

Mapping the Intersection of Immersive Technologies and Sustainable Innovations: A Bibliometric Study

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Abstract

Purpose- This study aims to investigate the intersection of immersive technologies and sustainable innovations by mapping the intellectual structure, publication trends, and emerging research themes within this interdisciplinary field.

Design/Methodology/approach- A bibliometric analysis was conducted using the Biblioshiny tool of the R package and VOSviewer to analyse 134 journal articles selected through a systematic PRISMA-guided process from the Scopus database. The study examined citation patterns, co-authorship networks, and keyword co-occurrences to identify key authors, influential countries, thematic clusters, and research hotspots.

Findings- The study uncovers distinct growth patterns, culminating in a notable surge of publications in 2023. This study identifies leading countries, institutions, and authors shaping the field, with China and the University of Konstanz emerging as prominent contributors. Five primary research themes are delineated: e-learning and augmented reality, virtual reality applications in sustainable development, climate change and environmental behaviour, Geotourism with heritage conservation, and advancements in artificial intelligence. These findings reveal the intellectual structure and evolving focus areas, highlighting key knowledge clusters and emerging trends that guide future research directions.

Research Implications- The study offers valuable insights for academics, policymakers, and industry stakeholders to strategically adopt immersive technologies in sustainability-related sectors such as education, tourism, and cultural heritage. It also suggests future research directions emphasizing long-term impacts, inclusivity, and multi-sector collaboration.

Originality/Value- This research provides a comprehensive and data-driven overview of how immersive technologies intersect with sustainability, contributing to theoretical understanding and practical applications. By leveraging bibliometric methods, it advances the

knowledge base beyond traditional literature reviews and guides future innovation pathways.

Key Words- Immersive Technologies, Sustainability, Bibliometric Analysis, Augmented Reality, Virtual Reality, Sustainable Innovation

Introduction

Technological advancements in the 21st century have significantly blurred the lines between the physical and digital worlds, fostering a new era where virtual experiences are deeply embedded in daily life. This convergence has paved the way for immersive technologies such as Virtual Reality (VR), Augmented Reality (AR), and the Metaverse to become central tools in various domains, including education, tourism, urban planning, and environmental sustainability (Maffei et al., 2016; Su & Cheng, 2019). As these technologies continue to evolve, their potential to support the United Nations' SDGs has gained increasing scholarly attention (ElMassah & Mohieldin, 2020; Abad-Segura et al., 2020). Recent studies highlight their transformative capabilities in promoting sustainable tourism, fostering virtual learning environments, and enhancing citizen engagement in climate-conscious behavior (Go & Kang, 2023; Scurati et al., 2021).

In particular, the Metaverse is a collective, persistent, and interconnected virtual space that offers unique opportunities to simulate real-world environments for education, cultural preservation, and smart city development (Gössling, 2021; Zhang et al., 2022). These immersive platforms can deliver interactive, emotionally resonant experiences that influence users' environmental attitudes and behaviours (Ketter et al., 2016). Despite these promising developments, research on the integration of immersive technologies with sustainability remains fragmented and underexplored, necessitating a comprehensive bibliometric analysis to map current trends, identify leading contributors, and highlight future directions in the field. This study seeks to bridge this gap by systematically reviewing high-quality academic publications to understand how immersive technologies intersect with sustainable innovation and development. The purpose of this study is to answer the following research

question:

RQ1. What are the publication patterns and trends in research linking immersive technologies and sustainable innovations?

RQ2. Who are the key authors, institutions, and countries driving this interdisciplinary field?

RQ3. What are the main thematic clusters and knowledge areas emerging from bibliometric analysis?

RQ4. How do citation networks and keyword co-occurrences reveal the intellectual structure of this research domain?

RQ5. What gaps exist in current literature, and what future research directions can advance sustainable applications of immersive technologies?

Methodology

To investigate the intersection of immersive technologies and sustainable innovations, this study employed bibliometric analysis. This technique provides insights into citation patterns, co-authorship networks, and keyword co-occurrence, making it a valuable tool for both researchers and practitioners to understand the intellectual structure and evolution of a field (Donthu et al., 2021). Bibliometrics enables the evaluation of a large volume of academic literature within a short time and supports the identification of highly cited publications, leading authors, influential countries, and emerging research themes (Wang et al., 2019). For this study, Biblioshiny tool of R package and VOSviewer was employed to perform the core visual analysis, including mapping citation links, detecting co-authorship collaborations, and analysing keyword co-occurrence to reveal research hotspots and thematic clusters. Microsoft Excel was also used to organize, filter, and manage the bibliographic data, supporting the interpretation of quantitative trends such as publication counts and temporal distribution.

