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Article

Research Trends and Academic Progress in Virtual Reality Environments within the Field of Visual Communication: An Exploration Based on Bibliometric Analysis

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Abstract

This study employs bibliometric analysis to explore research trends and academic advancements in Virtual Reality Environments (VREs) within the field of visual communication. Using the Scopus database, the study analyzes keyword co-occurrence networks, thematic evolution, and academic collaboration networks to identify research hotspots and gaps. Results show a consistent growth in research output, with a significant surge between 2018 and 2023. Core theoretical frameworks such as immersive learning theory and semiotics remain foundational, while emerging themes like gamification and cultural heritage gain traction. Global academic collaboration is prominent, with China and the USA as key contributors. The study emphasizes the need for integrating existing theories, expanding application scenarios, and fostering interdisciplinary collaboration to strengthen the theoretical and practical foundations of VRE research.

Keywords: Bibliometric Analysis, Thematic evolution, Virtual Reality Environments, Visual Communication.

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Introduction

Virtual Reality Environments (VREs) profoundly merge technology and creativity, offering transformative opportunities in visual communication, interactive design, education, cultural heritage preservation, and medical simulation (Tian, 2020). These immersive platforms have revolutionized how users interact with digital content and paved the way for innovative applications across interdisciplinary fields. However, despite widespread enthusiasm, the field faces significant challenges due to fragmented theoretical foundations and diverse methodological approaches, reflecting both its interdisciplinary richness and the complexities it entails.

At the core of VRE research are frameworks such as immersive learning theory and semiotics (Ho, Sun et al., 2019; Barricelli et al., 2016), which explore the intricate relationships between technological features and user interactions. These theories provide valuable insights into how virtual experiences are designed, perceived, and consumed, underscoring the interdependence between design elements and user behavior (Yu, 2023). Nevertheless, the rapid pace of technological advancement necessitates a more cohesive and comprehensive theoretical evolution. Key challenges include the development of scalable user interaction models and seamlessly integrating multisensory dimensions to enhance the depth and realism of virtual experiences.

The study addresses these gaps by employing bibliometric techniques to analyze publication trends and thematic developments in VRE research, specifically focusing on visual communication. Using the Scopus database, it identifies critical themes, evaluates interdisciplinary collaborations, and charts the progression of scholarly contributions. By leveraging keyword co-occurrence networks and analyzing publication patterns, this research reveals significant gaps, highlights emerging priorities, and provides a detailed overview of the academic landscape. Ultimately, the findings aim to guide future exploration and innovation, strengthening this rapidly evolving field's theoretical and practical foundations.

Literature Review

Research in virtual reality (VR) reflects significant theoretical diversity, with numerous studies adopting distinct frameworks to advance VR technologies. The literature identifies immersive learning theory, constructivist learning theory, semiotic theory, and VR interaction theory as central paradigms frequently utilized by researchers.

Immersive learning theory is widely recognized for its emphasis on enhancing user engagement and learning outcomes through high levels of immersion. This theory has been extensively applied to analyze interactive behaviors in VR environments (Song, Wu, & Ding, 2024; Ho, Sun, & Tsai, 2019), establishing itself as a foundational framework. However, it inadequately addresses the relationship between immersion and the complexity of social interactions, particularly in multi-user scenarios, thereby limiting its applicability in collaborative virtual spaces.

Constructivist learning theory and technology-enhanced learning (TEL) theory have also been employed, particularly in educational contexts. These theories emphasize knowledge construction through interactive and collaborative resources, making them well-suited for analyzing applications such as gamification and 3D animation (Ho et al., 2019). However, the absence of robust, objective methods for evaluating learning outcomes constrains their broader adoption. Addressing this methodological gap is essential for advancing these frameworks' theoretical and practical utility.

Semiotic theory offers a unique lens to examine VR as a symbolic communication process, emphasizing how users' meaning-making is influenced by the medium's characteristics (Barricelli, Gadia, Rizzi, & Marini, 2016). While this perspective enriches understanding of the interplay between media and symbols, its limited focus on technical implementation restricts its practical applicability in developing complex VR systems.

In response to these limitations, researchers have extended traditional frameworks. Gamification and interaction design theories have been utilized to address the shortcomings of immersive experiences, particularly by enhancing user engagement through enjoyment and control (Tabbaa, Ang, Siriaraya, She, & Prigerson, 2021). Similarly, visual communication theory has been introduced to broaden the scope of VR research, expanding its applications beyond education into design-oriented fields (Yu & Fan, 2023).

Mainstream theories such as immersive learning and constructivist learning continue to dominate due to their versatility in explaining user behavior and technological integration. However, some researchers have integrated these with specialized frameworks to address challenges in specific domains. Future research should focus on synthesizing these diverse theoretical paradigms into a cohesive framework, enabling a more comprehensive understanding of VR environments and their applications. This integrative approach could bridge existing gaps, providing a stronger foundation for interdisciplinary exploration and innovation.

