Augmented, Virtual and Mixed Reality Research in Cultural Heritage: A Bibliometric Study

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***Abstract*—Heritage allows us to learn about the different monuments of importance and the inherited traditions from our ancestors. However, many times the monuments get partly ruined due to natural wear and tear, sometimes due to attacks by invaders. To preserve the cultural heritage virtually, many researchers have used augmented, virtual and mixed reality for bringing ancient environments to live in those heritage sites. This study aims to identify publications related to virtual, augmented and mixed reality in cultural heritage and to present the bibliometric analysis of these studies. The research articles on virtual, augmented, and mixed reality in cultural heritage are retrieved using the Scopus database. The analysis is performed using VOSviewer and various parameters such as bibliographic coupling of the countries, publications, journals, authors, and co-occurrences of the author keywords are performed. From the analysis done in this study, it is discovered that the augmented, virtual and mixed reality research in the domain of cultural heritage is mostly concentrated in Italy and surrounding European countries. However, it is also found that the research in this domain is lagging in many countries even if those countries are the homes of various heritage sites. This study provides an extensive analysis of the recent literature related to augmented, virtual and mixed reality research in cultural heritage. This information science based analysis will help researchers to identify the prominent journals in this domain, recognize stalwarts in this field and follow their works, find out path-breaking publications to refer to, and predict the direction of future studies.**

Keywords*—*Augmented reality; bibliometric analysis; cultural heritage; information science; mixed reality; virtual reality

I. Introduction

For the essential growth of a community, its history plays a vital role. Heritage allows us to learn about the history, culture and inherited traditions from ancestors by observing the monuments, archaeological sites, forts, historical city centres, museums, etc. [1][2][3]. Millions of tourists visit the historical sites every year to get a feel of individual and collective identity. It contributes to the cohesion of various cultures across the world. This feel of cohesion can be enhanced by combining the real and digital content to provide sensory experiences. Depending upon the involvement of the user in this virtual environment, the technologies can be classified into three types namely, immersive, non-immersive and semi-immersive.

Immersive technologies create a virtual world by combining the physical world with a digital or simulated reality such that the user feels that (s)he is actually engrossed in that virtual world. On the other hand, non-immersive technologies also generate a virtual world for the user; however, the complete control of that virtual world lies with the user only. Semi-immersive technologies create a partial virtual environment that allows users to feel the virtually created world and remain aware about the physical surroundings simultaneously.

Augmented Reality (AR) is an immersive technology where real-world objects are upgraded with computer-aided non-cognitive visual and/or auditory information. Virtual Reality (VR) is a simulated experience that might be comparable to or wholly different from reality [4]. Mixed Reality (MR) is a combination of physical reality, AR, and VR. Virtual and mixed reality experiences can be fully immersive, semi-immersive or non-immersive. There are many applications of AR, VR and MR that include Education (such as medical or military training), Entertainment (such as movies, and video games), Business (such as virtual meetings), Tourism (virtual tours of cultural heritage and ancient structures sites), etc. [5].

Rejuvenating the demolished structures with augmented, and virtual reality helps the younger generation to understand the rich heritage of ancestral civilizations, their customs and traditions, the culture followed, and the stories of bravery and ethics. Storytelling using virtual reality enriches the learning experience of the young generation for exploring the rich heritage.

With the advent of mixed reality, countries having rich cultural heritage are coming up with mixed reality-based projects as well to preserve and protect their heritage architecture and assets.

A. Motivation and Contribution

With more researchers taking up similar projects, especially to preserve the cultural heritage of respective countries, more and more young people are getting aware of their own culture and tradition. However, there is a lack of thorough analysis of the difficulties in the field's research or its future directions. This study is done to review the current status of research in cultural heritage connected to AR, VR, and MR.

Research objectives of this paper are to:

1) Compile the peer-reviewed articles and conference papers on applications of AR/VR in cultural heritage during the period of 1999 to 2022.

2) Ascertain the spread of this field using bibliometric coupling of publications, journals, and authors.

3) Understand which countries have the most publications in this area.

4) Which technologies were employed for the implementation of cultural heritage projects.

This is accomplished through the use of bibliometric analysis. As defined by Pritchard, bibliometrics is "the application of mathematical and statistical methods to books and other media of communication" [48]. In this study, bibliometric analysis has been carried out for classifying the publications based on AR/VR in cultural heritage. The bibliographic information, like citations, keywords, link strengths, countries, journals, and authors of a publication has been considered for the analysis. Good quality publications have been selected from the widely-used and well-recognized online Scopus database for this study. This database includes almost all the important research papers in this domain. After retrieving the data, the same has been analyzed using the bibliometric visualization tool called VOSviewer.

B. Organization of the Paper

Section II presents a summary of cultural heritage projects where AR, VR, or MR has been deployed; Section III discusses the research methodology used for the bibliometric analysis; the results are analyzed in Section IV; Section V discusses the insights obtained from the results; are conclusions are available in Section VI.

II. Summary of Cultural Heritage Projects

This section presents a survey of various immersive, non-immersive, and semi-immersive projects implemented across the globe. The category-wise distribution is shown in Table I.

