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Bibliometric Mapping of Extended Reality (XR) in Education and Business Domains

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ABSTRACT

This study presents a comprehensive bibliometric mapping of Extended Reality (XR) research in education and business domains, providing insights into thematic trends, collaborative networks, and emerging areas of interest. Using the Scopus database as the primary data source, publications from 2010 to 2025 were retrieved and analyzed exclusively with VOSviewer to generate keyword co-occurrence, author collaboration, country collaboration, temporal evolution, and density visualizations. The results reveal that virtual reality, augmented reality, extended reality, and engineering education are the most prominent and interconnected themes, with newer research increasingly focusing on metaverse, artificial intelligence, and Industry 4.0 integration. Co-authorship and country network maps show that the United States, Italy, Germany, and India are central hubs driving global research partnerships, while author collaborations cluster into specialized yet interconnected groups. The study highlights how education-oriented XR research emphasizes immersive learning, e-learning, and gamification, while business-focused studies target marketing innovation, customer engagement, and sustainability. These findings contribute to a holistic understanding of XR's interdisciplinary evolution, offering strategic guidance for researchers, educators, industry leaders, and policymakers to foster innovation and cross-domain integration.

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1. INTRODUCTION

In recent years, the global adoption of Extended Reality (XR)—an umbrella term that encompasses Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR)—has surged significantly, influencing various sectors including education and business. The technological advancement in XR has been driven by rapid improvements in hardware capabilities, user interfaces, and immersive content development, resulting in transformative user experiences across domains. In education, XR offers immersive learning environments where students can engage with abstract concepts through simulations and virtual laboratories. For instance, [1] demonstrated that VR-supported learning leads to enhanced engagement and deeper conceptual understanding compared to traditional video-based instruction. Similarly, in the business sector, XR is revolutionizing operational processes such as product visualization, employee training, and remote collaboration, especially in response to

the demands of digital transformation and post-pandemic hybrid work models [2].

The rise of XR is not only a technical phenomenon but also reflects a broader paradigm shift in how organizations and institutions interact with digital content and remote users. In education, XR helps bridge the gap between theoretical and experiential learning, making it a powerful tool for science, engineering, and medical education [3]–[5]. These immersive technologies are increasingly used to simulate real-life experiences in controlled environments, allowing learners to safely practice skills that would otherwise be risky, expensive, or logistically challenging to replicate. On the other hand, the business domain has witnessed XR's potential in enhancing customer experience, digital marketing, and supply chain management. Retail companies like IKEA and L'Oréal have integrated AR apps that allow customers to preview products in real-world environments, thus enriching the decision-making process [6].

As XR becomes more deeply embedded in educational and commercial systems, research on the subject has expanded in both volume and complexity. Scholars are exploring the pedagogical implications of XR, its usability, cost-effectiveness, ethical concerns, and long-term impact on learners' cognitive development [7], [8]. In parallel, business scholars are assessing XR's return on investment, user adoption behavior, and the integration challenges with existing enterprise systems. Despite this proliferation of research, there remains a degree of fragmentation across disciplines. Studies may focus exclusively on one XR technology (e.g., AR in classroom settings) or address specific industry use cases (e.g., VR-based retail training), making it difficult to form a coherent picture of the overall development and direction of XR research across domains.

This interdisciplinary nature of XR research necessitates a mapping of the existing literature to uncover prevailing trends, collaborations, and thematic concentrations. Bibliometric analysis provides a valuable tool in this regard, allowing researchers to identify influential authors, journals, institutions, and countries contributing to the XR discourse. Furthermore, such analysis can uncover co-citation patterns and thematic clusters that reveal how the field is evolving over time. Previous bibliometric studies have addressed XR in isolated fields—such as in healthcare [9] or engineering—but few have comprehensively compared its role across both education and business contexts. This creates a pressing need to map how research outputs are distributed, how themes intersect, and where future research opportunities lie.