Methodology

The study adopts a bibliometric approach to analyze publication patterns within visual communication in virtual reality environments (VREs), with the Scopus database serving as the primary data source. The research identifies key priorities and advancements through keyword co-occurrence network analysis. During the data acquisition phase, relevant records were extracted from Scopus using targeted key terms, including *"Virtual Reality Environments," "visual,"* and *"communication."* A rigorous multistage screening process was employed to ensure precision and inclusivity by applying specific keyword combinations. The initial search retrieved 4,731 results, which were subsequently refined to 466 relevant records through additional filters based on temporal coverage (2014–2025), academic domains (Social Sciences and Arts and Humanities), publication types (Articles, Conference Papers, and Reviews), and language (English).

The filtering criteria were meticulously applied to ensure the dataset's representativeness and avoid redundancy. The final dataset of 466 records was analyzed using the Bibliometrix R package (http://www.bibliometrix.org/), a powerful tool for science mapping and bibliometric analysis.

Table 1 comprehensively summarizes the primary bibliometric data collected from 2014 to 2025. The Scopus dataset includes 462 scholarly publications from 263 unique journals, books, and other academic outlets. Using the Keywords Plus (ID) methodology, 2,467 keywords were identified, reflecting the field's diversity and breadth of topics. Additionally, authors contributed 1,572 unique keywords (DE), offering valuable insights into the specific themes explored during this period.

The dataset spans a ten-year timeframe, focusing on recent trends and developments. Each document received an average of 17.36 citations, indicating a moderate to substantial academic impact across the field. Contributions came from 1,548 distinct authors, with only 55 single-authored documents. It highlights the collaborative nature of research in this domain, further evidenced by an average of 3.71 co-authors per document. It underscores the increasing complexity and interdisciplinary scope of VRE-related topics.

The analysis also reveals that the average age of documents in the dataset is 2.95 years, emphasizing the field's continuous evolution and the prevalence of current research. International co-authorship accounts for 24.24% of the total collaborations, reflecting a significant level of global academic partnerships. This metric underscores

the international scope of the field, highlighting the importance of diverse perspectives and expertise in advancing VRE research.

In subsequent sections, quantitative and qualitative dataset analyses will be conducted to identify emerging themes, key contributions, and research gaps within this domain.

Table 1: Summary of the Main Information of Collected Bibliometric Data

Description	Results
Documents	462
Sources (Journals, Books, etc.)	263
Keywords Plus (ID)	2467
Author's Keywords (DE)	1572
Period	2014-2025
Average citations per doc	17.36
Authors	1548
Authors of single-authored docs	55
Document Average Age	2.95
Co-Authors per Doc	3.71
International co-authorships %	24.24

Analysis of Publication Years

Figure 1 depicts the annual scientific production from 2014 to 2025, showcasing key trends and shifts. The data reveals a consistent upward trajectory in research output, characterized by gradual growth in the early years and a notable surge between 2018 and 2023. The publication count peaked in 2023 with nearly 100 articles, reflecting heightened scholarly interest and intensified research activity in this domain.

This upward trend underscores the growing academic focus on virtual reality environments and sustained efforts to advance knowledge in visual communication

and related fields. These patterns suggest an expanding research community and increasing recognition of the importance of this interdisciplinary area.

In the following sections, quantitative and qualitative analyses will be conducted to identify critical trends, major turning points, and research gaps, offering insights into emerging priorities and future directions for the field.

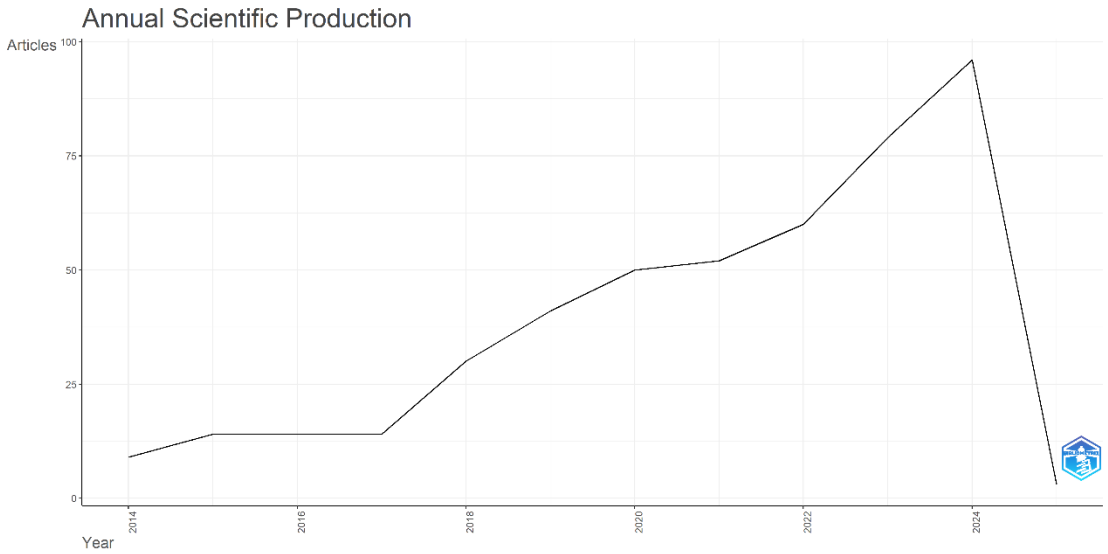

Figure 1: Annual scientific production of virtual reality environments as a visual communication research field within the 2014 to 2025 period.