TABLE I. Categorization of Cultural Heritage Projects

Project	Reference
Immersive	[6-8], [9-11], [12], [13-14], [15-16], [17], [18], [19-20], [21-22], [23-24]
Non-immersive	[25], [26], [27-28], [29], [30-31], [32-33], [34]
Semi-immersive	[35], [36-40], [41-42], [43], [44]

In the ''Museum of Pure Form'' [6-8] project, a virtual museum was created where users are allowed to have an immersive experience of interacting with an art piece by nestling before that art piece. A project entitled "CREATE" [9-11] was developed for creation and maneuvering of virtual worlds by using actual data source and integrating auditory and other haptic senses. Another research in Japan [12], included an interaction system with sight, hearing, smell, and touch for a digital museum. The "National Archaeological Museum" of Italy's Marche offered a novel blend of actual and virtual settings, as well as an immersive solution, to improve the understanding, knowledge, and holistic perception of museum visitors [13-14]. A project called "The Feelies" attempted to create a multi-sensory solution in 2015 using virtual reality in theatre settings, with a focus on developing, filming, and distributing quality content [15-16]. The "Interactive Haptic System for Archery" was designed with the objective of constructing engineering solutions for training purposes through virtual reality simulations, enabling users to engage in classical archery [17]. The project "Thresholds," showcased in the UK and Turkey, generated a virtual world that could be researched in a space that was emulated in person keeping with the virtual scenario [18]. The project "Zelige Door on Golborne Road" in London emphasised the connection between interaction design and people's perceptions by providing an augmented reality app with sensory technologies to overlay pre-recorded video and aromas [19-20]. The "M5SAR" project's approach for a mobile multi-sensory AR system for museums aimed to create an AR system that could serve as a tour guide for historical and cultural events [21-22]. The project "SensiMAR" proposed an AR based mobile experience outdoors that would render additional information during searching an archeological location in Portugal [23-24].

The "Haptic Museum" was a groundbreaking experiment that provided visitors a non-immersive experience by providing an opportunity to study 3-D works of art by virtually "touching" those art pieces via the internet [25]. In the Civic Museum of Como, Italy, the temporary museum exhibit named "The Fire and the Mountain" was designed with the intention of promoting active and social learning through a variety of media and multi-sensory experience [26]. Commercial haptic devices were incorporated for visitors to observe, hear, and feel virtual equivalences of the actual objects for a virtual exhibition in Colombia [27-28]. A virtual museum called "Museu3I" was created to enable users to conduct virtual tours using haptic devices [29]. A project entitled "Hapto-visual and Auditory Rendering," combined the senses of sight, hearing, and touch for museum visitors [30-31]. The multisensory study "The Reconstructed Historical City of Tomis," was developed to provide various assistance with the help of haptic devices in Romania [32-33]. A study on one more project to provide a multisensory experience was presented in [34].

The "SenSpace" initiative, deployed and tried in the USA, employed tactile, auditory, and visual evidence to help users understand the Narcissus story of Greek mythology in a physical environment in a semi-immersive way [35]. The project "MediaEvo" is a gaming application to examine the rebuilt historical setting of the Middle Ages through VR [36-40]. Another semi-immersive project called ''Virtual Kyoto'' provided users an opportunity to experience the Gion Festival, in Japan, with the help of optic and tactile senses, high-quality festival music, and a virtual Yamahoko float ceremony in 3D [41-42]. Some more studies on the projects that improved user experience statistically are presented in [43-44].

As observed from Table I, most of the museum tour related projects are based on immersive technology and comparatively less work is done in non-immersive and semi-immersive areas. Digging down further, it can be found that these projects mainly rely on stimulating the optic senses of users, followed by the haptic, auditory, smell, and taste senses.

Other than the domain of museology, AR, VR has widely been used in the reconstruction of demolished / semi-demolished historical sites as well. One of the most talked about reconstruction project was the Rome Reborn project where the concept of virtual reality was used to demonstrate the urban development of ancient Rome [45].

To preserve the virtual heritage of the first Afro-American Church of the Indianapolis, USA, the 3D reconstruction project "Virtual Bethel" was taken up by Indiana University, USA [46].

Another ambitious 3D-reconstruction project of an ancient monument in Istanbul, Turkey was the "Virtual Hagia Sophia" developed by researchers from MIRALab at the University of Geneva [47].

From the above discussion, it can be understood that AR, VR and MR have widely been employed in the domains of 3D reconstruction and in providing immersive or semi-immersive experiences to tourists at different historical sites and museums. However, there is a dearth of comprehensive studies for ascertaining the spread of this field in terms of good journals, pathbreaking researchers, technologies used by various researchers, and so on and so forth. This study is aiming to find such answers.

III. Research Methodology

The various databases available for retrieving the research work available in different domains are Scopus, ACM Digital Library, ERIC, IEEE Xplore, PubMed, ScienceDirect, Web of Science etc. Out of these databases, ERIC is specific to research articles related to Education, PubMed hosts papers related to medical science, IEEE Xplore hosts research articles related to engineering, while ACM Digital Library focuses primarily on Computer Science related articles. Scopus, ScienceDirect and Web of Science are multidisciplinary databases. For this bibliometric analysis, the Scopus database has been chosen as this is a widely accepted and reliable database. The database was searched on 11th August 2022 to find publications related to AR/VR in cultural heritage and 3D reconstruction.