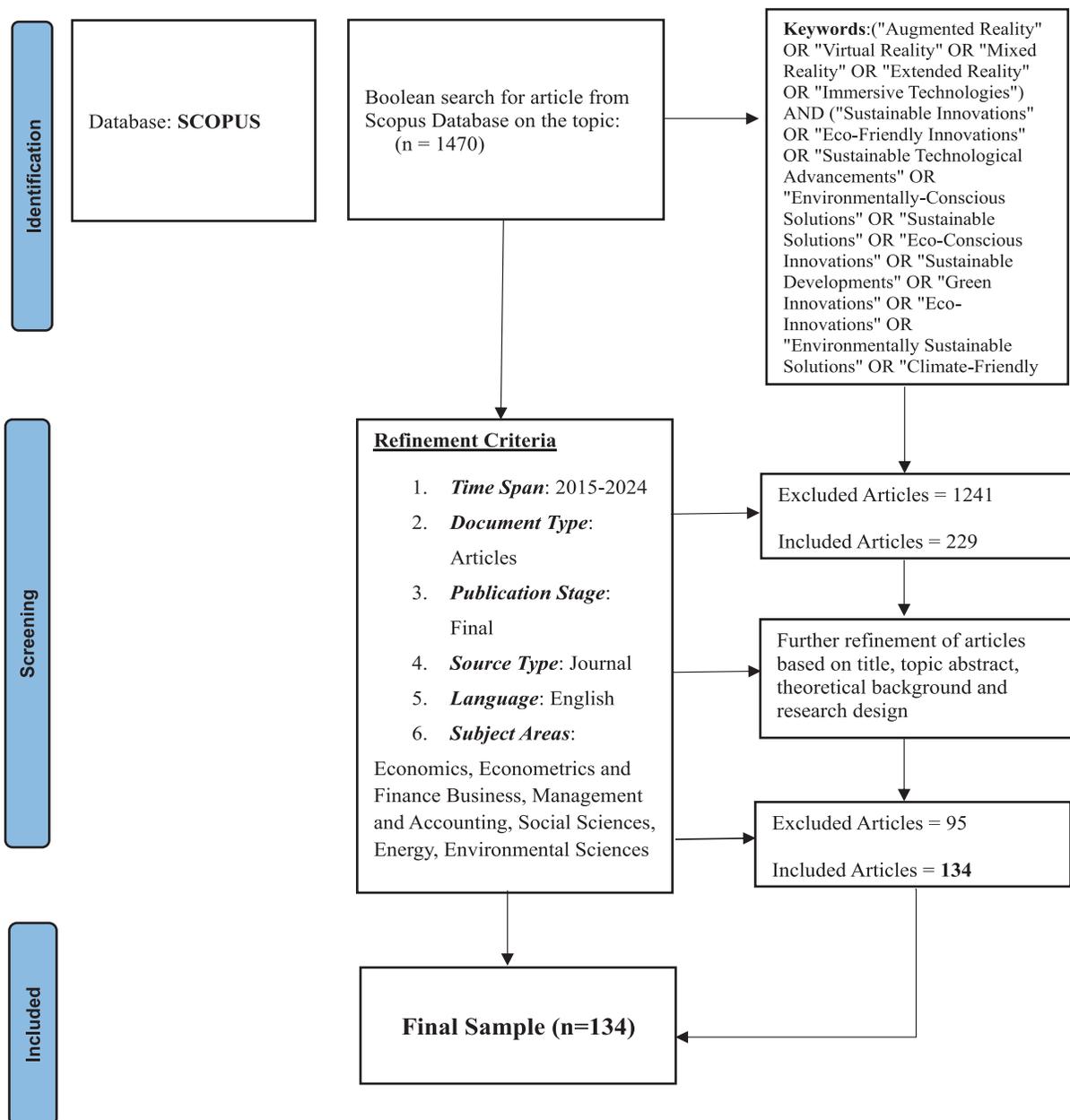
A systematic selection process based on the PRISMA framework guided the identification and refinement of the literature. An initial Boolean search was conducted in the Scopus database using a comprehensive set of keywords that combined terms related to immersive technologies (e.g., "Augmented Reality," "Virtual Reality," "Mixed

Reality”) with sustainability-related concepts (e.g., “Eco-Friendly Innovations,” “Sustainable Solutions,” “Climate-Friendly Technologies”). This initial query yielded 1,470 documents. The first screening phase applied six refinement criteria. As a result, 134 journal articles were finalized for bibliometric analysis. The entire document selection process is visually represented in Figure 1

Bibliometric analysis is a valuable method for objectively evaluating scientific literature, enabling the identification

of influential studies, key authors, and emerging research trends (Donthu et al., 2021). Unlike traditional reviews, it offers a systematic and data-driven approach to understanding the intellectual structure of a field (José De Oliveira et al., 2019). By examining citation patterns, keyword co-occurrence, and publication dynamics, bibliometric techniques help uncover knowledge gaps and guide future research directions (Wang et al., 2019).