The annual trend in average citations per article from 2014 to 2024 is shown in Figure 2, highlighting the impact of published articles during this period. The data initially indicates moderate growth, with a steady increase in citation impact observed until 2016, suggesting a phase of relative stability in scholarly attention. Around 2018, a notable peak emerges, reflecting a significant rise in citation counts per article. This peak likely corresponds to an increased emphasis on influential works published in preceding years.

Following 2018, the citation trend exhibits periodic fluctuations, with additional notable peaks around 2020 and 2022. These peaks may reflect renewed interest in specific topics or the impact of particularly influential studies. However, the average citation rate experiences a sharp decline after 2022, falling steeply by 2024. This downward trend may signify a potential saturation point in the field, a shift in academic focus, or reduced engagement with earlier literature as newer topics gain prominence.

These fluctuations and turning points provide valuable insights into the dynamic nature of academic influence. The observed trends underscore the evolving

research priorities and the emergence of high-impact contributions, which collectively shape the field's scholarly landscape over time.

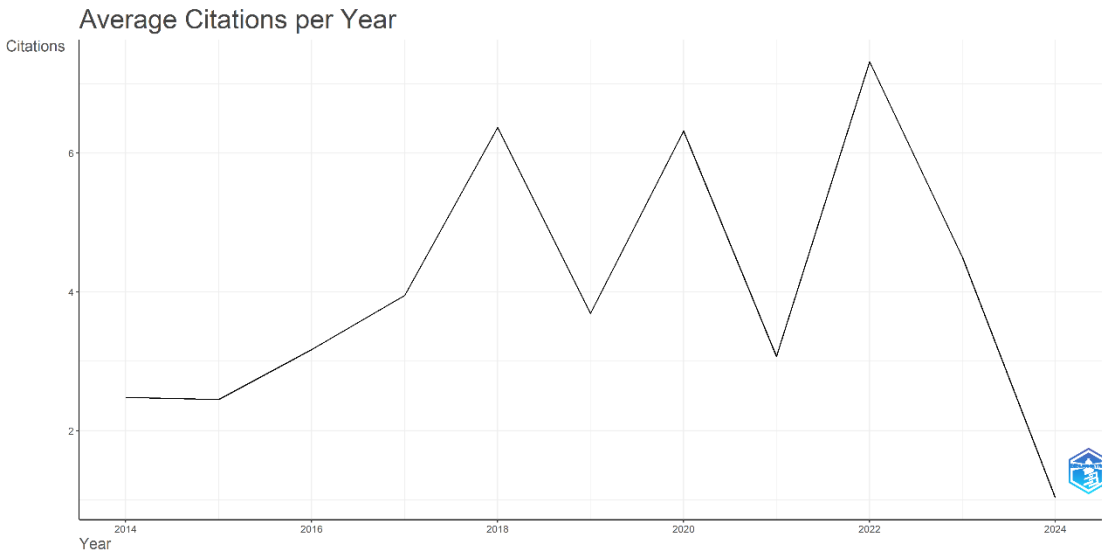

Figure 2: Average article citations per year of virtual reality environments as a visual communication research field within the 2014 to 2024 period.

Analysis of Authors

The productivity of key authors in the field from 2014 to 2024 is depicted in Figure 3, which highlights publication frequency and citation impact. Each red line represents an author's active publication timeline, while the size of the blue bubbles indicates the number of articles published in a specific year. The intensity of the bubble's color reflects total citations (TC) per year, showcasing the influence and recognition of each author's contributions.

Notably, authors such as JEON JY and JO HI demonstrate sustained productivity over multiple years, particularly from 2019 onward. For instance, JEON JY consistently published two articles per year from 2019 to 2022, achieving the highest citation impact in 2020, with an average of 41.6 citations per year. Similarly, JO HI maintained a steady publication record, contributing significantly to the field's growth. The high citation impact of these authors underscores their influential contributions and the academic value of their work.

In contrast, authors like KANG J and WANG H, though less frequent in publication count, exhibit concentrated citation impacts during specific years. KANG J, for example, achieved a notable citation peak in 2023, as represented by a larger and darker bubble in Figure 3, indicating substantial influence despite fewer publications.

The overall distribution of author productivity and impact reflects the collaborative and dynamic nature of the field. Some authors maintain consistent

publication rates over time, while others achieve significant influence through fewer but highly cited works. These findings highlight the diverse ways scholars contribute to the advancement of research. Subsequent analyses will delve deeper into the thematic contributions of these authors and their roles in shaping academic discourse within this domain.

