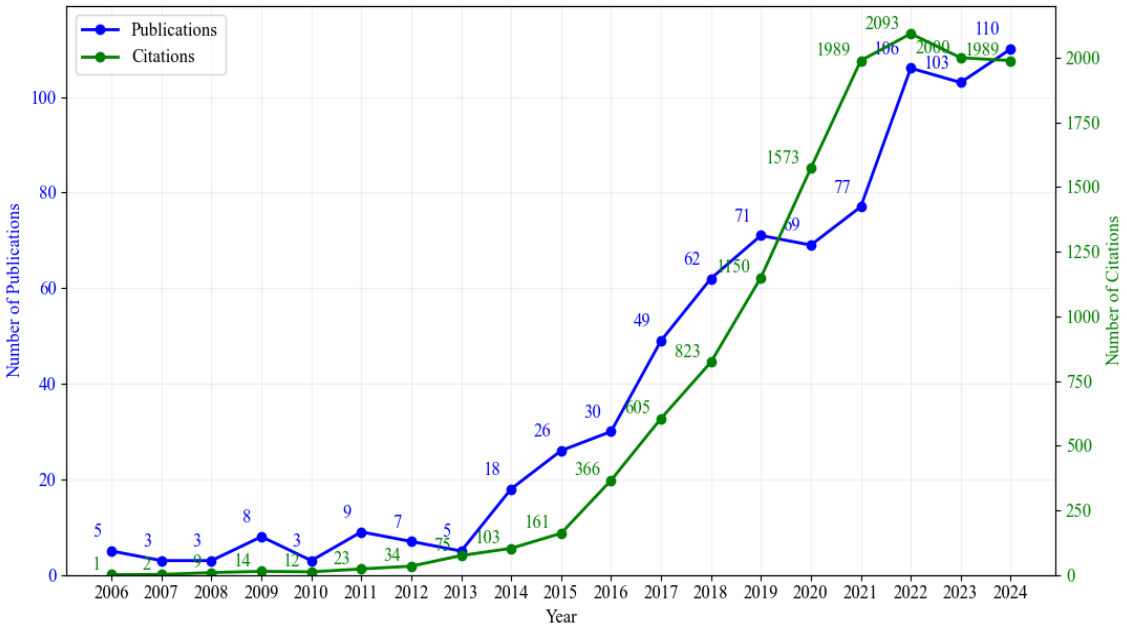
Author	Publication	Citation
Sanchez-Vives, Maria V.	1	751
Slater, Mel	1	751
Bellotti, Francesco	1	309
Catalano, Chiara Eva	1	309
Fiucci, Giusy	1	309
Houry-Panchetti, Minica	1	309
Mortara, Michela	1	309
Kim, Jin-Young	1	213
Koo, Chulmo	1	213
Okumuş, Fevzi	1	159

They are accompanied by Belotti, Catalano, Finucci, Houry-Panchetti and Mortara. These researchers have made significant contributions to the field's literature through their systematic studies. Their work's high impact

and acceptance within academic communities is evident from these findings.

Publication and citation counts for user experience research in digital reality technologies applied to cultural heritage are illustrated in Figure 12. Citations remained limited until 2014, after which academic acceptance and adoption gradually increased. A notable acceleration in citations occurred from 2019 onwards, reaching 2,000 citations by 2024. This indicates the growing scientific impact and strong influence of these studies within academic networks. Citation growth rates reached their highest points in 2007, 2015, and 2018, whereas publication growth showed notable increases in 2009, 2011, and 2014. Analysis of overall trends reveals that publication growth exhibited more volatility, while citation growth maintained relative stability. However, recent trends show a slowdown in both publication and citation growth rates.

Figure 12.
Comparison of Publication and Citation Counts



As shown in Figure 13, which presents the institutions with the highest citation counts, Manchester Metropolitan University holds the top position. The institution is followed by University College London and Universitat de Barcelona, with their high citation counts indicating frequent referencing of their research and significant field impact. When considering the geographic distribution of institutions with the highest citations, the data clearly shows the dominant influence of UK and Spain-based institutions in this field.