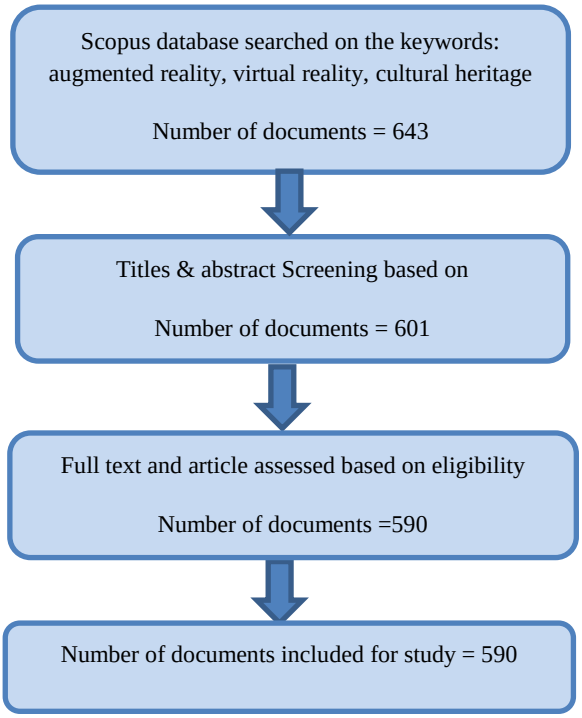

Fig. 1. PRISMA diagram.

Research articles in the duration of 1999 to 2022 have been considered for this study. Based on this search criteria, a total of 643 publications are acquired from the Scopus database. The author, affiliation, journal, year of publication, keywords, and counts of citations are all exported into CSV format for these 643 papers. However, a manual review is needed to assess whether all the retrieved publications are pertinent to the topic. The detailed process to finalize the list of documents as a part of the systematic review [49], is shown as a "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) flow diagram in Fig. 1.

As shown in Fig. 1, after scrutinizing the titles and abstracts of the papers, some of the publications related to 3D reconstructions in the medical surgery domain are removed resulting in 601 documents. Out of 601 documents, some are removed after full text analysis based on various parameters such as not sufficient data, no diagnostic criteria, etc. So, the final bibliometric analysis is presented based on 590 publications. The year-wise distribution of these documents is shown in Fig. 2.

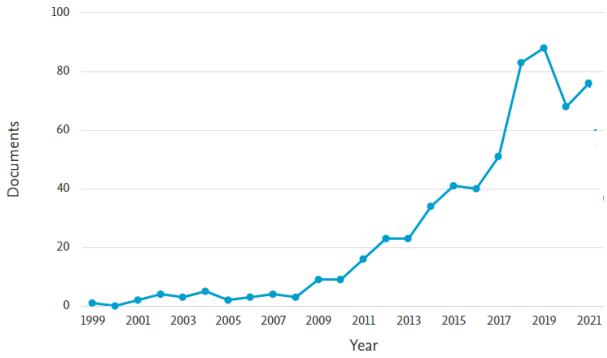

Fig. 2. Year-wise distribution of the shortlisted documents.

From Fig. 2, it can be observed that even if the research started before the year 2000, it started getting more attention from the year 2015 and it gained actual momentum from 2018 onwards.

As per the study, VOSviewer and CitNetExplorer are among the most popular computer visualization tools for bibliometric analysis [50-53]. Here, we have used VOSViewer version 1.6.17 for constructing and visualizing the bibliometric networks for analyzing the bibliographic information, like citations, keywords, link strengths, countries, journals, and authors of a publication.

IV. Results

This segment discusses the results of various bibliometric analyses. The term 'Bibliographic coupling' was coined by Kessler in the early 1960s [54-56]. It is a method for grouping scientific and technical publications. In this paper, the Bibliographic coupling of countries, journals, authors, publications, and author keyword co-occurrences of identified publications, discussed in Section 2, are analyzed. The results are presented in such a manner that helps researchers to understand the linkage by starting with more general information like major countries contributing research in this

domain to more specific information such as the most cited author or keywords-coupling of different publications.

A. Bibliographic Coupling of the Countries

A bibliographic connection of the countries is shown in Fig. 3 and Table II, along with a network visualization. There is a ten-country restriction per document. A country's minimum requirement for publications is 12. Thirteen of the seventy-one countries met the requirements. For each country, the number of documents, citations, and total link strength is computed. The countries with the most total connections are selected. Italy came in first with 157 publications, 1489 citations, and 3398 overall link strength. Rest countries are; United Kingdom (53; 1546; 2533), Spain (45; 338; 2121), Greece (61; 733; 2027), Portugal (29; 151; 1757), France (27; 354; 1124), Australia (17; 348; 953), South Korea (25; 352; 917), Germany (28; 296; 722), China (30; 61; 641), Malaysia (12; 48; 601), United States (22; 120; 498), and Indonesia (13; 39; 154). The first figure inside the parentheses indicates the number of documents, the second indicates the total citations, and the total strength of the other nations' links is indicated by the third figure.