Figure 1: Flowchart of document selection for bibliometric analysis



Analysis and Findings

Trends in publication and descriptive analysis

The table 1 indicates that this study used publications from 2015 to 2024, sourced from the Scopus database. Over this period, 134 articles were published, with an average citation rate of 24.59. The field has shown a robust annual growth rate of 49.36%, reflecting increasing academic interest. A total of 470 authors contributed to the dataset, of

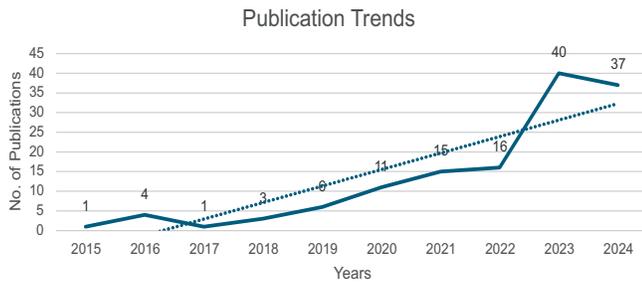
which 13 were single-authored documents. Figure 2 displays the year-by-year publication trend from 2015 to 2024. The number of publications has shown a strong upward surge, with a calculated annual growth rate of 49.36%. While the initial years of 2015 to 2018 shows limited output, the field began to expand steadily from 2019 onward. Notably, the number of publications peaked at 40 in 2023, followed by a slight dip to 37 in 2024.

Table 1: Data Summary

Description	Results
<i>Main Information about data</i>	
Timespan	2015:2024
Sources (Journals, Books, etc)	74
Documents	134
Annual Growth Rate %	49.36
Document Average Age	2.92
Average citations per doc	24.59
References	8570
<i>Document contents</i>	
Keywords Plus (ID)	865
Author's Keywords (DE)	535
<i>Authors</i>	
Authors	470
Authors of single-authored docs	13
<i>Authors collaboration</i>	
Single-authored docs	13
Co-Authors per Doc	3.62
International co-authorships %	31.34
<i>Document types</i>	
article	134

Source: Biblioshiny tool-main information

Figure 2. No. of Publications from 2015 to 2024



Citation Analysis

The traditional method of citation analysis relies on the total number of citations (TC) an author, article, or publication source has received. However, this approach tends to be biased, as older publications naturally accumulate more citations over time. To address this limitation and reduce the skewing effect of TC, three additional metrics were incorporated, including the h-index

(Costas & Bordons, 2008). 'h-index' refers to the number of publications with $TC \geq h$ (Costas and Bordons, 2008), i.e., if an author has ten publications, out of which three papers have $TC \geq 3$, his h-index will be 3.

Source dynamics

Table 2 presents the top journals, ranked by total citations, h-index, and total publications. At the forefront is Sustainability (Switzerland) with 37 number of publications and a total citation count of 904, supported by a strong h-index of 17. This indicates its central role in disseminating research on this emerging intersection. Other notable contributors include Resources, Conservation and Recycling and Ecological Economics, each with one publication, but significant citation impacts of 349 and 288, respectively. High-ranking A and A* journals from the ABDC list, such as Tourism Management, Journal of Sustainable Tourism, and Technological Forecasting and Social Change, are also represented, though with fewer articles, indicating selective but high-impact contributions.

Table 2: Top 10 most relevant sources

Source	h index	TC	TP	ABDC	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Sustainability (Switzerland)	17	904	37	-	0	0	0	2	4	4	6	5	13	5
Resources, Conservation and Recycling	1	349	1	-	0	0	0	0	0	1	0	0	0	0
Ecological Economics	1	288	1	A	0	0	0	0	0	1	0	0	0	0
Sustainable Cities and Society	5	191	5	-	0	1	0	0	1	0	0	1	2	0
Tourism Review	1	173	1	B	0	0	0	0	0	0	0	0	1	0
Tourism Mgmnt.	1	145	1	A*	0	0	0	0	0	0	0	1	0	0
J. of Sustainable Tourism	1	111	1	A*	0	0	0	0	0	1	0	0	0	0
Technological Forecasting and Social Change	3	87	4	A	1	0	0	0	0	0	0	0	0	3
MIS Quarterly: Mgmnt. Information Systems^	1	86	1	A*	0	1	0	0	0	0	0	0	0	0
Int. J. of Information Mgmnt.	1	67	1	A*	0	0	0	0	0	0	0	1	0	0

^In the list of FT50 Journals

Note. TC = Total Citations; TP = Total Publications; J. = Journal; Int. = International; Mgmt. = Management; ABDC = Australian Business Deans Council (ABDC) ranking 2022; h-index = author-level indicator that evaluates both author's productivity and its citation impact.