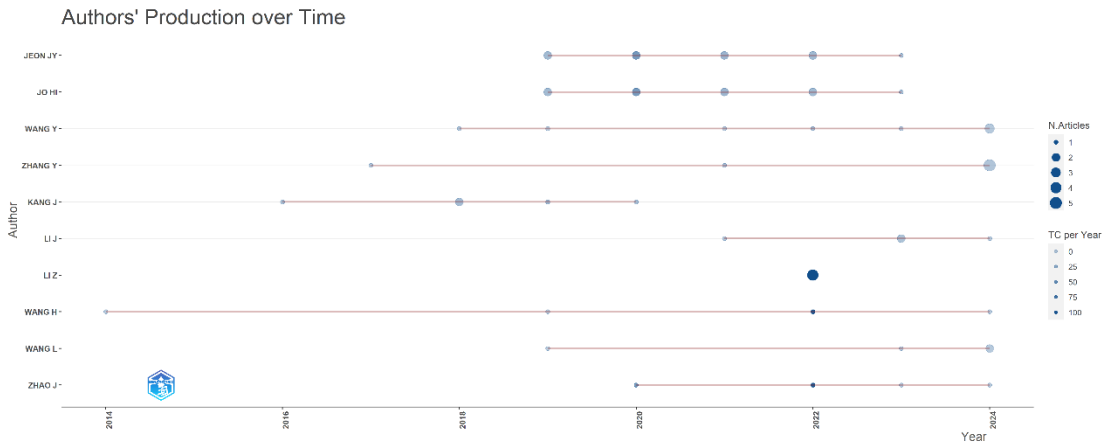

Figure 3: Top 10 most relevant authors' production on virtual reality environments as a visual communication research field from 2014 to 2024 (red line: the author's timeline, bubble size: the number of publications, bubble color intensity: total citations per year).

Analysis of Sources

The most relevant publication sources in this field are presented in Figure 4, highlighting the journals that have significantly contributed to the body of literature. The International Journal of Human-Computer Interaction leads with 22 articles, establishing itself as a core venue for research in this area. The proceedings of the ACM on human-computer interaction are closely followed by 16 articles, underscoring its role in disseminating research on user-centered design and interactive technologies. Other influential sources include Building and Environment, which has 13 articles, and Computers in Human Behavior, which has 11, each offering specialized insights into human-computer interaction's environmental and behavioral aspects.

These prominent sources represent critical platforms where researchers frequently publish, serving as valuable resources for understanding advancements and trends in the field. Their sustained contributions highlight their importance in

shaping the academic discourse on virtual reality environments and interactive design.

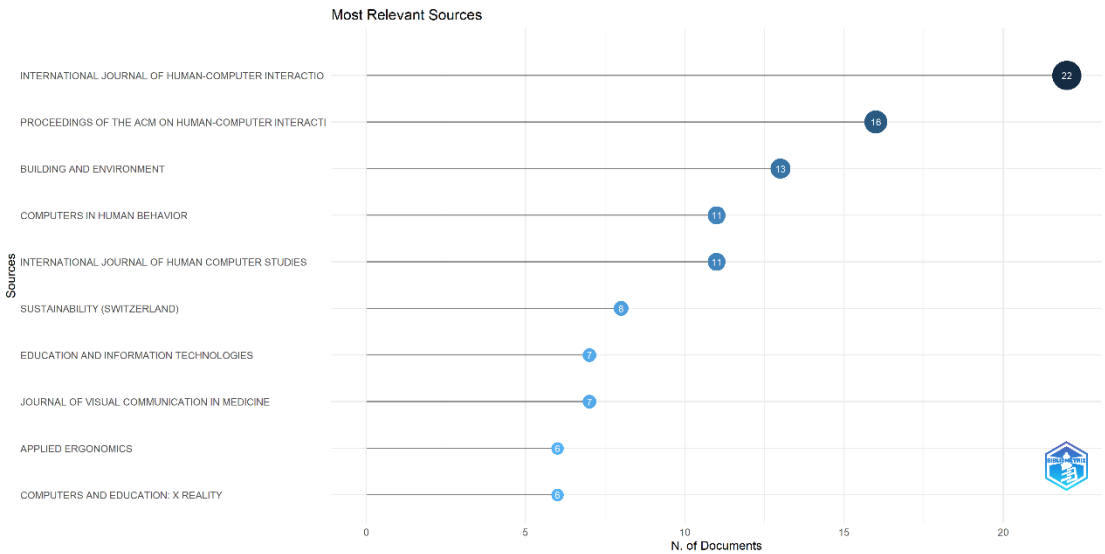

Figure 4: Top 10 most relevant sources by the number of documents published on virtual reality environments as visual communication research.

The production dynamics of these journals over time are depicted in Figure 5, which tracks cumulative publication occurrences from 2014 to 2025. Initially, publication activity across these sources was modest, but significant growth emerged around 2018. The International Journal of Human-Computer Interaction and Proceedings of the ACM on Human-Computer Interaction show steady increases, reflecting sustained academic interest and an expanding community of researchers contributing to these journals.

From 2020 onward, notable publication growth is observed in Building and Environment and Computers in Human Behavior, suggesting a growing interdisciplinary focus. This trend points to broader applications of human-computer interaction research in areas such as sustainability, behavioral analysis, and ergonomic design.

The cumulative trends depicted in Figure 5 provide insights into the evolving significance of these journals. Recent marked growth patterns indicate an increase in scholarly output and a diversification of research topics within the field. This surge

likely reflects a response to emerging challenges and technological advancements that continue to drive research in human-computer interaction.