Moreover, a bibliometric approach also facilitates evidence-based insights for policymakers, educators, and industry leaders by identifying which areas of XR are gaining scholarly momentum and which remain underexplored. This can directly influence investment decisions, curriculum design, and innovation strategies. For example, the increasing convergence of XR with artificial intelligence and data analytics has been highlighted as a future growth area in both academic and business settings [10]. Understanding the bibliometric landscape of XR is therefore critical for aligning technological development with educational and commercial priorities.

Despite the rapid growth of XR literature, there is currently no unified bibliometric overview that integrates both education and business domains. Most studies tend to remain domain-specific or technologically limited, leading to a siloed understanding of the broader XR ecosystem. This fragmentation impairs our ability to track interdisciplinary collaboration and identify cross-sector innovations. Moreover, it makes it difficult for stakeholders—whether academic researchers or industry practitioners—to navigate the field, assess the maturity of XR applications, or identify fruitful areas for collaboration and funding. Without a holistic understanding of how XR is evolving across domains, efforts to scale its application or measure its impact may be misguided or inefficient.

Given this gap, the objective of this study is to conduct a comprehensive bibliometric mapping of XR research within

the domains of education and business, drawing from publications indexed in the Scopus database between 2010 and 2025. The study aims to identify leading contributors, prominent journals, institutional affiliations, and thematic trends by analyzing keyword co-occurrence, citation networks, and publication patterns. By doing so, this research will provide an integrated view of how XR is shaping, and being shaped by, academic and industrial interests. Ultimately, the study intends to support the development of a more connected and coherent research landscape for XR by offering strategic insights for scholars, educators, innovators, and policymakers alike.

2. METHOD

This study employed a bibliometric analysis approach to map and evaluate the scientific literature on Extended Reality (XR) applications in the education and business domains. Bibliometric analysis offers a systematic and quantitative method to assess the structure, dynamics, and patterns of research outputs over time. The Scopus database was selected as the primary data source due to its broad indexing of peer-reviewed publications and strong coverage of both scientific and applied literature. The search strategy was carefully developed using relevant keywords such as "extended reality," "virtual reality," "augmented reality," "mixed reality," combined with domain-specific terms like "education," "learning," "teaching," "training," "business," "management," and "marketing." Boolean operators and wildcard characters were applied to ensure inclusivity and specificity in the retrieval process. The time frame was set from 2010 to 2025 to capture the most significant period of XR development across sectors.

The bibliographic data retrieved from Scopus were exported in CSV format, containing essential metadata such as authors, titles, abstracts, keywords, source titles, and citation counts. Data cleaning was performed to remove duplicates and standardize author names and keywords. This preparation was necessary to ensure the accuracy of the visualizations and network analyses generated by VOSviewer. No additional software was used; all mapping, clustering, and co-occurrence analyses were conducted within VOSviewer to maintain methodological consistency.

Within VOSviewer, the analysis focused on three primary techniques: co-occurrence analysis of author keywords to identify thematic trends; co-authorship analysis to reveal collaboration patterns among researchers and countries; and citation analysis to determine influential documents. The software's clustering algorithm grouped related keywords and authors into thematic clusters, enabling the identification of dominant research streams in XR within education and business contexts. Visual maps generated by VOSviewer were interpreted to highlight research hotspots, interdisciplinary connections, and emerging areas of interest.