Different colours in Fig. 3 represent different clusters that are more commonly related to one another. It indicates that studies from nations in the same cluster are more likely to cite each other. Spain, Portugal, France, Germany, Greece, UK, and China, make up the largest cluster. The second cluster includes Australia, Indonesia, Italy, and Malaysia. The third cluster includes South Korea and the United States.

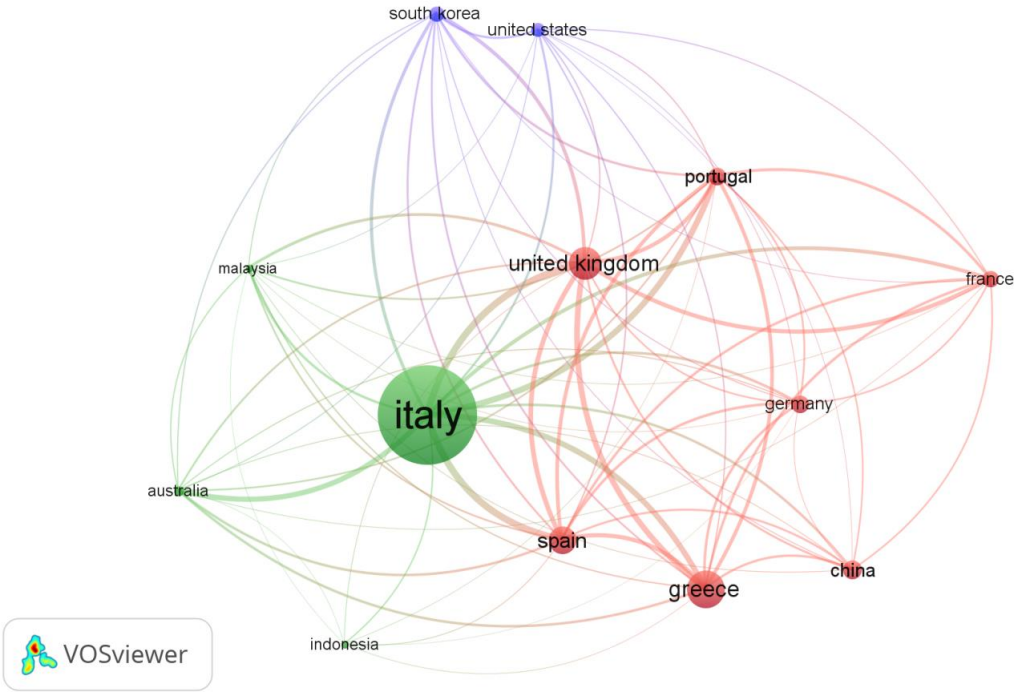

Fig. 3. Countries bibliographic coupling (network visualization).

TABLE II. COUNTRIES BIBLIOGRAPHIC COUPLING

Country	Documents	Citations	Total link strength
Italy	157	1489	3398
United Kingdom	53	1546	2533
Spain	45	338	2121
Greece	61	733	2027
Portugal	29	151	1757
France	27	354	1124
Australia	17	348	953
South Korea	25	352	917
Germany	28	296	722
China	30	61	641
Malaysia	12	48	601
United States	22	120	498
Indonesia	13	39	154

B. Bibliographic Coupling of the Journals

The bibliographic connection of the journals with density visualization is depicted in Fig. 4. As an inclusion criterion, the journal should have at least a specific number of articles. Only ten journals out of 288 passed the test. For those ten journals, the number of articles, citations, and total strength of bibliographic coupling relationships with other journals are calculated. The journals with the most total link strength are chosen and arranged as per the total link strength as shown in Table III.

Each circle in Fig. 4 depicts a journal, with varying colors representing the density of the journal. The density visualization is weighted based on the number of articles for each journal. The colors shifting to yellow and then red indicate that the associated journal has published more articles.

With 94 publications, 711 citations, and 647 total link strengths, the Lecture Notes in Computer Science series is the most popular. The "Journal on Computing and Cultural Heritage" is ranked second in terms of citations (396), overall link strength (429), but fifth in terms of content count (13 publications).

The second-highest number of articles (26), with the third-highest citations (202) and a link strength of 137, are published in "International archives of photogrammetry, remote sensing, and spatial information sciences".

C. Bibliographic Coupling of the Authors

Fig. 5 uses overlay visualization to demonstrate the authors' bibliographic connection. An author needs to have a minimum of six publications to be considered for this study. Only ten authors are chosen from a total of 1672. For each author, the number of documents, citations, and total link strength is calculated. The authors with the most total link strengths are chosen and arranged as per the total link strength as shown in Table IV.