Most cited Authors and Documents

Table 3 highlights key contributors and highly cited articles based on citation impact. The most influential article, "Industry 4.0 and circular economy" by (Dev et al., 2020), published in Resources, Conservation and Recycling, received 349 citations, showcasing its strong influence in sustainable reverse supply chains. Next by ElMassah &

Mohieldin (2020) with 288 citations for their work on digital transformation and SDGs, published in Ecological Economics. Go & Kang (2023) contributed to the metaverse-tourism field with 173 citations in Tourism Review. Zhang et al. (2022) from China explored virtual tourist sentiment during COVID-19, accumulating 145 citations in Tourism Management.

Institutions like the University of Konstanz (Germany), An-Najah National University (Palestine), and University of Salamanca (Spain) are among the most active, each contributing multiple authors and papers, signaling strong institutional engagement in immersive, sustainable innovation research.

Table 3. Top influential authors and institutions

Author	h index	TC	TP	Institutions	TP
Dev NK	1	349	1	Univ. of Konstanz,Germany	11
Qaiser FH	1	349	1	An-Najah National Univ., Palestine	9
Shankar R	1	349	1	Univ. of Salamanca,Spain	9
Elmassah S	1	288	1	Universitas Negeri Padang, Indonesia	7
Mohieldin M	1	288	1	Univ. of Jaén, Spain	7
Go H	1	173	1	Chengdu Univ. of Technology, China	6
Kang M	1	173	1	Curtin Univ., Australia	6
Li Y-Q	1	145	1	National And Kapodistrian Univ. Of Athens, Greece	6
Liu C-H	1	145	1	Phenikaa Univ., Vietnam	6
Ruan W-Q	1	145	1	Universidad De Buenos Aires,Argentina	6

Note. TP =Total Publications; TC=Total Citations; Univ.=Univ.

Table 4: The top 10 research articles

Author	Title	Source	TC
(Dev et al., 2020)	"Industry 4.0 and circular economy: Operational excellence for sustainable reverse supply chain performance"	Resources, Conservation and Recycling	349
(ElMassah & Mohieldin, 2020)	"Digital transformation and localizing the Sustainable Development Goals (SDGs)"	Ecological Economics	288
(Go & Kang, 2023)	"Metaverse tourism for sustainable tourism development: Tourism Agenda 2030"	Tourism Review	173
(Zhang et al., 2022)	"Would you enjoy virtual travel? The characteristics and causes of virtual tourists' sentiment under the influence of the COVID 19 pandemic"	Tourism Management	145
(Gössling, 2021)	"Technology, ICT and tourism: from big data to the big picture"	Journal of Sustainable Tourism	111
(Maffei et al., 2016)	"Immersive virtual reality in community planning: Acoustic and visual congruence of simulated vs real world"	Sustainable Cities and Society	103

Author	Title	Source	TC
(Ketter et al., 2016)	“A Multiagent Competitive Gaming Platform to Address Societal Challenges”	MIS Quarterly	86
(Su & Cheng, 2019)	“A Sustainability Innovation Experiential Learning Model for Virtual Reality Chemistry Laboratory: An Empirical Study with PLS-SEM and IPMA”	Sustainability	84
(Scurati et al., 2021)	“Exploring the Use of Virtual Reality to Support Environmentally Sustainable Behavior: A Framework to Design Experiences”	Sustainability	80
(Abad-Segura et al., 2020)	“Sustainability of Educational Technologies: An Approach to Augmented Reality Research”	Sustainability	77

Note. TC = Total Citations

Country wise contribution

Table 5 highlights the top 10 countries contributing to research on immersive technologies in sustainable innovations, focusing on publication volume and total citations . China leads with 68 publications and 580

citations, showing both high productivity and impact. Spain and the USA follow with 43 and 37 publications respectively, while India stands out for its exceptionally high average citations from fewer documents.