3. RESULT AND DISCUSSION

3.1 Keyword Co-Occurrence Analysis

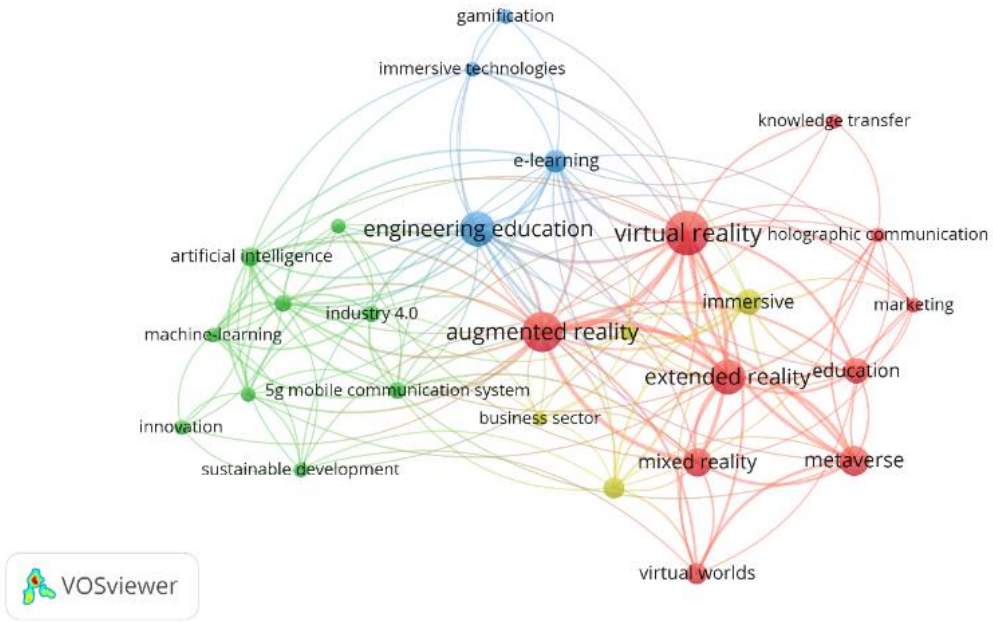

Figure 1. Network Visualization
Source: Data Analysis

Figure 1 reveals four distinct thematic clusters that together illustrate the intellectual structure of Extended Reality (XR) research in education and business domains. The red cluster appears as the central hub, with "virtual reality," "augmented reality," "extended reality," "mixed reality," "metaverse," and "education" as dominant nodes. These keywords are heavily interconnected, reflecting the strong scholarly focus on immersive learning experiences and technology integration in both educational and commercial contexts. The high density of links among these terms suggests that much of the XR literature addresses these technologies in an overlapping and often interdisciplinary manner, bridging theoretical frameworks with applied solutions such as marketing, knowledge transfer, and holographic communication.

The blue cluster, led by "engineering education," "e-learning," "gamification," and "immersive technologies," represents a concentrated body of research in pedagogical innovation. This thematic group reflects how XR is leveraged to improve educational delivery, particularly in technical and engineering contexts where simulation, gamified experiences, and immersive instructional tools can enhance comprehension and skills acquisition. The proximity between "engineering education" and "e-learning" in the map underlines the synergy between online learning frameworks and immersive technology adoption. The relatively smaller number of cross-links to business-oriented terms suggests that this cluster's focus is still predominantly academic.

The green cluster centers around "artificial intelligence," "machine learning," "industry 4.0," "5G mobile communication system," "innovation," and "sustainable development." This group reflects the technological backbone and enabling infrastructure that supports XR adoption. The strong ties between AI and XR-related terms indicate that

intelligent systems are increasingly being embedded into XR platforms to create adaptive, personalized, and more realistic immersive experiences. Furthermore, "industry 4.0" connects this cluster to business applications, highlighting XR's role in smart manufacturing, workforce training, and industrial process optimization. The presence of "sustainable development" suggests emerging discourse on how immersive technologies can contribute to economic, social, and environmental sustainability goals.

The yellow cluster, with keywords such as "business sector" and "virtual worlds," acts as a bridge between education and business themes. Though relatively smaller, it plays an important role in linking technological innovation with market-driven applications. The connection of "business sector" to "augmented reality" and "mixed reality" points to XR's adoption in retail, corporate training, and remote collaboration. Similarly, "virtual worlds" intersects with "metaverse" and "marketing," highlighting the growing commercial interest in immersive brand experiences and virtual economies.

