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Global trends in the study of projection mapping technology using bibliometric analysis

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Abstract

Projection mapping has emerged as a compelling new medium, experiencing continual growth due to technological innovations across diverse fields, including medicine, communication, and science. Consequently, the volume of articles addressing technological advancements in projection mapping has surged over the past two decades. This article conducts a comprehensive bibliometric analysis on projection mapping technology, employing statistical and publication characteristic analyses to offer insights into research progress and trends spanning from 2003 to 2022. The results, based on 440 documents (journal articles, conference papers, book chapters, conference reviews, reviews, and books) retrieved from the Scopus database on February 9, 2023, indicate a consistent increase in publications on projection mapping technology, although research remains somewhat limited. Utilizing VOSviewer, Microsoft Excel, and Tableau Public, the bibliometric analysis unveils notable authors in the field, highlighting metrics such as the number of citations, country productivity, and key periodicals publishing projection mapping technology content. Iwai, D., from Osaka University emerges as the most prolific author on projection mapping technology, while Ishikawa, M., stands out as the researcher with the highest citation frequency. Japan is identified as the most productive and cited country of origin for researchers in this domain. Notably, "IEEE Transactions on Visualization and Computer Graphics" holds significant influence, having the highest citation count and serving as a vital reference source. Empirical researchers can leverage articles from this journal to track the evolving research topics in projection mapping technology year by year.

Keywords: research trend, bibliometric analysis, Scopus database, citation

1. Introduction

Projection mapping is a novel medium capable of projecting optical illusion content in the form of images or videos onto various surfaces, including buildings, facades, structures, and complex 3D surfaces (Rodriguez, et al., 2015). Projection mapping has the potential to transform visual perception into something more captivating (Fujimoto, 2018). The concept of projection mapping continues to evolve, enabling users to interact directly with the mapping results; this is commonly referred to as interactive projection mapping. The rapid development of physical processing technologies, such as electronics, sensors, and digital projections, creates an immersive experience through projection mapping that enhances the user's comprehension and retention of the presented content (Nofal, et al., 2018). By combining technology and art, projection mapping can stimulate visual perception and enable users to physically interact with the content (Krautsack, 2011).

Projection mapping enhances user engagement by creating a very immersive and participatory experience. Visual stimulation has the capacity to captivate, amuse, and convey fascinating knowledge (Krautsack, 2011). An immersive experience refers to a situation when the consumer experiences a deep sense of connection and integration with the technology being utilized (Handa, Aul and Bajaj, 2012). Immersive technology, which merges the boundaries between the physical and virtual realms, enables consumers to indulge in a delightful digital encounter. Immersive technologies encompass augmented reality (AR), virtual reality (VR), mixed reality (MR), and extended reality (XR) (Hein, Wienrich and Latoschik, 2021). Immersive tech-

nology allows users to actively participate in genuine explorations of the real world, making complicated subjects easier to understand. Additionally, immersive technology can motivate users to improve their abilities (Suzanna and Lumban Gaol, 2021).

A significant amount of research and development has been focused on studying projection mapping technology as a means of implementing recent breakthroughs in new media. Based on the studies conducted by Rodriguez, et al. (2015), Fujimoto (2018), Krautsack (2011), Degner, Moser and Lewalter (2022), and Nofal, et al. (2018), it can be inferred that no research has utilized bibliometric analysis methods in the domain of projection mapping. Projection mapping has emerged as a prominent immersive technology in the ongoing development of new media. The authors aim to comprehend the scope and advancement of projection mapping research, prevailing worldwide research patterns, and the prospects for future research expansion in this domain. Hence, it is important to consult scientific literature in order to ascertain any shortcomings in the field of projection mapping study. The aim of this analytical study is to present scientific literature using bibliometric analysis approaches related to projection mapping technology. The research topics examined in this analysis are as follows:

RQ 1: Who are the influential authors in projection mapping technology research?