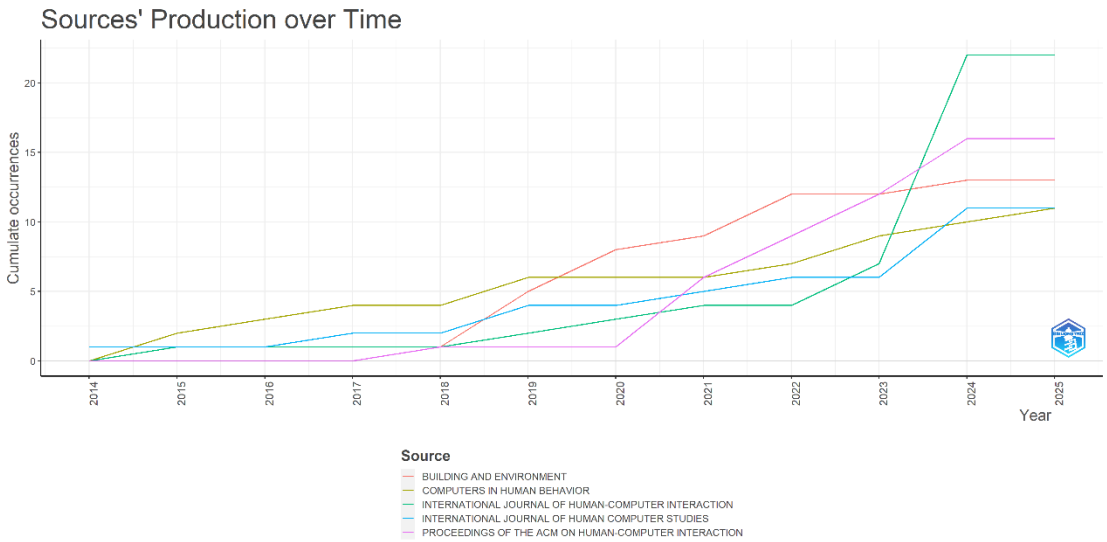

Figure 5: Cumulative publication trends across sources from 2014 to 2025, showing growth dynamics.

Subsequent analyses will delve into the specific topics within these journals, identifying core themes and assessing the impact of interdisciplinary research in advancing the field.

Analysis of Countries

The geographic distribution of research production and collaboration is analyzed through Figures 6, 7, and 8, providing insights into this field's global research network. Figure 6 ranks the most relevant countries based on the number of authored documents, distinguishing between single-country publications (SCP) and multiple-country publications (MCP). China and the USA lead significantly, with China producing 53 publications, primarily through SCP, reflecting a high rate of domestic collaborations. The USA follows with 44 publications, showing a balanced distribution between SCP and MCP, indicative of its strong international research collaborations. While having similar publication counts, South Korea and the United Kingdom

demonstrate higher MCP percentages, underscoring their emphasis on international partnerships.

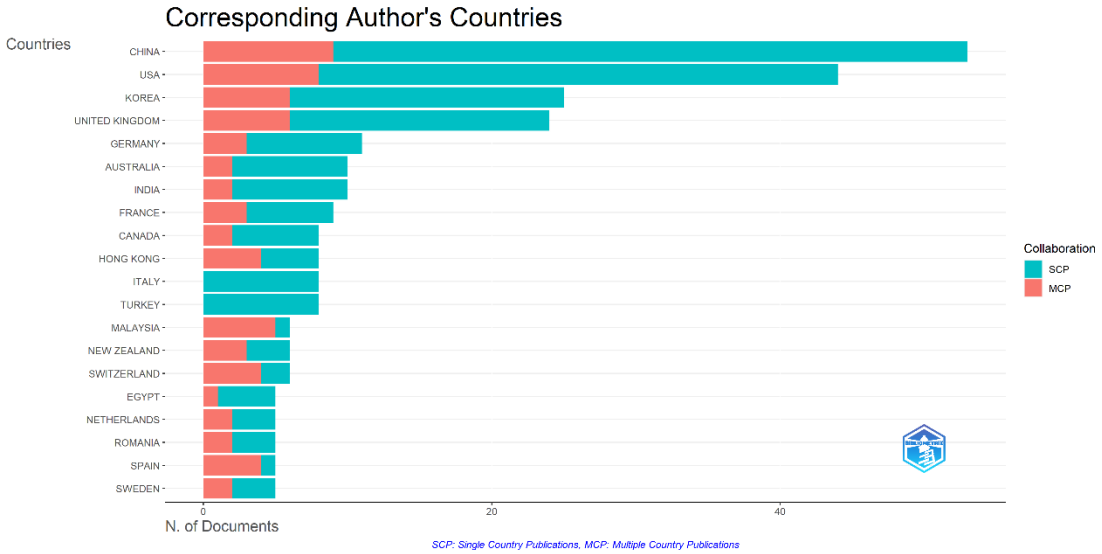

Figure 6: Top 20 corresponding authors' country (red line: Multiple Countries Publication (MCP), blue line: Single Country Publication (SCP)).

Figure 7 offers a global perspective on scientific production, with darker blue shading representing countries with higher publication outputs. China and the USA are major contributors, with significant research concentrated in Europe and parts of Asia. These regions emerge as key hubs, highlighting their importance in advancing research within the domain.