Figure 13.
Institutions with Highest Citation Counts

Organizations	Citation Counts
Manchester Metropolitan Univ	851
University College London	819
Universitat De Barcelona	773
Catalan Institution for Research and Advanced	757
Institut D'investigacions Biomèdiques August	751
Kyung Hee University	491
Coventry University	340
Scuola Superiore Sant'anna	314
University of Genoa	312
IMATI	309

Scientific Collaboration and Interaction

Scientific interaction and collaboration of author are visualized in Figure 14. In this figure, nodes represent individual researchers and links indicate collaborations.

Node size reflects researcher productivity and impact,

while network density indicates the strength of interactions. The thickness of connections demonstrates collaboration intensity. Color clusters represent research communities with similar interests and frequent collaboration, with similar clusters in the collaboration network shown in the same colors (Fagan et al., 2018; Waltman & Ed Noyons, 2018). In the figure, four main research clusters—red, blue, green and yellow—have emerged. Each of these clusters represents internal research relationships and interactions with other clusters. Central nodes, in particular, act as bridges between different research areas. Upon analyzing the network, the red cluster stands out with the highest connection density. The strong connection between authors Bruno and Cozzo within this cluster, along with their extensive collaboration network, highlights the structural importance of the cluster and its contribution to the development of the field. This network structure also enables high interaction between clusters, forming multidirectional research connections. In the blue cluster, key connections are driven by Boskovic and Rizvic. While other authors in the cluster maintain strong ties with Boskovic, their connections with each other are relatively weaker. In the green cluster, Liarokapis stands out due to their central role within the cluster and their connections to the red cluster. Although the green cluster demonstrates strong internal cohesion, its interactions with other clusters are more limited. The yellow cluster, centered around Angelos, shows strong collaborations with the red cluster. However, its connections to other clusters (blue and green) are relatively limited.