Table 5: Top 10 countries based on productivity and citations

Country	TP	Country	TC	Average Article Citations
China	68	China	580	27.6
Spain	43	India	349	349
USA	37	Egypt	320	160
Germany	28	USA	253	28.1
Greece	26	Italy	229	45.8
South Korea	22	Spain	219	19.9
Italy	21	Germany	143	14.3
Romania	16	South Korea	135	22.5
Australia	15	Australia	90	30
UK	13	Finland	67	33.5

Note. TP =Total Publications; TC=Total Citations

Most relevant keywords

Figures 3 and 4 illustrate the most frequently used keywords through a Word Cloud and Tree map, respectively. In these visuals, larger font sizes and blocks represent higher keyword frequency. The most prominent terms are “virtual reality,” “augmented reality,” “sustainable development,” and “sustainability,” showing the central themes of the research. The current analysis

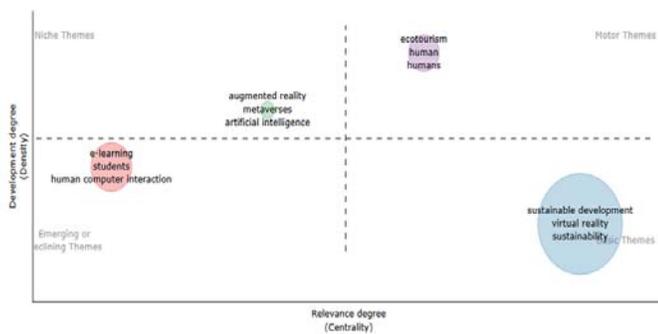
highlights “virtual reality” and “sustainable development” as the top-used keywords. The presence of terms like “AI,” “blockchain,” “education,” and “climate change” underscores the growing interdisciplinary focus on how emerging technologies support sustainability within the metaverse context.

The second quadrant comprises those themes which are highly relevant as well as highly developed, known as motor themes (Cobo et al., 2011). Findings show that “ecotourism” and “human” belong to this category.

Although highly developed, the themes falling in the third quadrant still have a low relevance in the field of study, known as niche themes. The themes “augmented reality,” “metaverses,” and “artificial intelligence” are in this category.

The fourth quadrant comprises themes that are either emerging or declining. This study found themes – “e-learning,” “students,” and “human computer interaction” – in this quadrant, indicating their emerging nature.

Figure 6: Thematic Map

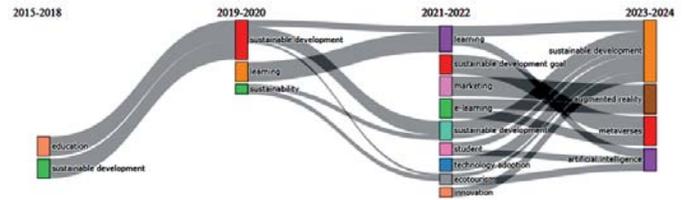


Thematic Evolution

Thematic evolution analysis reveals a significant shift in research focus from foundational concepts such as "education" and "sustainable development" (2015–2018) toward more integrated and technology-driven themes in recent years. Between 2019 and 2020, emphasis expanded to include "sustainability" and "learning," which evolved by 2021–2022 into more specialized topics like "e-learning," "technology adoption," and "ecotourism." By 2023–2024, the landscape prominently features cutting-edge themes such as "augmented reality," "artificial intelligence," and "metaverses," highlighting a clear trajectory toward digital and immersive solutions for sustainable development. The recurring presence of "sustainable development" highlights its central

importance, while the growing focus on virtual and augmented technologies signals a key shift toward the integration of education, innovation, and sustainability

Figure 7: Thematic Evolution



Intellectual Structure

The intellectual structure encompasses a set of attributes that offer a systematic and comprehensive understanding of a knowledge domain (Goswami & Agrawal, 2019). Two key methods used to uncover this structure are co-citation analysis and bibliographic coupling, which help identify the foundational relationships within a field of study (Khare & Jain, 2022). Clusters obtained through bibliographic coupling reflect the core themes of the field and represent the current state of knowledge (Boyack & Klavans, 2010; Donthu et al., 2021). Therefore, this method is suitable for emerging fields with limited academic literature.