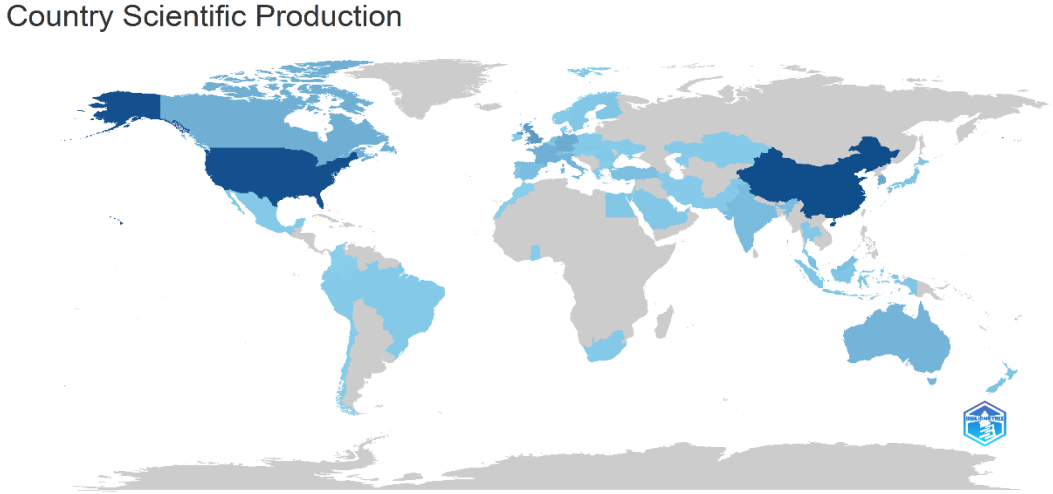

Figure 7 Country's scientific production world map of virtual reality environments as a visual communication research field (blue color intensity: the number of authors affiliated with each country, grey color: non-related country).

To further explore international collaboration, Figure 8 maps partnerships across countries, with thicker red lines indicating stronger connections. The most prominent link between the USA and China reflects a significant and impactful research partnership. Additional strong ties are observed between the USA and several European nations, emphasizing the USA's central role in facilitating global research networks. The map also highlights active collaboration between Oceania, Asia, and Europe, underscoring the field's international scope and the diverse perspectives driving research forward.

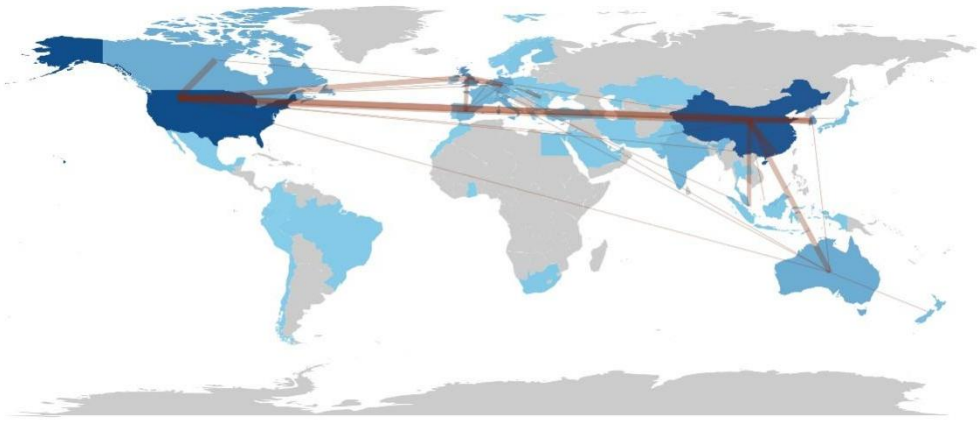

Figure 8. Country collaboration world map of virtual reality environments as a visual communication research field (blue color intensity: the number of authors affiliated with each country, grey color: non-related country, red line thickness: the number of joint publications).

Analysis of Topics

The thematic map of keywords within virtual and augmented reality research fields is shown in Figure 9, categorizing research topics by relevance (centrality) and development degree (density). The map identifies four main clusters, positioning themes based on their academic centrality and research density, offering valuable insights into the structure of this research domain.

The top-right quadrant, labeled Motor Themes, includes high centrality and density clusters, representing critical and well-developed topics. This area features augmented reality, telepresence, and mixed reality, reflecting their established relevance and significant impact within immersive technology research.

The bottom-right quadrant, Basic Themes, encompasses foundational but less developed topics. Despite their relatively lower research density, these include virtual reality, immersion, and cultural heritage, which are core concepts in immersive

experiences. Additionally, including the metaverse and augmented reality (AR) in this quadrant highlights their emerging importance as mainstream research themes.

The Niche Themes quadrant in the top-left contains highly specialized topics such as head-mounted displays, meta-analysis, and improving classroom teaching. While lacking broad research impact, these themes reflect targeted force with potential for further development in specific applications, particularly in educational and analytical contexts.

Finally, the bottom-left quadrant, labeled Emerging or Declining Themes, features topics like soundscape, audio-visual interaction, and visualization, alongside older platforms such as Second Life. These themes represent declining relevance or nascent areas of interest with growth potential, particularly in audio-visual and interactive applications.

Overall, the thematic map depicted in Figure 9 provides a comprehensive overview of key research clusters, illustrating areas of established, emerging, and niche interest. This layout serves as a roadmap for future studies, encouraging the expansion of foundational concepts into specialized applications and the exploration of new research directions.