Figure 14.
Co-authorship of Author

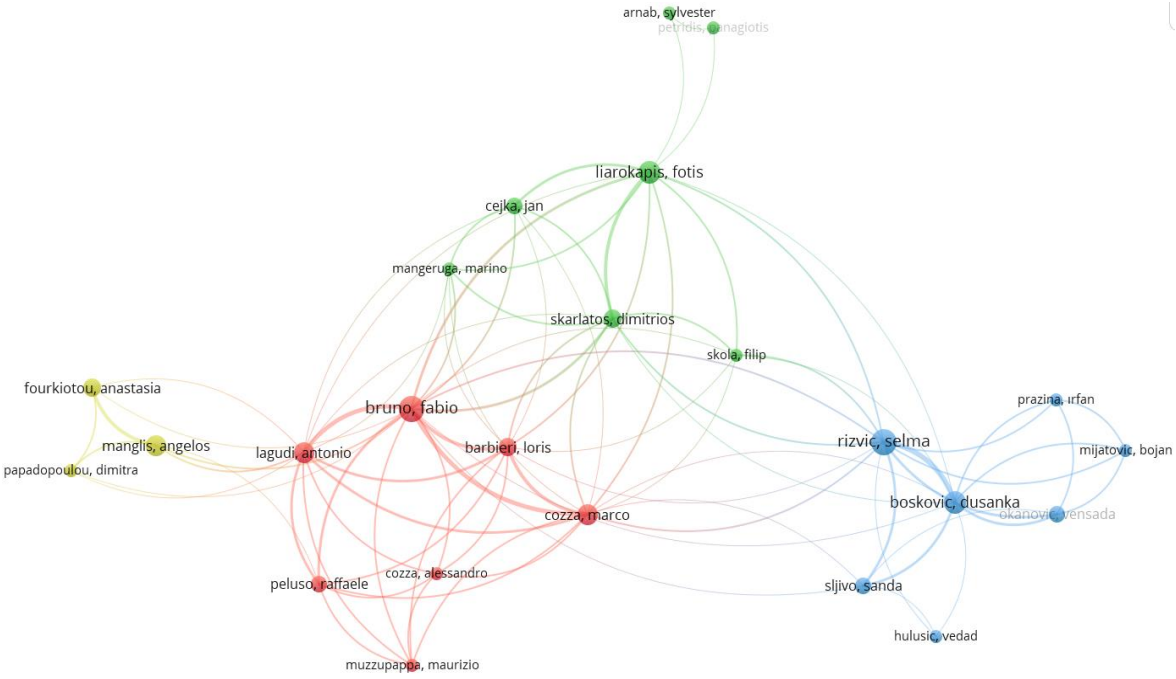


Figure 15, which illustrates the analysis of institutional collaboration networks, reveals distinct collaboration clusters and interaction patterns among institutions. The network includes academic institutions from various countries, highlighting the global context of research in this field. However, the network map also shows limited connections between certain regions, indicating that collaboration has primarily occurred on a local or regional scale. The blue cluster centered at Cyprus University of Technology, the red cluster at Politecnico di Milan, the

green cluster at the University of the Aegean and the yellow cluster of Chinese institutions reflect distinct regional research groups. The University of the Aegean occupies the network's center, establishing strong connections with various institutions and serving as a bridge between different clusters. The network around the University of the Aegean demonstrates strong regional research partnerships. Similarly, Cyprus University of Technology has created a robust network with universities in its geographical area. Manchester Metropolitan University and its surrounding institutions form a separate cluster, while Chinese universities have developed prominent partnerships among themselves. The graph also reveals some institutions in isolated positions with limited connections, suggesting untapped collaboration potential. The overall network structure indicates that geographical proximity and regional collaborations play a significant role but there is still a need to develop international collaboration networks. However, the connections between Manchester Metropolitan University, King's College London and Kyung Hee University highlight the presence of global collaborations. Another noteworthy feature of the network map is the inclusion of organizations like Atlantis Consulting SA and 3D Research SRL alongside academic institutions. This suggests that scientific research in this field is not limited to academic institutions alone and other organizations also play an active role. In addition to these clusters, the map reveals that some institutions are in more isolated positions with limited collaboration connections. This points to the untapped collaboration potential. Overall, the network structure demonstrates that in research on user experience in digital reality technologies for cultural heritage applications, geographical proximity and regional collaborations play a crucial role but international collaboration networks still need to be further developed.

The scientific collaborations and interactions among countries are illustrated in the network map shown in Figure 16. An examination of the network structure reveals clusters that have formed based on geographic or cultural proximity.

Figure 15.