RQ 2: Which nations frequently conduct research on projection mapping technology, and what outputs do they produce?

RQ 3: Which projection mapping technologies have been the subject of research?

2. Methods

The analysis utilized bibliometrics, focusing on evaluating individual and institutional scientific outputs through bibliographic databases (Baker, 1991). Documents for this study were extracted from the Scopus database. Since data mining is conducted on public databases, ethical board approval is unnecessary (Xie, et al., 2020). Scopus was chosen as it is the predominant database used by academics across various multidisciplinary fields for searching journal articles, conference proceedings, and book chapters (Mongeon and Paul-Hus, 2016; Singh, et al., 2021). As illustrated in Figure 1, the authors initiated a search of the Scopus database on February 9, 2023, using keywords (TITLE-ABS-KEY (“projection mapping” OR “video mapping”

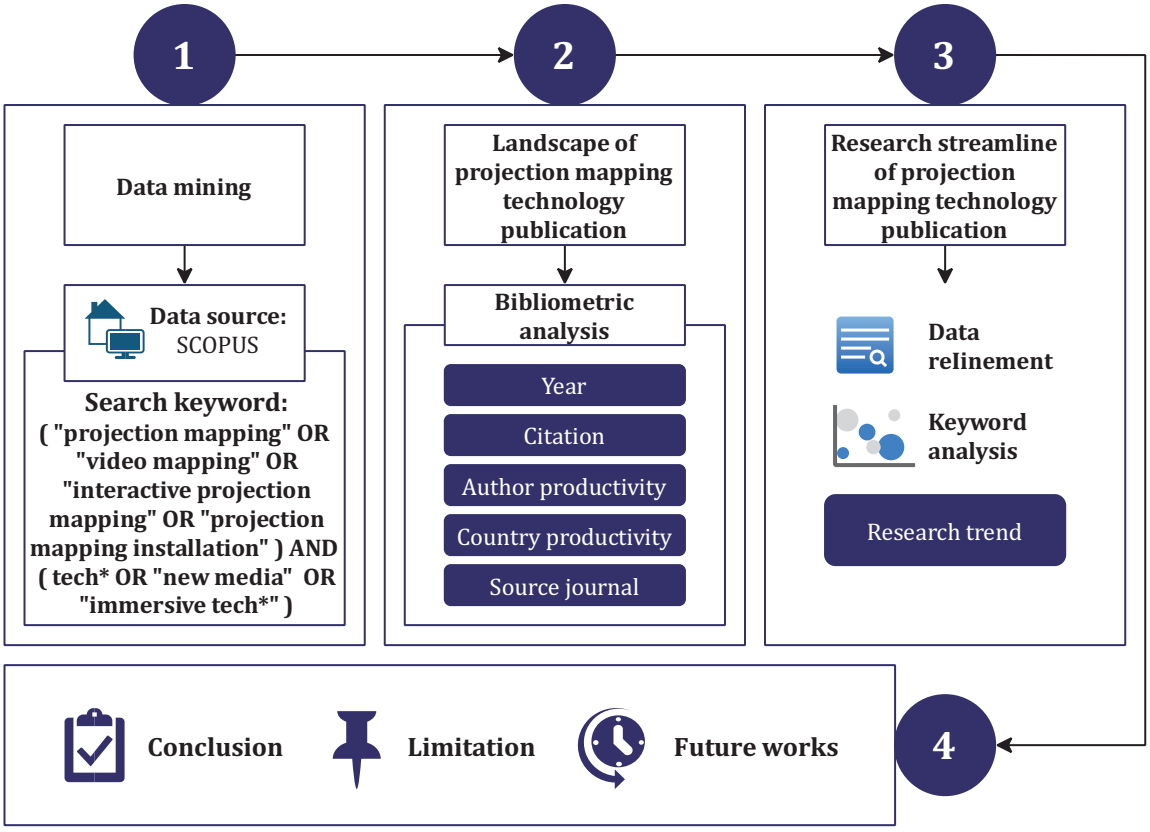

Figure 1: Research method

OR "interactive projection mapping" OR "projection mapping installation") AND TITLE-ABS-KEY (tech* OR "new media" OR "immersive tech*")) to identify research developments in projection mapping technology. Beyond trends, numerous intriguing findings requiring visualization and thorough analysis emerged. The data collection on this date yielded 440 documents (180 journal articles, 213 conference papers, 20 book chapters, 16 conference reviews, 8 reviews, and 3 books) on the topic. The metadata for these 440 documents were then downloaded as comma-separated value (CSV) files. This study restricts the search time period to the last 20 years in order to identify the most recent research trends. The literature data sources were limited to the Scopus database. The inclusion of other databases, such as Web of Science or Google Scholar, and other types of documents, such as patents, might have revealed further insights that were not included in this study.