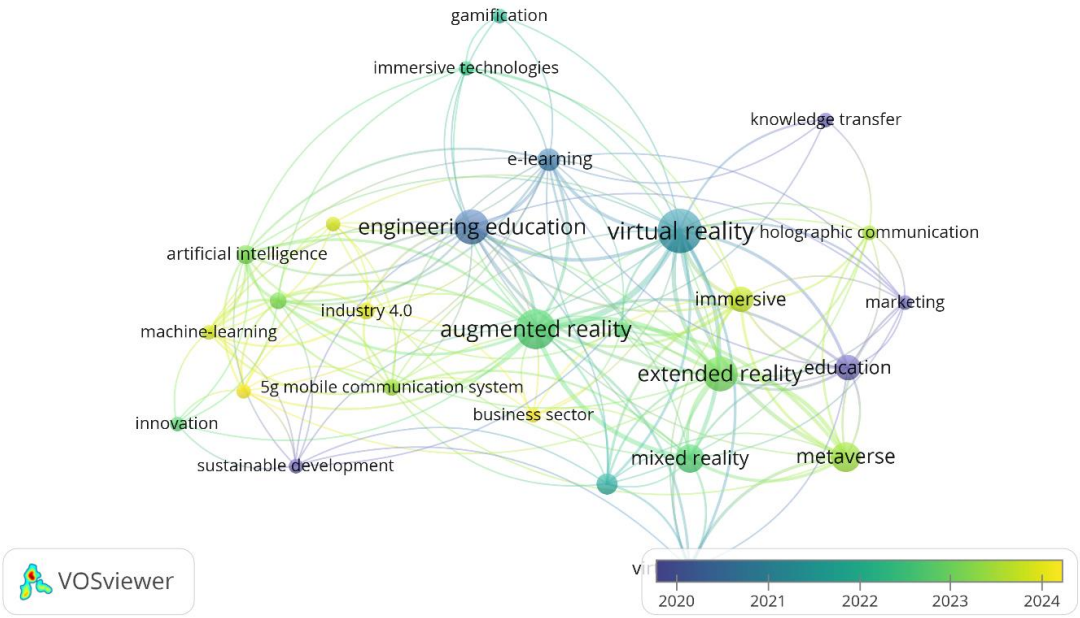

Figure 2. Overlay Visualization
Source: Data Analysis

Figure 2 shows the temporal evolution of keywords related to Extended Reality (XR) in education and business domains between 2020 and 2024. Dark blue nodes such as "engineering education," "e-learning," and "virtual reality" indicate earlier research focus areas that gained prominence around 2020–2021. These early studies predominantly explored foundational XR applications in structured learning environments and the initial adoption of immersive technologies for pedagogical purposes. The strong interconnectedness among these earlier keywords reflects the establishment of XR's conceptual and technological groundwork in both academia and industry.

As the timeline moves toward green and yellow nodes, representing more recent years (2022–2024), the focus shifts toward emerging technologies and cross-domain integration. Keywords like "artificial intelligence," "machine learning," "industry 4.0," "5G mobile communication system," and

"innovation" show growing attention, particularly in research that merges XR with advanced computing and networking capabilities. These developments suggest a movement toward more adaptive, intelligent, and scalable XR solutions. In the business context, this aligns with trends in smart manufacturing, immersive product visualization, and virtual collaboration, while in education it supports personalized and data-driven learning experiences.

The most recent keywords, appearing in bright yellow tones such as "business sector," "sustainable development," "marketing," and "metaverse," point to expanding applications beyond traditional use cases. These terms reflect a strategic pivot toward market-oriented XR deployments, immersive branding, and alignment with global sustainability goals. The appearance of "metaverse" in the newest spectrum underlines a rapid and recent surge in interest, signaling that future research may increasingly converge on creating persistent, interconnected virtual environments for both learning and commerce.