Co-authorship of Organization

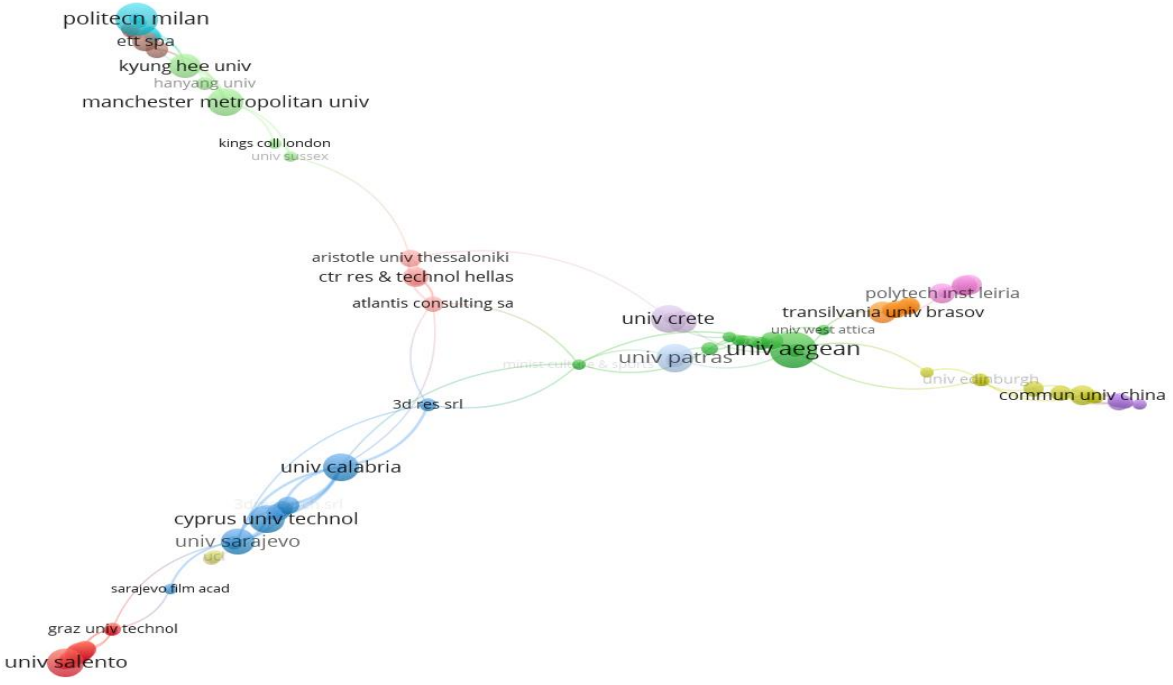
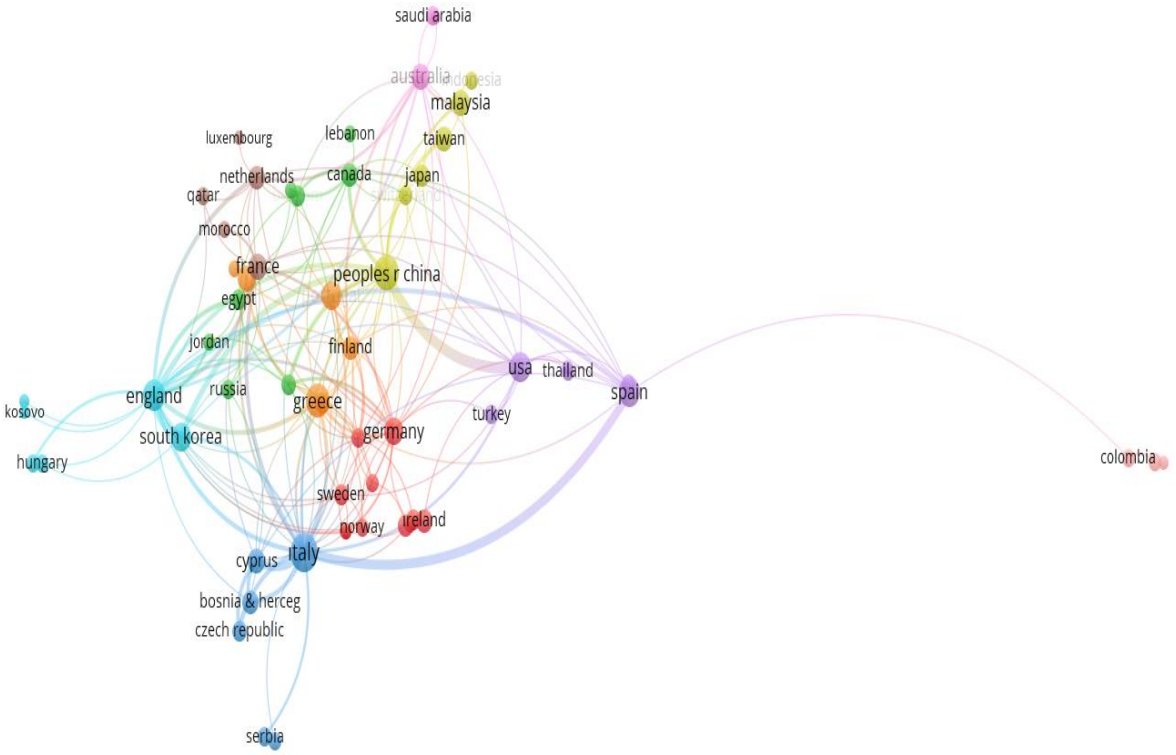