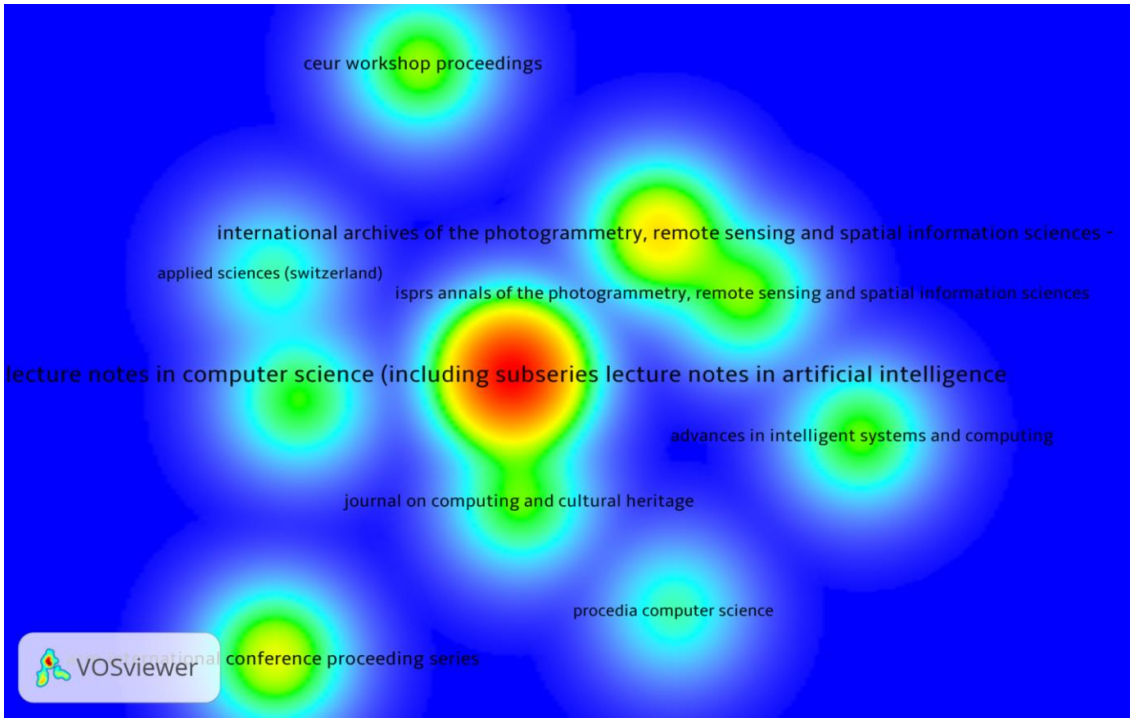

Fig. 4. Journals' bibliographic coupling (density visualization).

TABLE III. JOURNALS' BIBLIOGRAPHIC COUPLING

Source	Documents	Citations	Total link strength
"Lecture notes in computer science"	94	711	647
"Journal on computing and cultural"	13	396	429
"Applied sciences (Switzerland)"	7	28	263
"ACM international conference proceedings"	20	118	172
"ISPRS annals of photogrammetry, remote sensing, and spatial information sciences"	14	61	164
"Communications in computer and information science"	12	21	153
"International Archives of the photogrammetry, remote sensing, and spatial information sciences"	26	202	137
"Advances in intelligent systems and computing"	13	20	98
"CEUR workshop proceedings"	15	27	73
"Procedia computer science"	7	31	56

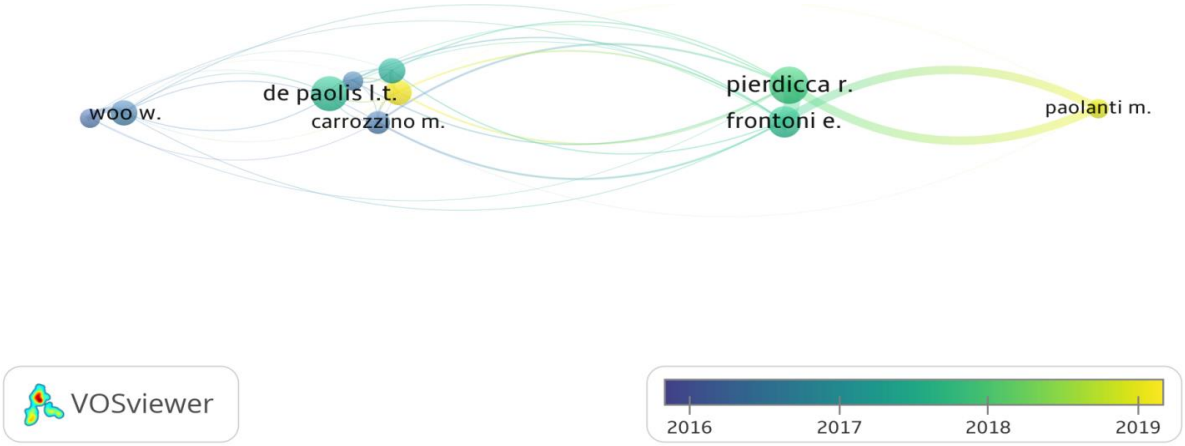

Fig. 5. Authors' bibliographic coupling (overlay visualization).

