Extended reality applications: A bibliometric analysis

Damla KARAGOZLU [1], Huseyin BICEN [2]

[1] Department of Management Information Systems,
Cyprus International University, Nicosia

[2] Educational Sciences Research Center, Department of Computer Education and Instructional Technology, Near East University, Nicosia

dkaragozlu@ciu.edu.tr, huseyin.bicen@neu.edu.tr

Abstract: *In this paper Bibliometric analysis of articles scanned with the title "Extended Reality Applications" in the Web of Science database. This study was conducted using VosViewer software. The aim of this study is to determine which authors, which journals and countries have conducted the most studies on "Extended Reality Applications" with bibliometric analysis. On July 26, 2024, all fields were selected in the Web of Science database and studies on "Extended Reality Applications" were scanned. The countries most cited in the field of study are the United States and Germany. The journal "Applied Sciences-Basel" contains the most important studies on "Extended Reality Applications". As a result, the keywords virtual reality, augmented reality and mixed reality are the most used in Extended Reality Applications studies.*

Keywords: Extended Reality, Virtual Reality, Augmented Reality, Mixed Reality, Bibliometric Analysis, Research Trends.

1. Introduction

The change has been an undeniable reality throughout human life and has transformed into technological developments over time, becoming an element that makes human life easier. Technological developments in many areas affect many areas. Examples of this include people's lifestyles, their interactions with their environment, and even their living standards (Daskin, 2024).

Nowadays, virtual information environments are used by a continuously increasing proportion of societies through mobile devices such as tablets and smartphones. The ongoing development in human-computer interface research is planned to be completed by providing users with six degrees of freedom (up/down, forward/back, left/right, pitch, roll, yaw). In this way, user experience can be provided with interesting visualization in 3D digital environments, allowing them to interact with different virtual objects without being disconnected from the real world (Salehi et al., 2023).

The term extended reality (XR) is used as an umbrella term covering different technologies located along the reality–virtuality continuum (Schaal, 2019; Salmon et al, 2020; Memmesheimer & Ebert, 2022; Anastasiou, Balafoutis & Fountas, 2023; Arslan, 2023; Chuah, 2023). The first attempt to explain these

https://doi.org/10.58503/icvl-v19y202408

concepts by placing them along a continuum between reality and virtuality was made in 1994 by Milgram, Takemura, Utsumi and Kishino. Extended reality is a concept that covers different types of reality, such as augmented reality (AR) virtual reality (VR) and mixed reality (MR), which has a wide range of applications, including military, health, gaming, education, training and design visualization. These reality technologies are created by computers, are either completely virtual or are formed by blending the virtual and real world, have a high level of engagement, provide a sense of presence and are interactive. While augmented reality combines virtual and real objects on a real-time screen, virtual reality allows users to experience real or imaginary allows them to control and direct their movements in a world (Ro et al., 2018; Suh & Prophet, 2018). AR and VR technologies are also used together to create a more engaging and realistic experience called mixed reality. For example; watching a 360˚ movie, playing a game, Wandering around 3D models for buildings and travelling in the universe are application areas where the two technologies can be used together. In summary, XR devices are technologies that can provide a feeling for users like they are in a completely new digital environment (O'Donnell, 2018). Creating virtual tours in stores and virtually inspecting the design of a car regarding both interior and exterior, are some examples of applications (Sheikh, 2016).

The elements that must be present in VR technology are the virtual environment and the user's ability to feel their presence in the virtual environment. In VR, the feeling of presence for a person could be stated as being able to interact with the environment as in physical reality, and their actions must have a response. Presence refers to the feeling of being there even if the user is physically in a different place (Jerald, 2015). One of the main elements that distinguishes virtual reality from virtuality is the state of presence that makes the user feel like it is real. Milgram and Kishino (1994) stated that AR refers to situations that involve the augmentation / enrichment of the real environment with computer-based virtual objects, while they generally define MR as the merging of the real and virtual worlds. The relationship between the three concepts is expressed as; While VR includes users in a completely virtual environment, AR creates a virtual layer on reality without allowing real-virtual interaction, and MR can create virtual objects that can interact with the real environment (Alcañiz, Bigné & Guixeres, 2019).

The concept of MR can be expanded to include the senses of touch (haptic/tactile), taste and smell, as well as sound (Speicher et al., 2019). Today, headsets that act as head-mounted displays are used for augmented, virtual and mixed reality. These headsets create a 3D environment for the user by processing inputs from the computer they are connected to or using the processor and imaging power within themselves. Nowadays, studies are ongoing on clothing that allows users to feel sensory stimuli such as contraction, tension, stinging, etc. in certain parts of their bodies according to their experience in VR.

Previous research has documented an exponential rise in publications on extended reality, indicating the increasing significance of extended reality

applications in various fields. XR technology is increasingly being integrated into a wide range of areas, from education (Kerawalla et al., 2006), tourism (Jung et al., 2015), retail (Yim et al., 2017) and healthcare (Glegg, 2017) gaming (Rauschnabel et al., 2017) to manufacturing (Choi et al., 2015). The main aim of study is to conduct a bibliometric analysis by focusing on highlighting the citation of authors, co-occurances of a keyword, bibliographic matching (coupling) of documents, bibliographic matching of sources and bibliographic matching of countries regarding articles on extended reality applications.

2. Method

In this paper Bibliometric analysis of articles scanned with the title "Extended Reality Applications" in the Web of Science database. This study was conducted using VosViewer software. The aim of this study is to determine which authors, which journals and countries have conducted the most studies on "Extended Reality Applications" with bibliometric analysis. On July 26, 2024, all fields were selected in the Web of Science database and studies on "Extended Reality Applications" were scanned. While performing the analyses in VosViewer, "Citation of authors, Co-occurrence-all keywords, Bibliographic coupling of documents, Bibliographic coupling of sources, Bibliographic coupling of countries" were examined. Within the scope of the research, the analyses related to 68 studies on "Extended Reality Applications" were tabulated and presented with graphics.