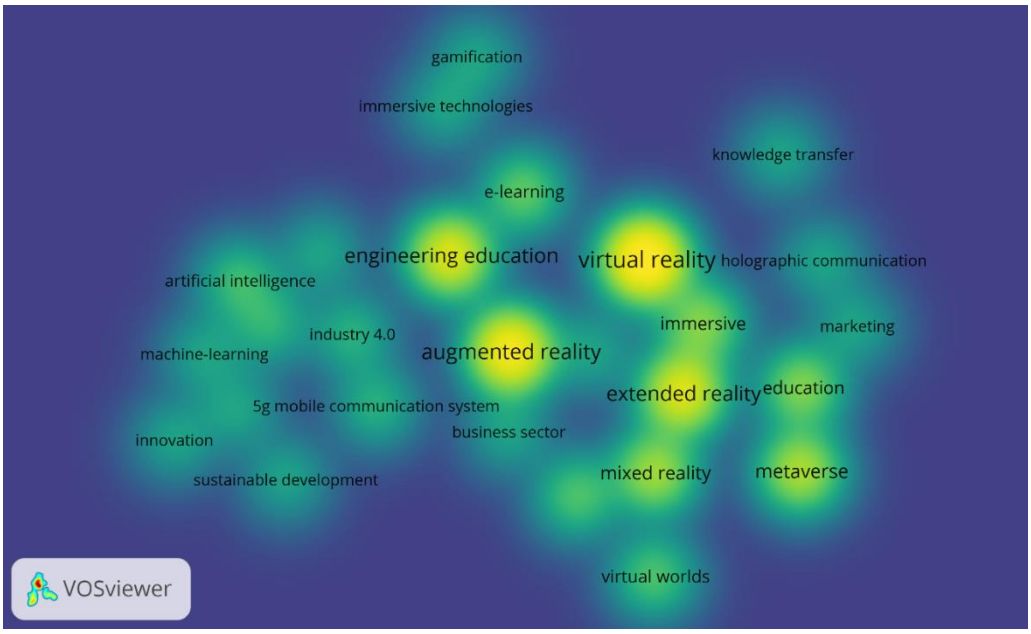

Figure 3. Density Visualization
Source: Data Analysis

Figure 3 highlights the most frequently occurring and strongly connected keywords in XR research within education and business domains. The brightest yellow zones—such as "virtual reality," "augmented reality," "engineering education," "extended reality," and "metaverse"—indicate the areas of highest research intensity. This suggests that these concepts form the core of scholarly discussions, acting as focal points that link diverse research themes. The clustering of these high-density terms also reflects the interdisciplinary nature of XR studies, where pedagogical innovations, immersive learning, and commercial applications intersect. The surrounding green areas, which include terms like "artificial intelligence," "machine learning," "industry 4.0," "business sector," and "sustainable development," represent moderately high research activity. These concepts often appear as enabling technologies or thematic contexts that complement the core XR applications. The lower-density blue zones, such as "knowledge transfer," "holographic communication," and "virtual worlds," indicate emerging or niche topics that may hold potential for

future growth but currently have a smaller publication volume.