The second stage involves conducting a bibliometric analysis to explore the research landscape of projection mapping technology. VOSviewer, Microsoft Excel, and Tableau Public are utilized for this analysis, focusing on factors such as annual publication trends, citations, author productivity, country productivity, and publications on projection mapping technology. Following the analytical strategy of Qin, et al. (2022), the analysis considers yearly publication trends and citations based on total publications (TP), their total citations (TC), and resulting average citations per publication (AC = TC/TP).

The third stage is dedicated to identifying keywords and streamlining research on projection mapping technology. Keywords are identified by analyzing their frequency of use and relationships with one another. Before analysis, author keywords and indexed keywords are refined using Open Refine to reduce bias, preventing the separate counting of keywords with the same meaning. The enhanced database is then used for analysis. The outcomes of this research streamlining analysis will help ascertain thematic evolution and the most recent trends in projection mapping technology research, aiding empirical researchers in identifying research gaps and novelties.

3. Results and discussion

3.1 Landscape of projection mapping technologies publications

3.1.1 Characteristics of projection mapping technology publications

This analysis utilized a total of 440 documents from the Scopus database, containing the searched phrases (see 2. Methods) and covering the time period from 2003 to 2022. An analysis was conducted to study the progression of publications on the topic of projection mapping technology, utilizing metrics including TP, TC, and AC. Figure 2 shows the growth of publications on this topic.