The bibliographic coupling analysis revealed four distinct thematic clusters defining the intellectual structure of the field. Table 7 and figure 8 presents a brief overview of the obtained intellectual clusters. Cluster 1 (Red) centres on the convergence of e-learning and augmented reality, emphasizing immersive educational environments and human–technology interaction. Influential contributors such as Milgram P., Azuma R.T., and Venkatesh V. bridge foundational AR frameworks with user acceptance and technology adoption models. Cluster 2 (Green) integrates virtual reality with sustainability discourse. Leading authors including Loureiro SMC, Jung T., Davis FD, and Fornell C. explore the intersection of consumer experience, immersive technology, and sustainable consumption. Cluster 3 (Blue) is grounded in sustainable development and climate change. Prominent scholars like Ajzen I., Bandura A., and Slater M. provide critical insights into the cognitive, social, and motivational factors that shape environmental behaviours. Lastly, Cluster 4.

Figure 8: Bibliographic Coupling by Authors

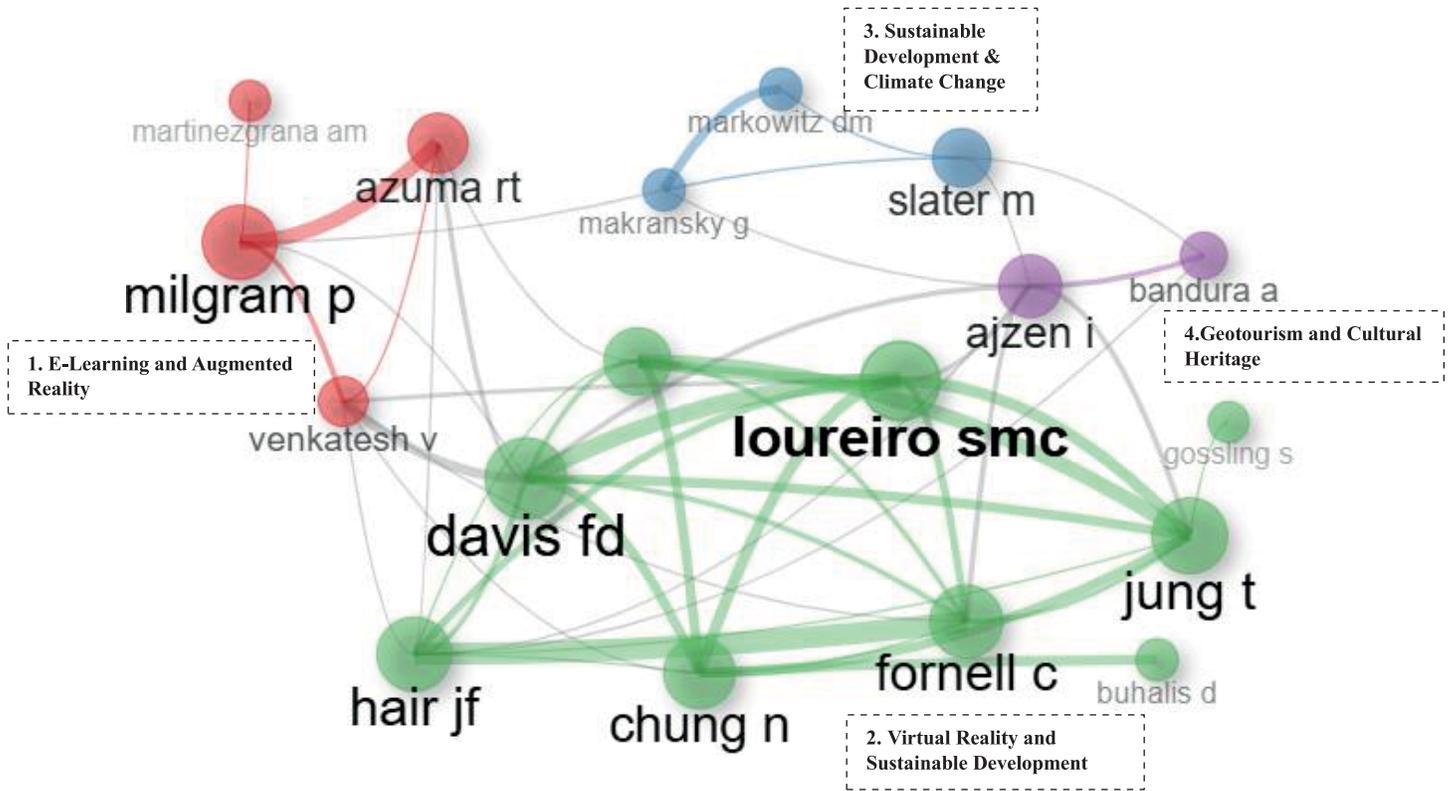


Table 7 :Intellectual structure of the field of study

Cluster	Central Focus	Influential Area Explored	Notable Authors
1 (Red)	E-learning & Augmented Reality	Immersive digital education, AR frameworks, digital tools for learning and engagement	Milgram P., Azuma R.T., Venkatesh V.
2(Green)	Virtual Reality & Sustainable Development	Technological applications in sustainability, Consumer interaction, sustainability	Loureiro SMC, Jung T., Davis FD, Fornell C.
3(Blue)	Sustainable Development & Climate Change	Environmental behavior, game theory, climate policy, Ecological resilience	Ajzen I., Bandura A., Slater M.
4(Purple)	Geotourism & Heritage Conservation	Cultural preservation, GIS, sustainable tourism	Martínez-Graña A., González-Delgado J.A.