TABLE IV. AUTHORS' BIBLIOGRAPHIC COUPLING

Author	Documents	Citations	Total link strength
Pierdicca R.	12	339	804
Frontoni E.	10	337	798
Paolanti M.	6	46	423
Woo W.	8	66	161
Marto A.	8	34	143
Kim J.	6	54	138
Carrozzino M.	7	66	118
Liarokapis F.	8	290	94
Bostanci E.	6	66	87
De Paolis L.T.	11	214	62

With 12 publications, 339 citations, and a total link strength of 804, Pierdicca R. (Università Politecnica Delle Marche, Italy) was the most prominent author. With 10 articles and 798 links, Frontoni E. (Università Politecnica Delle Marche, Italy) is the second most cited author (337). Lucio Tommaso De Paolis (Università del Salento, Italy) is the second strongest author in terms of documents (11), citations (214), and link strength (62).

Liarokapis F. (Cyprus University of Technology, Cyprus) is the third strongest author in terms of citations (290), with 8 publications and 94 link strengths.

The first number reflects the total number of documents, the total number of citations are represented by the second number, and the total number of link strengths by the third number. The remaining authors are listed in order of total link strength: Paolanti Marina (University of Macerata, Italy) (6; 46; 423), Woo Woontack (Korea Advanced Institute of Science and Technology, Korea) (8; 66; 161), Marto Anabela (Polytechnic of Leiria, Leiria, Portugal) (8; 34; 143), Kim J. (Seoul National University, Seoul, Korea) (6; 54; 138), Carrozzino (6; 66; 87). There are five experts from Italy, two from South Korea, and one each from Turkey, Cyprus, and Portugal among the top ten authors.

It demonstrates Italy's dominance in this field of study. The color disparities in Fig. 5 depict the groupings of those writers based on the years in which their research is published. It reveals that among these authors, Paolanti Marina, Pierdicca, and Frontoni E. have the most recent studies.

D. Bibliographic Coupling of the Publications

Fig. 6 shows the publications' bibliographic coupling with network visualization. The papers with at least 100 number of citations are considered for this study. Only 10 documents out of 590 met the criteria, and three of those do not have any coupling with other papers. As a result, just seven publications are studied. For each article, the number of citations and overall link strength is calculated.

The documents are arranged as per the total link strength as shown in Table V. Anderson et al. (2010) [57] has the highest link strength of 8 and the second highest citations of 205. Bekele et al. (2018) [58], on the other hand, have the most citations 240 and the second strongest link strength of 5. Styliani et al [2009; (207; 4)] [59], Wojciechowski et al [2004; (228; 3)] [60], Schmalstieg et al [2007; (115; 2)] [61], Tom Dieck et al. [2017; (101; 1)] [62], Sylaiou et al [2010; (146; 1)] [63] are the other papers listed in order of overall link strength.

The first number inside the parentheses represents the number of citations, while the second is the total link strength for each article.

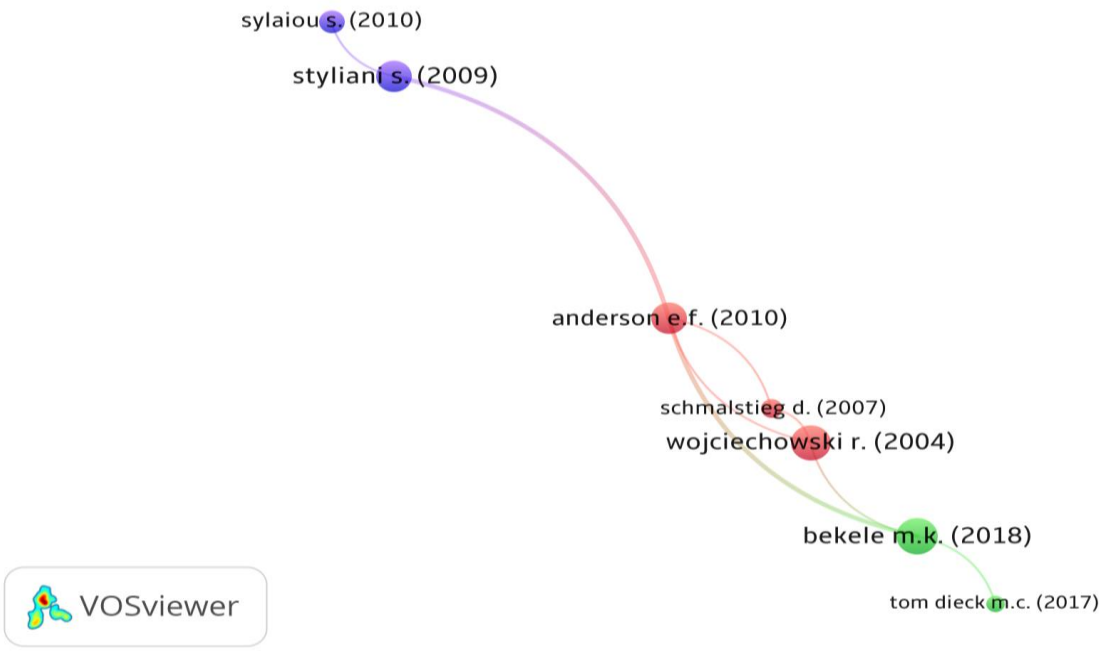

Fig. 6. Publications' bibliographic coupling (network visualization).