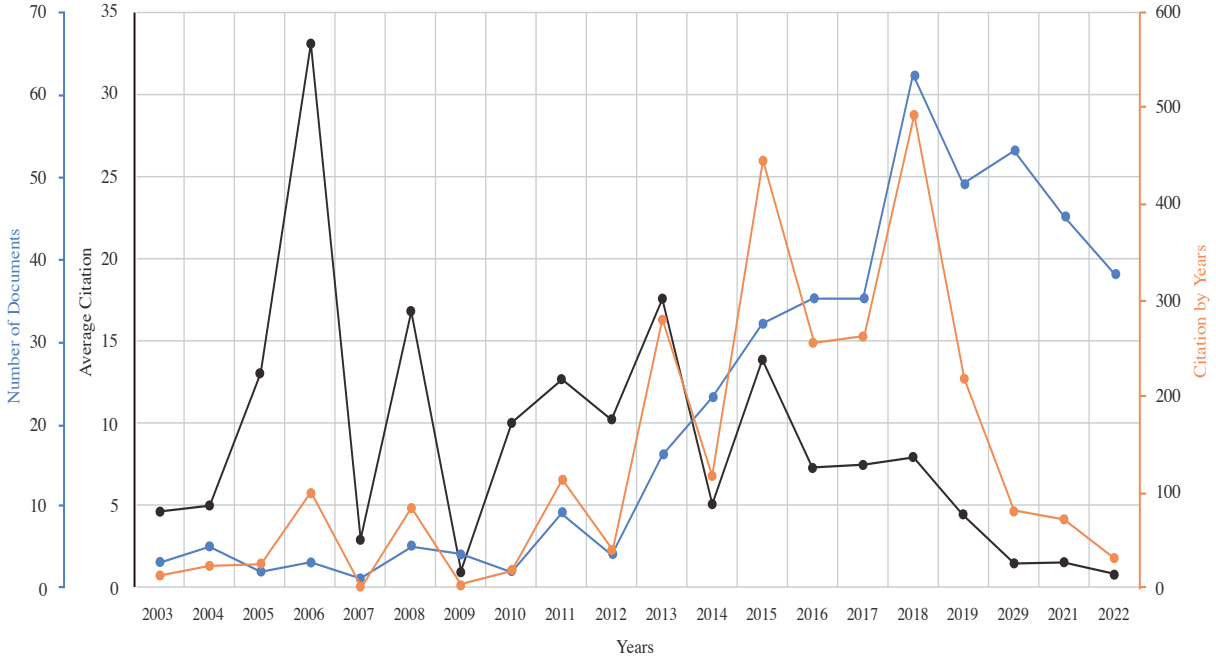

Figure 2: Trend distribution of publications from individual years and their citations in projection mapping technology

Analysis of the data on the number of publications (the blue line in Figure 2) reveals a moderate development of publications on projection mapping technology between 2003 and 2012. However, from 2012 to 2018, the average annual publication count was increasing on average by 95 %, related to the first year of this period. The number of scientific articles on projection mapping technology saw a significant surge between 2017 and 2018, aligning with rapid advancements in the discipline. Post-2018, research on projection mapping technology shows a declining trend, possibly influenced by factors such as the COVID-19 pandemic, which has impacted empirical research and development (Tuttle, 2020; Riccaboni and Verginer, 2022).

Over the last two decades, 440 documents were published, with 388 in the last ten years, indicating that publication productivity in the last decade contributed 88 % of the total during the developmental period of projection mapping technology research. This underscores the rapid development in the field, with an acceleration of research in recent years.

Similarly to the increasing trend in the number of publications, total citations of documents published in individual years (orange line in Figure 2) also show an upward trajectory till 2018. For documents from 2013, there were 280 citations; for those from 2015, the count rose to 444 citations, and for 2018 publications, it reached 492 citations. Researchers worldwide have conducted numerous studies on projection mapping technology in recent years. However, post-2018, the citation trend tends to decrease, possibly due to factors such as a decline in studies related to this topic and a reduced need for references among researchers. Additionally, the average number of citations reached its peak for publications from 2006, with 33.

3.1.2 Characteristics of projection mapping technology publications based on author productivity and number of citations

Scientists, innovators, practitioners, and academics conduct research to discover new things or to test something already in existence so that it can be eval-

Table 1: Top 5 authors by number of documents

No	Author/ Institution	Country	Number of documents	Number of citations
1	Iwai, D./ Osaka University	Japan	20	132
2–3	Hashimoto, N./ The University of Electro-Communications	Japan	13	37
2–3	Sato, K./ Osaka University	Japan	13	82
4	Ishikawa, M./ The University of Tokyo	Japan	12	206
5	Watanabe, Y./ Tokyo Institute of Technology	Japan	10	198

Table 2: Top 5 authors by number of citations

No	Author/ Institution	Country	Number of documents	Number of citations
1	Ishikawa, M./ The University of Tokyo	Japan	12	206
2	Watanabe, Y./ Tokyo Institute of Technology	Japan	10	198
3	Huang, C.-C., Sugino, K., Shima, Y., Guo, C.,Bai, S., Mensh, B.D., Nelson, S.B., Hantman, A.W./ Howard Hughes Medical Institute and Brandeis University	United States	1	153
4	Iwai, D. Osaka University	Japan	20	132
5	Ofek, E./ Microsoft Research Lab – Redmond	United States	2	115

uated and implemented in their respective fields of work. Research publications serve as a chronicle of a specialist's accomplishments. Numerous researchers in the field of projection mapping technology have developed, evaluated, and implemented this concept in various contexts. The authors have compiled a list of researchers whose works have been published and are listed in the Scopus index in order to determine who are the most productive and influential researchers in projection mapping technology research.