Social Structure

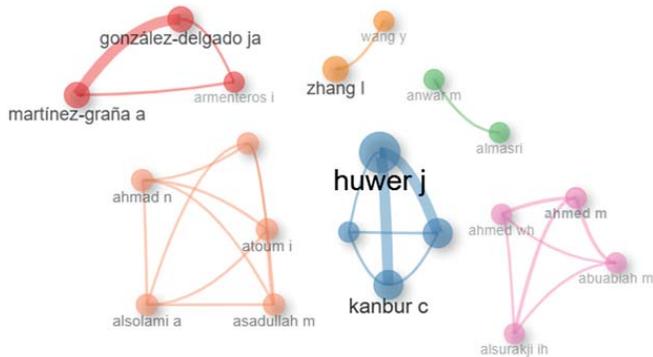
The social structure represents the collaborative network of authors, institutions, and countries that contribute collectively to the advancement of a specific field of study. Figure 8 presents the author collaboration network,

indicating active group collaborative efforts. Notably, Huwer J and Kanbur C form the most prominent and densely connected cluster, suggesting strong ongoing partnerships. Other clusters, such as those led by González-Delgado JA, Ahmad N, and Ahmed M, also demonstrate significant intra-group collaboration.

Figure 9 illustrates the institutional collaboration network, showcasing cooperative research efforts among universities across different regions. The most prominent collaborations are led by the University of Konstanz and the National and Kapodistrian University of Athens, both of which exhibit strong linkage strength and multiple partnerships.

The geographical collaboration network illustrated in the figure 10 reveals the presence of four distinct country clusters. Cluster 1, in green, includes China, the USA, India, South Korea, and Australia, showing strong interconnections and China emerges as a central hub within this cluster. Cluster 2, marked in purple, features Germany, Switzerland, Indonesia, and Poland, indicating moderate collaboration with a focus on European partnerships. Cluster 3, in red, consists of the United Kingdom, Brazil, and Italy, demonstrating strong intra-cluster cooperation, particularly between the UK and Brazil. Lastly, Cluster 4, shown in orange and blue, includes countries like Spain, Portugal, Greece, and Romania, which are more regionally connected.

Figure 9. Author collaboration network (20 nodes, 1 minimum edge, walktrap clustering algorithm, association normalization).



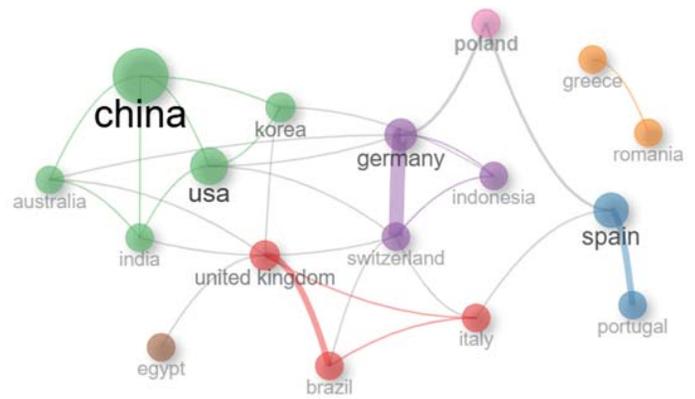
Discussions

The bibliometric review highlights the evolving research focus at the intersection of immersive technologies and sustainable innovation. A notable rise in publications, especially in 2023, reflects growing academic interest, with most studies published in reputed ABDC-ranked journals. Sustainability (Switzerland) leads in citations and output, while China and the University of Konstanz stand out for

Figure 10. Institutional collaboration network (20 nodes, 1 minimum edge, walk trap clustering algorithm, association normalization).