3.2 Co-Authorship Analysis

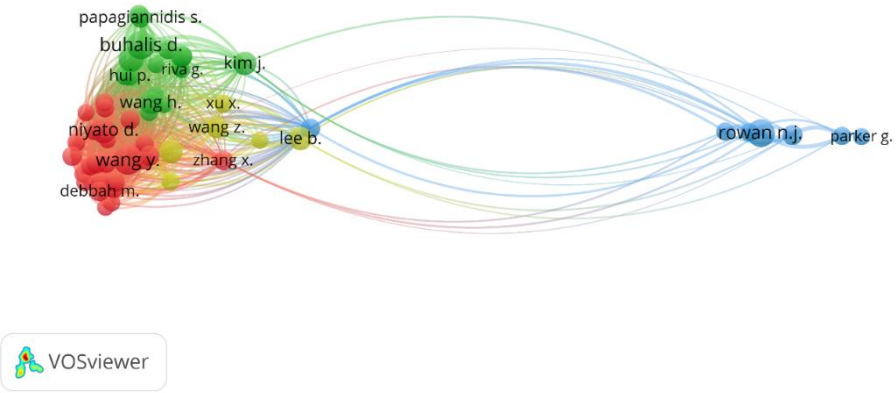

Figure 4. Author Visualization
Source: Data Analysis

Figure 4 shows three main clusters of researchers working on Extended Reality (XR) topics in education and business, with varying degrees of collaboration. The dense red and green clusters on the left represent a large interconnected group of authors such as Wang Y., Niyato D., Debbah M., Papagiannidis S., and Buhalis D., indicating a strong collaborative network primarily focused on technical development, tourism applications, and XR adoption studies. The green subgroup, which includes Kim J., Hui P., and Riva G., appears to serve as a bridge between highly technical research and applied XR themes. A smaller bridging cluster led by Lee B. connects these dense networks to the blue cluster on the right, which is composed of Rowan N.J. and Parker G., suggesting specialized or regionally distinct collaborations. The blue cluster has fewer members but strong internal links, indicating concentrated research efforts, possibly in niche or emerging XR application areas, with cross-links to the main network through key intermediaries.

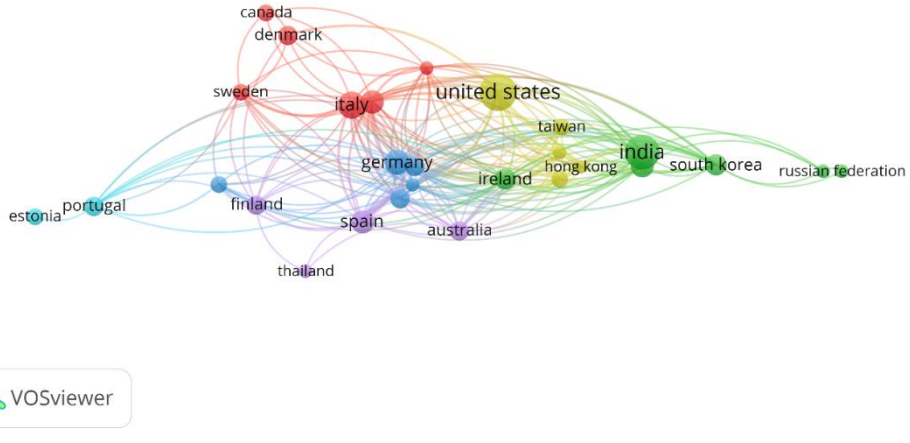

Figure 5. Country Visualization
Source: Data Analysis

Figure 5 indicates several distinct but interconnected clusters of nations actively contributing to XR research in education and business. The United

States, Italy, Germany, and India emerge as central hubs, each connecting with multiple other countries, suggesting they play pivotal roles in fostering international research partnerships. The red cluster, dominated by Italy alongside countries like Canada, Denmark, and Sweden, shows strong intra-European and transatlantic collaboration. The yellow-green cluster led by the United States links closely with Asian economies such as Taiwan, Hong Kong, and India, highlighting cross-regional knowledge exchange. The blue and turquoise clusters, including Germany, Spain, Portugal, and Finland, appear to bridge European collaborations with outlier countries like Estonia and Australia. Meanwhile, the green cluster connecting India, South Korea, and the Russian Federation demonstrates an emerging Asia-centric network with growing global integration