In Table 1, the authors are ranked based on the number of published works, with Iwai, D., leading the list with a total of 20 published documents, cited by 132 other works. The second and third positions are held by Hashimoto, N. and Sato, K., both with 13 documents. Sato, K., has 82 citations, while Hashimoto, N., has 37 citations. Notably, Iwai, D., often collaborates with Sato, K., who shares the same affiliation at the Graduate School of Engineering Science, Osaka University, Japan. Their research discusses the latest technologies developed in the field of projection mapping, such as the use of convolutional neural networks (Kageyama, Iwai and Sato, 2022), visuo-haptic augmented reality (VHAR) systems and tactile display control signals (Miyatake, et al., 2021), computational imaging (Iwai, 2019), visual markers for geometric registration (Asayama, Iwai and Sato, 2018), distributed optimization framework (Tsukamoto, Iwai and Kashima, 2017), and monocular projector-camera system (Yamamoto, et al., 2022).

Frequently cited studies often indicate greater influence. In the topic of projection mapping technology research, the authors have compiled a list of the ten

Table 3: Top 10 articles with the highest number of citations

Authors (Year)/ Title	Year	Source title / Quartile	Document type
Huang, et al. (2013)/ Convergence of pontine and proprioceptive streams onto multimodal cerebellar granule cells	2013	eLife / Q1	Article
Pejsa, et. al. (2016)/ Room2Room: Enabling life-size telepresence in a projected augmented reality environment	2016	Proceedings of the ACM Conference on Computer Supported Cooperative Work, CSCW	Conference Paper
Narita, Watanabe and Ishikawa (2017)/ Dynamic projection mapping onto deforming non-rigid surface using deformable dot cluster marker	2017	IEEE Transactions on Visualization and Computer Graphics	Article
Ishikawa, Shimuta and Häusser (2015)/ Multimodal sensory integration in single cerebellar granule cells in vivo	2015	eLife / Q1	Article
Nishino, et al. (2018)/ Real-time navigation for liver surgery using projection mapping with indocyanine green fluorescence: development of the novel medical imaging projection system	2018	Annals of Surgery / Q1	Article
Chee, Arrigoni and Maratos-Flier (2015)/ Melanin-concentrating hormone neurons release glutamate for feedforward inhibition of the lateral septum	2015	Journal of Neuroscience / Q1	Article
Bonaventura, et. al. (2019)/ High-potency ligands for DREADD imaging and activation in rodents and monkeys	2019	Nature Communications / Q1	Article
Chen, et al., (2018)/ Efficient in situ barcode sequencing using padlock probe-based BaristaSeq	2018	Nucleic Acids Research / Q1	Article
Grundhöfer and Iwai (2018)/ Recent advances in projection mapping algorithms, hardware and applications	2018	Computer Graphics Forum / Q1	Article
Rodriguez, et al. (2015)/ Developing a mixed reality assistance system based on projection mapping technology for manual operations at assembly workstations	2015	Procedia Computer Science / Q2	Conference Paper

most frequently cited researchers over the past two decades, presented in Table 2. Serving as a valuable reference for researchers in the field, this table supplements the existing literature. Ishikawa, M., tops the list, cited in 206 other documents based on his 12 publications. His research delves into technological applications in projection mapping, particularly high-speed image processing (Ishikawa, 2014; 2019), high-speed vision (Ishikawa, 2022), high-speed focal tracking projection (Wang, et al., 2020), intelligent imager and GPU (Miyashita and Ishikawa, 2020), MIDAS projection (Miyashita, Watanabe and Ishikawa, 2018), high-speed projector (Mikawa, et al., 2018), dot cluster marker (Narita, Watanabe and Ishikawa, 2017; Watanabe, Kato and Ishikawa, 2017), and mirror-based robust high-speed tracking (Sueishi, Oku and Ishikawa, 2016). Watanabe, Y., has 10 documents that have been cited by 198 other documents, while the authors in third place have 1 document that has been cited by 153 other documents. These authors are incorporated in one document that discusses the use of projection mapping technology in the medical field (Huang, et al., 2013).