TABLE V. PUBLICATIONS' BIBLIOGRAPHIC COUPLING

Document	Citations	Total link strength	Domain of discussion
Anderson E.F.(2010)	205	8	Game Development for Cultural Heritage
Bekele M.K.(2018)	240	5	AR,VR and MR in Cultural Heritage
Styliani S.(2009)	207	4	Virtual Museums
Wojciechowski R.(2004)	228	3	AR, VR in museum exhibition
Schmalstieg D.(2007)	115	2	Handheld AR
Tom Diek M.C. (2017)	101	1	Visitor experience at heritage sites
Sylaiou S. (2010)	146	1	Virtual Museum

E. Co-occurrences of the Author Keywords

Fig. 7 shows the author keywords' co-occurrences in a network format. The minimal number of occurrences of a keyword is 12 as an inclusion criterion. Only 14 of the 1296 keywords passed the test.

The frequency and its linkage with other keywords is computed for each keyword. Keywords with the most total link strength are chosen as shown in Table VI. With 332 occurrences and 377 total link strength, Augmented Reality is the most popular keyword. With 282 occurrences and 343 total link strength, Cultural Heritage is the second most popular keyword. Virtual Reality (91; 126), Mixed Reality (33; 67), Photogrammetry (23; 39), Storytelling (13; 30), 3D Reconstruction (14; 29), Education (16; 28), User Experience (15; 26), 3D Modeling (15; 23), Intangible Cultural Heritage (16; 20), Mobile Application (12; 20), Museums (12; 19), Mobile augmented Reality (22; 17). For the rest, the first number inside the parentheses represents the number of occurrences, and the total link strength is represented by the second number.

Fig. 7 depicts different colored clusters representing the more frequently connected keywords. Education, Intangible Cultural Heritage, Mixed Reality, Mobile Augmented Reality, Narrative, and User Experience make up the largest cluster. The second cluster is comprised of augmented Reality, Cultural Heritage, Mobile Application, Photogrammetry, and 3D-Reconstruction. Each of the other three clusters consists of a single element each, viz. 3D-Modeling, Virtual Reality, And Museums. The research is mainly done in two broader areas. The first one is learning about cultural heritage through mobile applications using Mixed Reality. The second one is a 3D-reconstruction of cultural heritage using augmented Reality and photogrammetry.

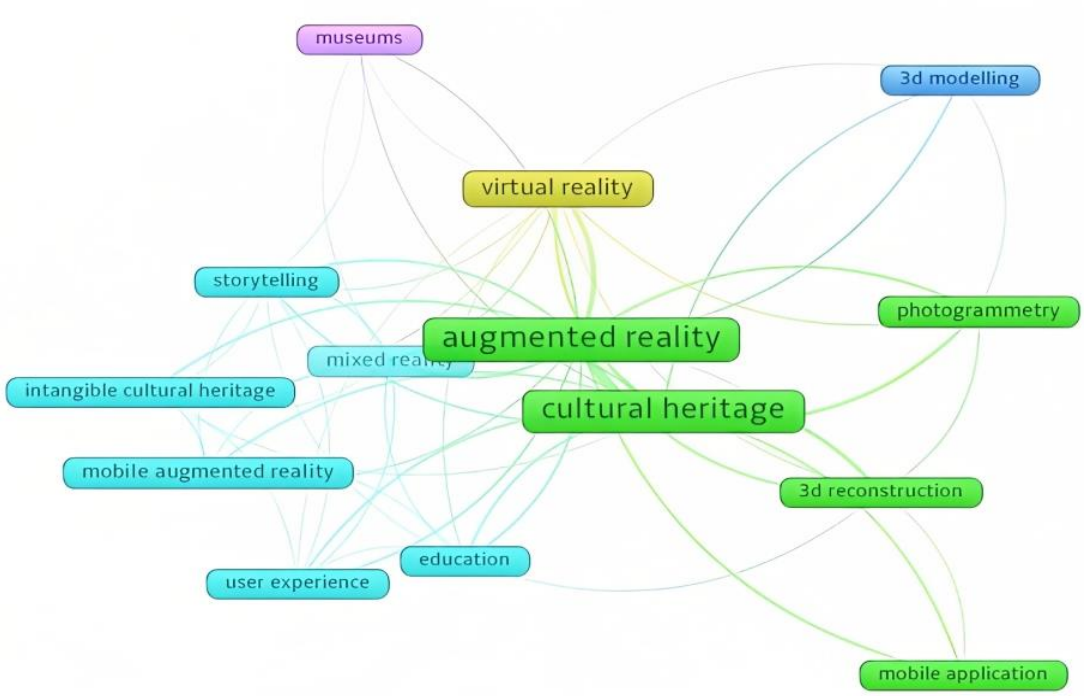

Fig. 7. The author keywords' co-occurrences (network visualization).

TABLE VI. THE AUTHOR KEYWORDS' CO-OCCURRENCES

Keyword	Occurrences	Total link strength
Augmented Reality	332	377
Cultural Heritage	282	343
Virtual Reality	91	126
Mixed Reality	33	67
Photogrammetry	23	39
Storytelling	13	30
3D-Reconstruction	14	29
Education	16	28
User Experience	15	26
3D-Modelling	15	23
Intangible Cultural Heritage	16	20
Mobile Application	12	20
Museums	12	19
Mobile Augmented Reality	22	17

V. DISCUSSION

The following paragraph discusses how the research objectives specified in Section I.A, are achieved through bibliometric analysis and systematic literature survey.