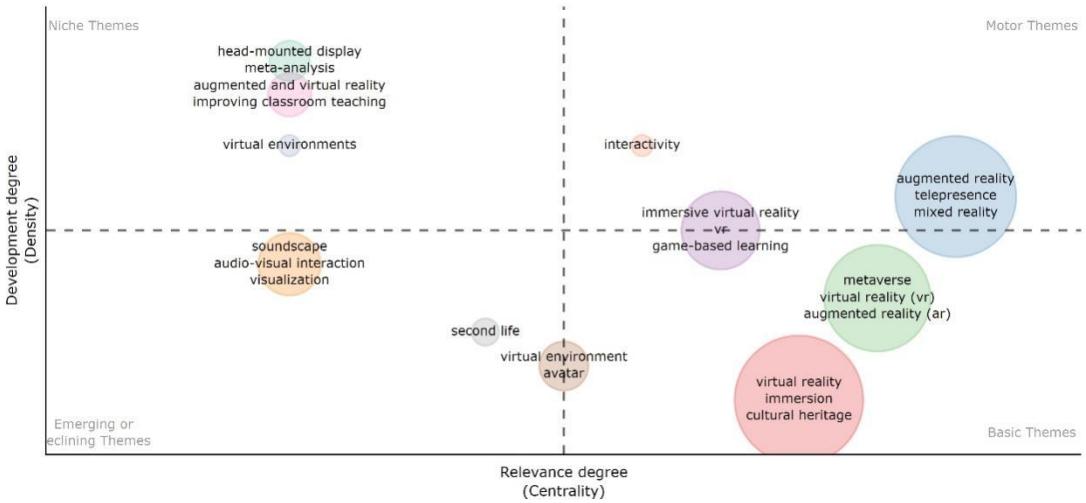

Figure 9: The thematic map of keywords network clusters in virtual reality environments as a visual communication research field (bubble size: cluster word occurrences).

Analysis of Keywords

Based on the three-field plot analysis (Figure 10), the intersection of authors, keywords, and journals reveals significant patterns within immersive and virtual technologies. Among the primary authors, Jo H.I. and Jeon J.Y. stand out as the most productive, each contributing five papers. Other influential contributors, such as Carey B. and Fernández Galeote D., also appear frequently but with slightly fewer publications. Figure 10 demonstrates the strong link between top authors, frequently

used keywords like *"virtual reality,"* and key publication venues such as the *International Journal of Human-Computer Interaction.*

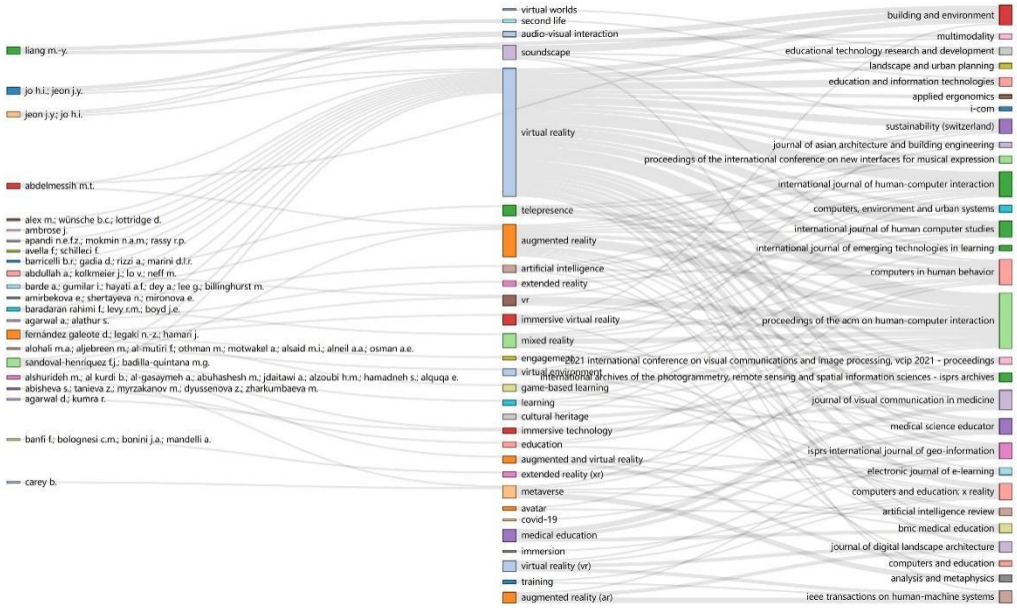

Figure 10: Three-field plot for the relationship among top keywords (the middle field), top authors (the left field), and top journals (the right field) in virtual reality environments as visual communication publications.

In addition to the three-field plot, a conceptual structure map (Figure 11) offers further insights into the clustering of research topics. Two prominent clusters emerge: one focused on foundational concepts such as *"virtual reality"* and *"augmented reality,"* and the other exploring practical implementations like *"game-based learning"* and *"medical education."* The blue cluster, highlighting *"immersion"* and *"training,"*

emphasizes technological engagement, while the red cluster underscores applications in broader domains.