Table 3 reveals that the most cited papers are published in Scopus Q1-indexed international journals, indicating that articles in Q1 journals are a primary source for scientific advancement, particularly in the field of projection mapping technology. The size of a journal cluster correlates with the difficulty of publishing within it, reflecting the caliber of the research and articles. Analyzing a database of research publications on projection mapping technology from 2003 to 2022, the ten articles with the highest citations were published between 2013 and 2019, amassing a total of 832 citations, equivalent to 31 percent of the total citations over the past two decades. Subsequently, we will provide a brief analysis of some of these highly-cited articles on projection mapping technology.

The first among the ten articles with the highest citations was published in 2013 by Huang, et al. (2013), accumulating a total of 153 citations. This article explores the application of projection mapping technology in the medical field, specifically for viewing synaptic resolution cell activity. The second article, published in 2016 by Pejsa, et al. (2016), employs projection mapping as a tool for long-distance teleconferencing, displaying the interlocutor's object at its actual scale. The investigation utilized three ceiling-mounted camera projector units (procam), projectors, and Kinect. The third article, published by Narita, Watanabe and Ishikawa (2017), addresses a challenge in projection mapping, namely its inability to project onto dynamic objects. The authors propose the use of the deformable dot cluster marker (DDCM) to track non-rigid surfaces at high-speed using high frame rate cameras, enabling

Figure 3: Distribution of the number of documents based on the country of origin of the researcher

projection on moving objects. In the fourth article, published by Nishino, et al. (2018), a novel imaging technology called the medical imaging projection system (MIPS) is introduced to overcome limitations in intraoperative imaging methods. The authors demonstrate the efficacy and clinical utility of MIPS in identifying anatomical markers for parenchymal dissection, presenting it as a promising real-time navigation system for liver resection. The fifth article, published by Rodriguez, et al. (2015), introduces mixed reality implemented via projection mapping to generate simulations or industry tools. This technology assists users with no prior experience in conducting tasks.

3.1.3 Characteristics of projection mapping technology publication by country

The purpose of the country-by-country analysis of projection mapping technology publications is to determine which countries have published the most documents and exert the most influence on this topic. Figure 3 displays the top ten countries with the most publications on projection mapping technology out of the 86 countries included in this analysis.

Japan has the highest number of published documents, specifically 124. The United States follows with 65 documents, while China is third with 49. South Korea has 24 documents, Italy has 23, France has 15, and both the United Kingdom and Australia have 12. Spain and Canada each have 10 documents.

3.1.4 Characteristics of projection mapping technology publication based on frequently cited sources

The purpose of frequency-based analysis of cited sources is to identify how much of influence showed by these sources on the study subject of projection mapping technology. Table 4 displays the top five sources

Table 4: Characteristics of sources in projection mapping technology-themed publications

No	Sources	Number of documents	Number of citations	Type	IF 2022–2023	H-Index
1	IEEE Transactions on Visualization and Computer Graphics	9	149	Journal	5.226	158
2	Conference on Human Factors in Computing Systems – Proceedings	6	95	Proceedings		
3	IEEE Access	7	56	Journal	3.476	204
4	ACM International Conference Proceeding Series	13	35	Proceedings		
5	Lecture Notes in Computer Science	14	16	Journal	0.407	446