Figure 16.
Co-Authorship of Country



For instance, European countries, Asian countries and Middle Eastern countries show stronger connections within their respective regions. China and its neighboring East Asian countries form a distinct cluster, while Eastern European countries create a separate collaboration group. Southern European countries, particularly those in the Mediterranean basin, demonstrate significant interactions. This pattern highlights the important role of geographic proximity in fostering collaborations. Italy stands at the center of the strong collaboration network in Europe, forming robust connections with Spain and South Korea. Notable interactions are also observed among Greece, Spain, and France. Another significant hub of collaboration is evident among China, Malaysia, Japan and Australia. However, the connections between these countries are weaker compared to the networks observed among European countries. The United Kingdom and Greece have established partnerships with countries in different regions, bridging Europe and Asia. Across Europe, strong while the United States and China emphasize broader global linkages. China, in particular, has formed strong ties with the United States and South Korea. In contrast, countries such as Israel, Indonesia, Iceland, and Colombia are positioned on the outer edges of network with limited or weak collaboration links to the central actors.

Conclusion and Recommendations

In this study, user experience research in the applications of digital reality technologies in cultural heritage has been examined using bibliometric methods. A rapid development in this field has been observed since 2019. The increase in the number of publications and citations indicates a strengthening of academic productivity, impact, and visibility in this area. However, a slowdown trend in both publication and citation counts has been observed in recent years. While there have been fluctuations in the growth rates of academic publications, a more stable increase in citation counts has been noted. Another key finding of the study is that the multidisciplinary nature of the literature facilitates a holistic approach to addressing various aspects of user experience in the digitization of cultural heritage. Additionally, while institutional collaboration networks in the research are mostly clustered at the regional level, global collaborations are also emerging. The presence of academia-industry collaborations has enabled the integration of theoretical and practical dimensions of the field. This could accelerate the process of translating

academic knowledge into industrial applications and contribute to the widespread practical use of digital reality technologies in the field of cultural heritage. In conclusion, it is crucial to extend the existing regional collaborations in the field of cultural heritage to a global level, strengthen academia-industry partnerships and bring together researchers from various disciplines. Adopting these multi-stakeholder and interdisciplinary approaches will foster the development of the field and pave the way for research that contributes to making cultural heritage accessible to broader audiences. This, in turn, will strengthen intercultural dialogue and contribute to a mutual understanding of the cultural values of different societies. Additionally, it will facilitate the development of tourism, the emergence of new business models, the creation of new markets and the increase of entrepreneurial opportunities**.**

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Genişletilmiş Özet

Dijital gerçeklik teknolojileri, fiziksel dünya ile dijital içerik arasında köprü kurarak etkileşimi mümkün kılan ve kullanıcı deneyimini zenginleştiren bir dizi teknolojiyi kapsayan çerçeve bir kavramdır. Bu teknolojiler, kültürel ve sanatsal varlıklara erişimdeki coğrafi ve ekonomik engelleri kaldırarak, kültürel miras alanında önemli dönüşümlere yol açmaktadır. Sanal müzeler, arkeolojik alanların rekonstrüksiyonları ve interaktif tarihî deneyimler gibi uygulamalar kültürel mirasın korunması, incelenmesi ve gelecek nesillere aktarılması için yeni ve heyecan verici olanaklar sunmaktadır. Bu dijital deneyimlerin başarısı ve yaygınlaşması ise büyük ölçüde kullanıcı deneyiminin kalitesine bağlıdır. Toplumun bu teknolojileri benimsemesi, kullanıcıların bu platformlarla nasıl etkileşime girdiğinin, nelerden keyif aldığının ve ne gibi zorluklarla karşılaştığının anlaşılmasına bağlıdır. Bu nedenle, kullanıcı davranışlarının sistematik olarak incelenmesi, alanın gelişimi açısından kritik öneme sahiptir.