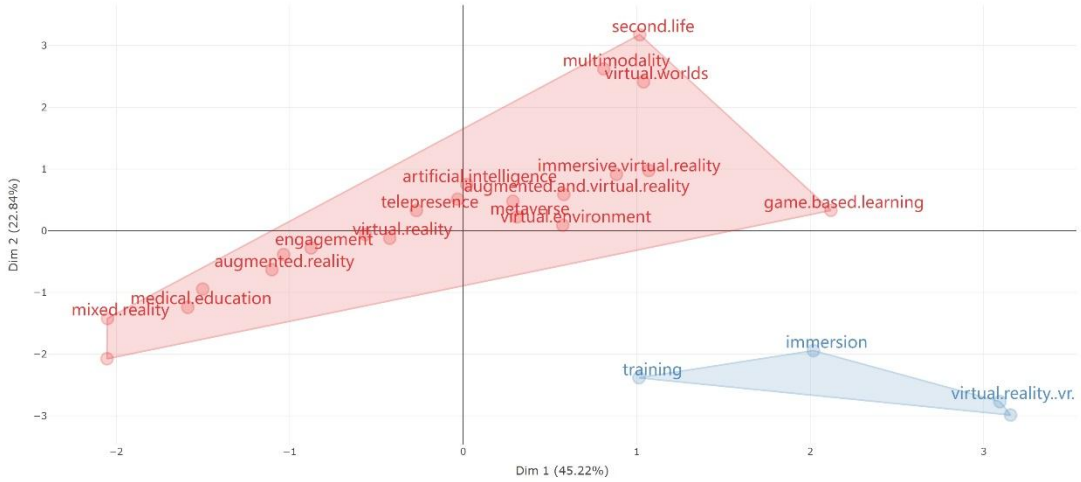

Figure 11: Conceptual structure map of keywords in virtual reality environments as visual communication publications (Dim one and Dim 2: the average position of the articles included in each keyword).

Figure 12, the dendrogram analysis, systematically visualizes relationships among research keywords, showcasing thematic groupings. Keywords such as *"augmented reality," "telepresence,"* and *"mixed reality"* form coherent subfields, indicating the diverse applications and interdisciplinary nature of the research. Hierarchical clustering confirms immersive technologies' thematic richness in addressing theoretical and practical challenges.

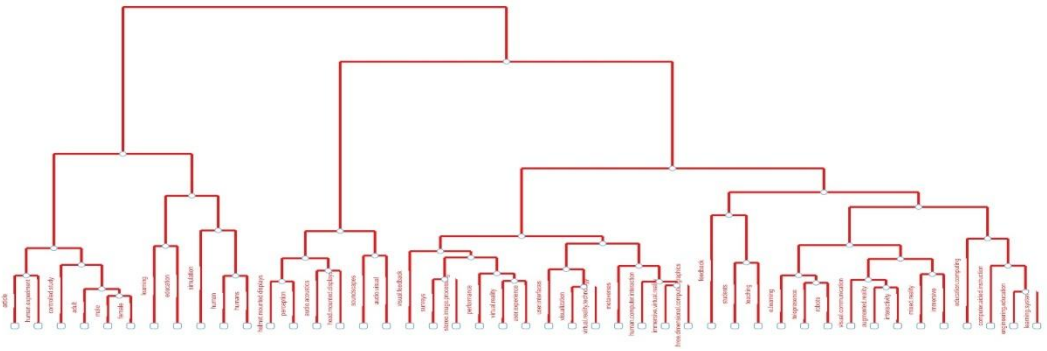

Figure 12: Conceptual structure dendrogram of keywords in virtual reality environments as visual communication publications (height: the distance among clusters of words).

Lastly, the word cloud visualization (Figure 13) highlights the dominance of *"virtual reality"* as the central theme, with other prominent terms such as *"augmented reality," "visual communication,"* and *"cultural heritage"* representing the breadth of the

field. This visualization reinforces the field's focus on creating impactful education, health, and cultural preservation applications.

Figure 13: Word cloud of top keywords plus in virtual reality environments as visual communication publications (font size: word occurrences).

These analyses underscore a robust and interdisciplinary research landscape, emphasizing advancing immersive technology applications, particularly in education, interaction design, and medical training, as evidenced by the dominance of specific keywords and publication patterns.

Conclusions

This bibliometric analysis of visual communication in virtual reality environments (VREs) offers a comprehensive perspective on the evolution of this interdisciplinary field. Utilizing the Scopus database, the study highlights key trends, thematic shifts, and collaborative networks that shape the academic landscape of VRE research. The findings emphasize the centrality of immersive and interactive design theories as foundational frameworks and identify emerging areas such as gamification and cultural heritage applications.

The analysis reveals a significant increase in scholarly output between 2018 and 2023, underscoring the growing interest and innovation in VRE-related technologies. Collaborative efforts, especially between China and the USA, highlight this research domain's global and interconnected nature. Established themes, such as augmented and mixed reality, coexist with niche areas like soundscapes and audio-visual interaction, presenting diverse opportunities for future exploration and innovation.

By integrating bibliometric insights into thematic mapping, this study provides actionable directions for advancing VRE research. It encourages the synthesis of existing theories, the development of novel applications, and the fostering of interdisciplinary collaboration. Addressing gaps in theoretical cohesion and

expanding the scope of research topics will enrich the field's theoretical foundations and drive practical innovations in visual communication. Ultimately, this study offers a strategic roadmap for researchers and practitioners aiming to contribute to the future of VRE research and its applications.

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