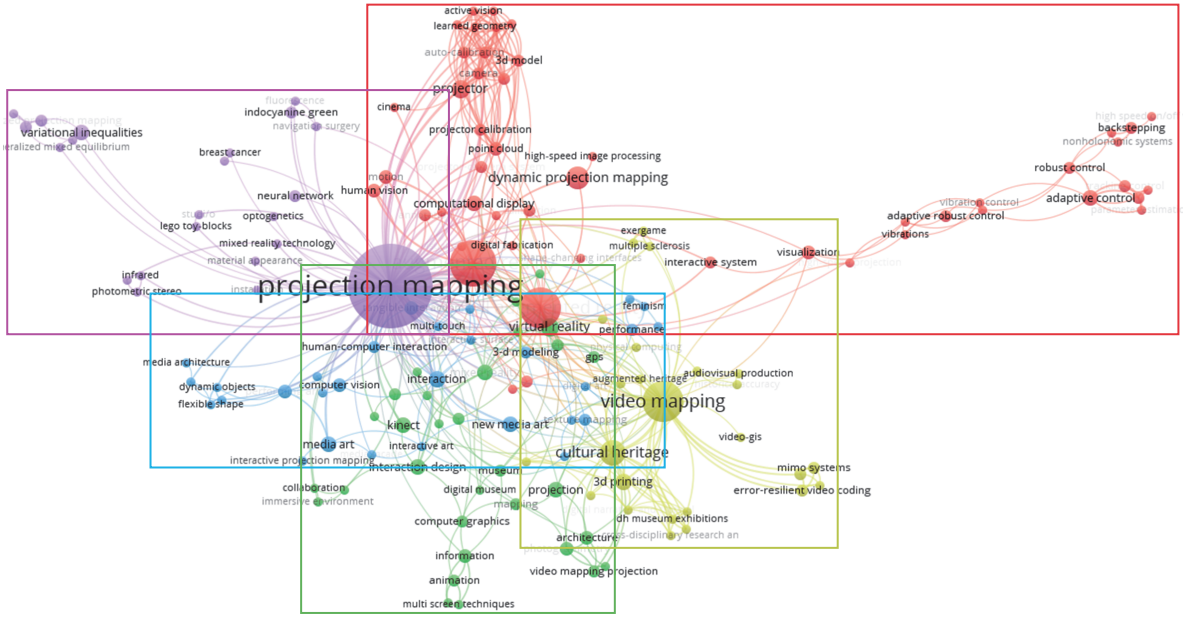

Figure 4: Cluster co-occurrence in projection mapping technology

that are frequently used as references in research about projection mapping technology.

The journal IEEE Transactions on Visualization and Computer Graphics is classified as a Q1 journal. It contains 9 documents that pertain to projection mapping technology. However, it is not as extensive as Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), which is ranked fifth and has 14 documents. Despite this, the IEEE Transactions on Visualization and Computer Graphics journal has received the highest number of citations, specifically 149 citations, compared to Lecture Notes in Computer Science, which has only been cited 16 times. The second most often referenced source was the proceedings of the Conference on Human Factors in Computing Systems, cited 95 times. Following that, IEEE Access was cited 59 times, and the ACM International Conference Proceedings series was cited 35 times.

3.2 Research streamline of projection mapping technology publications

Author keyword analysis is a crucial component of bibliometric research as it identifies the most significant research topics (Kumar Kar and Harichandan, 2022).

In this subparagraph, authors present the research process for publications on projection mapping technology, conducting an in-depth analysis of author keywords and current topic trends (see Figure 4).

In Cluster 1, marked in red, additional research focuses on the projection mapping technology tool processing system. Keywords in this cluster include camera, actuator, adaptive control, calibration, slide mode control, stereoscopic device, computational display, digital fabrication, digital projection mapping, human vision, screen correction, digital sculpture, spatially enriched reality, tracking control, high speed, and others.

Cluster 2, denoted in green, emphasizes research on projection mapping related technology and content. Keywords in this cluster encompass 3D construction, animation, photogrammetry, computer graphics, entertainment computing, GPS, VR, MR, projection mapping installation, laser scanning, and transducer sensors, among others.