3.3 Citation Analysis

Table 1. Most Cited Article

Citations	Author and Year	Title
1770	[11]	Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy
191	[12]	Constructing an Edu-Metaverse Ecosystem: A New and Innovative Framework
110	[13]	A process model for entrepreneurship education and development
72	[14]	European consensus on a competency-based virtual reality training program for basic endoscopic surgical psychomotor skills
44	[15]	Contemporary trends in East Asian higher education: Dispositions of international students in a Taiwan university
38	[16]	Exploring User Experience and Usability in a Metaverse Learning Environment for Students: A Usability Study of the Artificial Intelligence, Innovation, and Society (AIIS)
32	[17]	Multisensory Metaverse-6G: A New Paradigm of Commerce and Education
25	[18]	Regulating the Metaverse, a Blueprint for the Future
24	[19]	DARQ technologies in the financial sector: artificial intelligence applications in personalized banking
24	[3]	Extended Reality in Education and Training: Case Studies in Management Education

Source: Scopus, 2025

3.4 Practical Implication

The findings provide actionable insights for educators, business leaders, and policymakers seeking to maximize the impact of XR technologies. In education, the identification of strong clusters around *virtual reality*, *augmented reality*, and *engineering education* indicates that institutions can prioritize immersive learning content development and invest in faculty training to integrate XR into curricula effectively. For the business sector, the emergence of terms such as *metaverse*, *marketing*, and *business sector* highlights growing opportunities for customer engagement, brand storytelling, and remote collaboration. The country collaboration map also underscores the importance of forming international research partnerships—organizations in countries with fewer XR publications can leverage connections with hubs like the United States, Italy, and India to accelerate adoption and innovation. Furthermore, the co-authorship patterns suggest that fostering interdisciplinary collaborations between technical experts and domain specialists can produce more impactful XR applications.

3.5 *Theoretical Contribution*

This study advances the literature on XR by offering a comprehensive bibliometric mapping that bridges education and business domains, rather than treating them as separate spheres. The keyword co-occurrence, temporal evolution, and density analyses provide an integrated understanding of thematic development, revealing how core XR concepts are supported by enabling technologies such as AI, machine learning, and Industry 4.0 infrastructure. By mapping author and country collaboration networks, the study also contributes to the theoretical understanding of knowledge diffusion in emerging technology research, aligning with innovation network theory and the concept of technology convergence. Moreover, this dual-domain approach highlights the cross-fertilization of ideas between educational and commercial XR applications, providing a framework for future research that seeks to unify theory across different sectors.

3.6 Limitations

While the study provides valuable insights, certain limitations must be acknowledged. First, the reliance solely on the Scopus database may have excluded relevant publications indexed in other repositories such as Web of Science, IEEE Xplore, or specialized conference proceedings, potentially limiting the breadth of coverage. Second, the analysis was conducted exclusively using VOSviewer, which, while robust, focuses on visualizing bibliometric relationships and does not perform in-depth content analysis of individual articles. This means that the interpretation of thematic clusters is based on keyword co-occurrence patterns and not on full-text semantic analysis. Third, the time frame of 2010–2025 captures the most relevant developments but may miss earlier foundational studies that could contextualize current trends. Finally, bibliometric data reflects publication patterns, which may be influenced by regional funding priorities, institutional capabilities, and language biases, and thus may not fully represent the global scope of XR research activities.

4. CONCLUSION

This bibliometric mapping of Extended Reality (XR) research across education and business domains reveals a dynamic and interdisciplinary field that has evolved from early explorations of *virtual reality* and *augmented reality* into more complex integrations involving *metaverse*, *artificial intelligence*, and *Industry 4.0*. The keyword, author, and country collaboration analyses demonstrate that while XR scholarship is globally dispersed, it is anchored by key hubs such as the United States, Italy, Germany, and India, with significant cross-continental linkages. The thematic clusters indicate that education-focused research emphasizes immersive learning, engineering education, and e-learning innovations, while business-oriented studies increasingly explore marketing, customer engagement, and sustainable development applications. By uncovering the structure, collaborations, and emerging trends in XR literature, this study provides a comprehensive knowledge base for researchers, practitioners, and policymakers to leverage XR's transformative potential and guide future interdisciplinary advancements.

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