Figure 11. Geographical collaboration network (20 nodes, 1 minimum edge, walk trap clustering algorithm, association normalization).



their contributions. Table 8 presents a summary of the bibliometric review. The bibliographic coupling analysis identified four thematic clusters reflecting distinct research trajectories. Cluster 1 focuses on E-learning and AR, highlighting the adoption of immersive digital tools in educational contexts, guided by foundational AR frameworks. Cluster 2 centres on VR and Sustainable Development, emphasizing the integration of immersive technologies with consumer interaction and sustainability goals. Cluster 3 encapsulates studies on Sustainable Development and Climate Change, underpinned by behavioral theories, game theory, and ecological policy discourse. Cluster 4 addresses Geotourism and Heritage Conservation, stressing the use of geospatial tools and cultural preservation practices.

The co-occurrence analysis further validates these themes through keyword associations. Keywords such as VR, AI Metaverse, and Smart Cities are strongly linked with technological innovation in sustainable development, while terms like Sustainable Tourism, Education for

Sustainable Development, and Higher Education indicate a parallel focus on pedagogical transformation and policy discourse. An emerging fifth cluster marked by AI reflects the field's rapid technological progression and signals a future research avenue.

Table 8: A summary of bibliometric review

Descriptive Analysis	Bibliographic Coupling	Co-occurrence Analysis
<p>Publication Trends</p> <ul style="list-style-type: none"> A total of 134 publications in ABDC A*, A or B category journals from 2015 to 2024. 2023 was the most substantial year with 40 publications. 	<p>Cluster 1: E-learning & Augmented Reality</p> <ul style="list-style-type: none"> Immersive Digital Education AR frameworks Digital tools for learning and engagement 	<p>Cluster 1</p> <p>Virtual Reality, Cultural Heritage, Sustainable Tourism, Innovation, Immersion, Climate Change</p>
<p>Citation Analysis</p> <ul style="list-style-type: none"> Top Journals Sustainability (Switzerland) with 904 total citations, 37 publications, and h-index value of 17 	<p>Cluster 2: Virtual Reality & Sustainable Development</p> <ul style="list-style-type: none"> Technological Applications in sustainability Consumer interaction Sustainability 	<p>Cluster 2</p> <p>Augmented Reality, Artificial Intelligence, Metaverse, Sustainability, Smart Cities, Virtual Worlds, Bibliometric Analysis</p>
<ul style="list-style-type: none"> Top Articles “Industry 4.0 and circular economy” by (Dev et al., 2020), published in Resources, Conservation and Recycling, received 349 citations Top Institutions Univ. of Konstanz, Germany with 11 publications 	<p>Cluster 3: Sustainable Development & Climate Change</p> <ul style="list-style-type: none"> Environmental behaviour Game Theory Climate policy Ecological resilience 	<p>Cluster 3</p> <p>Sustainable Development, Education for sustainable development, SDGs</p>
<ul style="list-style-type: none"> Top Countries China with 68 Publications and 580 total citations Top Authors Dev NK is the most influential author with 349 citations. 	<p>Cluster 4: Geotourism & Heritage Conservation</p> <ul style="list-style-type: none"> Cultural preservation GIS Sustainable Tourism 	<p>Cluster 4</p> <p>Educational Innovation, Higher Education, Mobile Learning</p> <p>Cluster 5</p> <p>Artificial Intelligence</p>

Future Research Directions

Future research should deepen the exploration of immersive technologies like augmented reality, artificial intelligence, and metaverses, which remain underdeveloped yet promising. Studies can focus on their long-term impact on behavior, sustainability, and policy integration. The low density of e-learning themes suggests a need to revisit digital education models, especially for adaptability and inclusivity. Heritage-focused research

should explore localized AR/VR applications to enhance cultural preservation. Finally, adopting the triple helix model can strengthen collaboration across academia, industry, and government, driving practical innovation in sustainability.

Implications of the Study

Theoretically, this study contributes to the understanding of how immersive technologies intersect with sustainable development by mapping the intellectual and thematic

structure of the field. It highlights the evolution of key concepts and the interdisciplinary integration of technology, education, and environmental sustainability. Managerially, the findings offer insights for policymakers, educators, and tourism stakeholders to strategically adopt emerging technologies like AR, VR, and AI. These tools can enhance user engagement, drive sustainable practices, and support data-driven decision-making, especially in education, smart tourism, and heritage conservation sectors.

Limitations

This study has certain limitations. First, it relies solely on the Scopus database to identify relevant literature. While Scopus is the largest bibliographic database covering a wide range of disciplines including science, technology, social sciences, and humanities (Pranckutė, 2021), using additional databases could have minimized the risk of omitting important studies. Second, only English-language publications were included due to the researchers' linguistic limitations. Additionally, the exclusion of books and book chapters—owing to difficulties in accessing their full texts—may have introduced type I and II errors (Khare & Jain, 2022).

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