In projection mapping technology, the interaction between content and technology is crucial. The technology employed influences the content created, resulting in engaging concepts for immersive experiences. An example in this cluster is OptiSpace, developed by Fender, et al. (2018), a system used to optimize the positioning of interactive projection mapping content in a physical environment for human–computer interaction. This reflects research focused on developing interactive systems that utilize projection mapping technology to enhance users' immersive experiences.

In Cluster 3, denoted in cyan, additional research focuses on techniques, maintenance, and interactive tools for developing content on projection mapping media. Keywords in this cluster include 3D modeling, dynamic objects, flexible shapes, projection mapping interactions, interactive surfaces, reverse perspective mapping, motion capture, multi-touch, performance, real-time masking, real interaction, texture mapping, virtual reconstruction, and human–computer interaction.

This cluster represents research that concentrates on the development of interactive techniques for projection mapping. The use of interactive technologies based on projection mapping, such as augmented reality, can result in more precise, stable, and natural information delivery. In the study of Yuan, et al. (2021), an appealing interaction design concept tailored to the intended audience resulted in an enhanced user experience.

The application of dynamic and adaptable projection mapping content is characterized by the use of interactive devices, a defining feature of the new media concept. Utilized interactive devices include motion capture, human–robot interaction, multi-touch, and interactive projection. Techniques and content used in this context include real-time masking, 3D modeling, dynamic objects, flexible forms, texture mapping, etc. Pmomo, created by Zhou, et al. (2016), is a prime example of interactive device development. Pmomo can project objects in real-time and directly interact with 3D objects in 360 degrees, employing sensors, depth cameras, and tracking algorithms to provide users with an interactive experience.

In Cluster 4, marked in yellow, the research focuses on the implementation of projection mapping in the fields of history and culture. Keywords in this cluster include augmented heritage, audiovisual production, design practices, cultural heritage, museum exhibitions, digital narratives, storytelling, improvement of error-resistant video coding, historical monuments, holographic techniques, mixed media installations, multimedia communications, coding with multiple descriptions, multiple input, multiple output (MIMO) systems, physical computing, and video mapping.

In these studies, projection mapping has been implemented in informal spaces such as museums and historical monuments to introduce knowledge about cultural and historical heritage. This is achieved through projection mapping installations or mixed media installa-

tions, applying audiovisual content, digital narratives, and storytelling. The goal is to create immersive experiences and interact with visitors, enriching the way they understand and appreciate culture and history.

In Cluster 5, colored violet, there is additional discussion of the medical applications of projection mapping. Keywords in this cluster include breast cancer, fluorescence, generalized mixed equilibrium problem, indocyanine green, infrared, Lyapunov functional, mixed reality technology, navigation surgery, neural network, optogenetics, photometric stereo, sentinel lymph node biopsy, uniformly smooth Banach space, and variational inequalities. According to Rodriguez, et al. (2015) research, the implementation of mixed reality using projection mapping can assist the operation process, allowing real-time control visualized directly in the operator's workplace.

4. Conclusions

This study conducted a comprehensive bibliometric analysis on the research topic of projection mapping technology using VOSviewer, Microsoft Excel, and Tableau Public. The analysis was based on the Scopus database, focusing on the growth of the number of publications from 2003 to 2022, prolific authors, citation analysis, country productivity, sources publishing documents on projection mapping technology, and research trends. Over the period from 2003 to 2022, the annual number of articles on projection mapping technology in international journals, proceedings, and publications has consistently increased. However, there are variations in the total and average number of citations to documents published in individual years. Iwai, D., from Osaka University emerged as the most prolific author in projection mapping technology, while Ishikawa, M., received the highest number of citations for his works. Japan is identified as the most productive country of origin for researchers in this field. The journal with the highest number of citations, making it a crucial reference, is "IEEE Transactions on Visualization and Computer Graphics." Empirical researchers can use articles from this journal to track the evolution of research subjects and the ongoing development of the projection mapping technology research topic. The analysis suggests that projection mapping technology, currently evolving, has potential applications in education and entertainment, in addition to the medical and telecommunications fields discussed in the analyzed articles.

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