Dijital gerçeklik ekosistemi, farklı teknolojilerin bir araya gelmesiyle oluşur. Sanal Gerçeklik (VR), kullanıcıyı tamamen dijital bir ortama taşıyarak sürükleyici bir deneyim sunarken, artırılmış gerçeklik (AR), dijital içeriği gerçek dünya üzerine bindirerek etkileşimi sağlar. Karma Gerçeklik (MR) ise gerçek ve sanal dünyaları birleştirerek daha interaktif ve dinamik bir deneyim yaratır. 360 derece videolar ve fotoğraflar, kullanıcıya panoramik bir görüş sağlayarak keşif hissini artırırken, sürükleyici teknolojiler, çoklu duyusal girdilerle daha etkileyici ve gerçekçi deneyimler sunar.

Bu teknolojilerin kullanım alanları oldukça çeşitlidir. Malzeme analizi ve hasar tespiti, tıbbi görüntüleme teknikleriyle eserlerin içyapısının incelenmesi, psikolojik tedavilerde sanal ortamların kullanılması gibi farklı alanlarda uygulama örnekleri bulunmaktadır. Kültürel mirasın korunması, incelenmesi ve sunumu, bu teknolojilerin en yaygın kullanım alanlarından biridir. Sanal müzeler, etkileşimli sergiler, tarihî eserlerin dijital olarak restore edilmesi, dijital hikâye anlatımı, oyunlaştırma ve üç boyutlu rekonstrüksiyon gibi uygulamalar kullanıcı deneyimini zenginleştirmek ve kültürel mirası daha erişilebilir kılmak için kullanılmaktadır.

Web of Science veritabanında 1999-2024 yılları arasında gerçekleştirilen kapsamlı bir sistematik inceleme, kültürel miras alanındaki dijital gerçeklik teknolojileri uygulamalarında kullanıcı deneyimine odaklanan 791 bilimsel yayını analiz etmiştir. Bu analiz, hem yayın sayısının hem de akademik etkinin yıllar içindeki değişimini ortaya koymuştur. 2013-2017 yılları arasında yayın sayılarında belirgin bir artış gözlenirken, atıf sayıları 2019 yılından itibaren önemli bir yükseliş göstermiştir. Bu durum, yapılan araştırmaların daha geniş bir kitle tarafından kabul gördüğünü göstermektedir. İlginç bir şekilde, yapılan analizler bir ülkenin UNESCO Dünya Miras Listesi'ndeki kültürel varlık sayısının, o ülkenin bu alandaki akademik üretkenliğiyle doğrudan bir ilişki içinde olmadığını göstermiştir. Bu durum teknolojik altyapı, araştırma fonları ve akademik ilgi gibi faktörlerin, kültürel miras varlıklarından daha belirleyici olduğunu düşündürmektedir.

Kültürel miras alanındaki dijital gerçeklik uygulamalarına yönelik araştırmalar, disiplinler arası bir yapı sergilemektedir. Mühendislik, bilgisayar bilimleri, beşerî bilimler, turizm, kültür ve sanat gibi farklı disiplinlerden araştırmacılar, bu alana katkıda bulunmaktadır. Alanın önde gelen araştırmacıları arasında De Paolis ve Pierdicca, Frontoni yer alırken, kurumsal düzeyde University of the Aegean, Polytechnic University of Marche, Polytechnic of Milan gibi kurumlar önemli katkılarda bulunmaktadır.

Küresel ölçekte bilimsel iş birliği ağları incelendiğinde, kültürel miras ve dijital gerçeklik alanındaki çalışmaların çoğunlukla yerel veya bölgesel ölçekte yürütüldüğü görülmektedir. Uluslararası iş birliği, alanın potansiyelini tam olarak gerçekleştirebilmesi için geliştirilmesi gereken önemli bir husustur. Mevcut iş birlikleri genellikle coğrafi ve kültürel yakınlığa dayalı kümeler oluşturmaktadır. Özellikle Avrupa ülkeleri arasında güçlü bağlantılar gözlenirken, diğer bölgelerde iş birliği fırsatlarının artırılması gerekmektedir. Bu farklı kültürlerdeki kullanıcı deneyimlerini karşılaştırmak, en iyi uygulamaları paylaşmak ve daha kapsamlı ve etkili çözümler geliştirmek için önemlidir.