1) Compile the peer-reviewed articles and conference papers on applications of AR/VR in cultural heritage during the period of 1999 to 2022.

In this work, publications from the Scopus database those are relevant to Augmented Reality or Virtual Reality-based solutions for learning and reconstruction of cultural heritage are retrieved, analyzed, and visualized using descriptive and evaluative bibliometric analytic methodologies. To evaluate and visualize the linked data, VOSviewer 1.6.17 software is employed. Bibliographic coupling of publications, journals, countries, authors, and author keywords co-occurrences from associated publications are examined and illustrated.

2) Ascertain the spread of this field using bibliometric coupling of publications, journals, and authors.

As per the journals' bibliographic coupling, the premier journal in AR and VR literature related to cultural heritage is "Lecture notes in the computer science" series with the highest

publications, citations, and total link strength. Few more important journals in this area are; "Journal on computing and cultural heritage" (impact factor: 2.64), "International Archives of the photogrammetry, remote sensing and special information sciences" (impact factor: 0.82), "Applied sciences" (impact factor: 2.73), ACM International conference proceeding series (impact score: 0.61), "ISPRS Annals of the photogrammetry remote sensing and special information sciences" (impact score: 1.45), "Communications in Computer and information science" (impact factor: 0.48), "Advances in intelligent systems and computing" (impact factor: 0.63), CEUR workshop proceedings (impact score: 0.55), and "Procedia Computer science" (impact score: 2.09). The scopes of top journals are innovative usage of AR/VR for the discovery, reconstruction, experiencing, and learning of cultural heritage.

As observed from Table IV and Table V, the highest cited paper in this area is written by Anderson E. F. (2010) [57] which is co-authored by Liarokapis who is the eighth author as per the total link strength. Similarly, it is also observed that the second highest cited publication is by Bekele M. K. (2018) [58] and co-authored by Pierdicca R. and Frontoni E., who are the most cited authors. The third most cited publication is by Styliani S. (2009) [59] which is also co-authored by Liarokapis.

3) Understand which countries have the most publications in this area.

As per results shown in Table II related to the bibliographic coupling of countries, the maximum work in this area has been done in Italy which is the home of 58 UNESCO world heritage sites. The next three countries as per the number of publications are Greece with 18 UNESCO sites, the United Kingdom with 33 UNESCO sites, and Spain with 49 UNESCO sites. The other important countries have been: Portugal, France, Australia, South Korea, Germany, China, Malaysia, the United States, and Indonesia.

As per the authors' bibliographic coupling, the top three authors, Pierdicca, Frontoni E., and Paolanti are from Italy and worked together in many of the publications. Among the 10 strongest authors five are from Italy out of which the first two authors are from the same university that is Università Politecnica Delle Marche, Italy.

4) Which technologies were employed for implementation of cultural heritage projects?

As observed from Table I, most of the museum tour related projects are based on immersive technology and comparatively less work is done in non-immersive and semi-immersive areas. It is also found that mainly the immersive experience is provided by stimulating the optic senses of users, followed by the haptic, auditory, smell and taste senses.

The co-occurrences of author keywords show that the authors have largely employed augmented reality for 3D-reconstruction of cultural heritage using photogrammetry. It is also seen that Augmented Reality is used more often than Virtual Reality to provide users with an immersive experience of ancient cultural heritage.

By examining the co-occurrences of author keywords, the publications' and journals' bibliographic couplings, it can be concluded that most of the researchers either tried to reconstruct the ancient environment of cultural heritage through mobile applications using Augmented Reality and photogrammetry or the researchers tried to create a submerging user experience of intangible cultural heritage through storytelling and using the Mixed Reality, especially for educational purpose. The most cited review papers by Anderson et.al (2010) [57] and Bekele et.al (2018)[58] also support this finding.

VI. Conclusion and Future Work

The results of the different types of analysis performed here indicate that the AR,VR and MR related research in the field of cultural heritage is mostly concentrated in Italy and surrounding European countries which are the home of many ancient monuments and other heritage sites. Other than Europe, some researchers from South Korea are also working in the same domain for providing information about their cultural heritage sites through mobile applications. It is also observed that although Mexico has 35 UNESCO heritage sites, the research in this area is still lagging behind there.

This study would help researchers to identify the prominent journals in the said domain, recognize stalwarts in the field and follow their works, find out path-breaking publications to refer to, predict the direction of future studies, etc. Here, we have presented the bibliometric analysis of the publications related to AR,VR and MR in cultural heritage. The work can be further extended to include publications related to specific areas such as 3D-reconstruction of heritage sites, gaming and educational applications related to this domain, etc. In a conclusion, it can be commented that AR, VR and MR in cultural heritage and 3D-reconstruction has a great scope and potential for immediate research.

VII. Conflicts of Interest

The authors have no conflicts of interest to declare.

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