3. Findings

3.1 Citation of authors

When analyzing the data regarding citations of authors, the "lowest number of documents of an author" was identified as 1. The "lowest number of citations of an author" was identified as 23, and only 6 of 209 authors meet the thresholds. Figure 1 and Table 1 show the most cited authors.

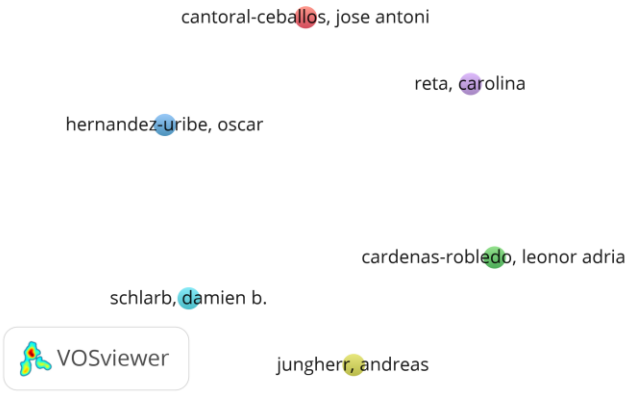

Figure 1. Graph generated with VosViewer for citation of authors

Table 1. Table of citations of authors

Author	Documents	Citations	Total link strength
"cantoral-ceballos, jose antonio"	1	23	0
"cardenas-robledo, leonor adriana"	1	23	0
"hernandez-uribe, oscar"	1	23	0
"jungherr, andreas"	1	25	0
"reta, carolina"	1	23	0
"schlarb, damien b."	1	25	0

3.2 Co-occurrence-all keywords

While performing the relevant analysis, the “lowest number of occurrences of a keyword” was identified as 5. Among the 239 keywords, 5 meet the thresholds. In Figure 2 and Table 2 highlights the ”Co-occurrence-all keywords”.

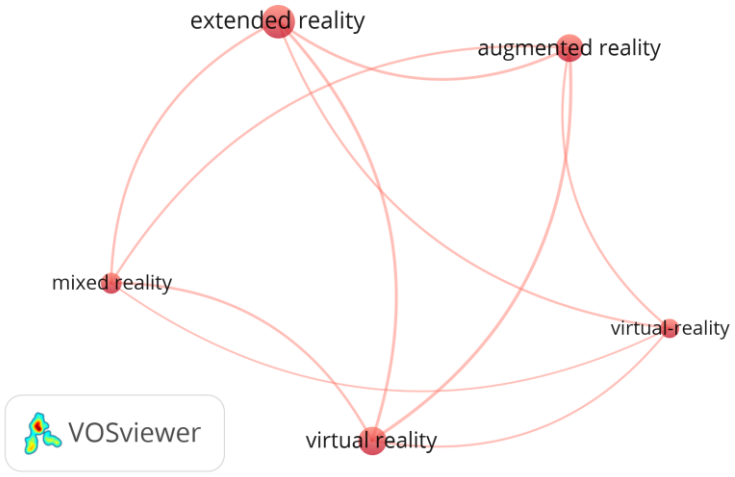

Figure 2. Graph generated with VosViewer for co-occurrence-all keywords

Table 2. Table for co-occurrence-all keywords

Keyword	Occurrences	Total link strength
virtual-reality	6	17
mixed reality	7	20
augmented reality	12	26
virtual reality	13	27
extended reality	18	26

3.3 Bibliographic coupling of documents

While conducting the relevant analysis, the "lowest number of citations of a document" was selected as 5. 14 out of 50 documents meet the threshold. In Figure 3 and Table 3 shows that "bibliographic coupling of documents".

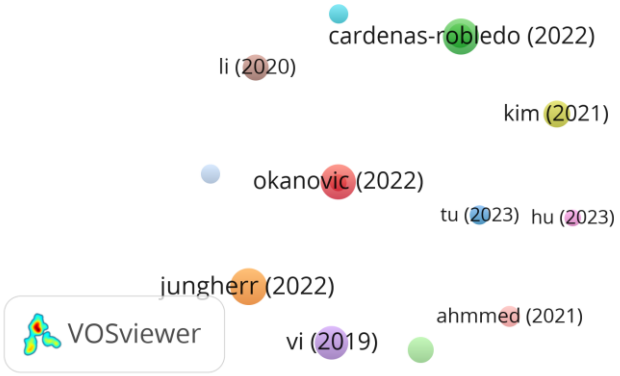

Figure 3. Graph generated with VosViewer for bibliographic coupling of documents

Table 3. Table for bibliographic coupling of documents

Document	Citations	Total link strength
tu (2023)	7	0
cardenas-robledo (2022)	23	1
kim (2021)	13	0
okanovic (2022)	22	1
vi (2019)	20	0
catalano (2022)	11	1
sundararajan (2021)	7	0
jungherr (2022)	25	0
li (2020)	12	0
vanoverschelde (2019)	5	1
hu (2023)	5	0
ahmmed (2021)	8	0
vadakital (2022)	12	0
israr (2019)	7	0

3.4 Bibliographic coupling of sources

While conducting the relevant analysis, the "lowest number of documents of a source" was identified as 2. The "lowest number of citations of a source" was

selected as 0. 3 out of 47 sources meet the thresholds. Figure 4 and Table 4 shows that bibliographic coupling of sources.

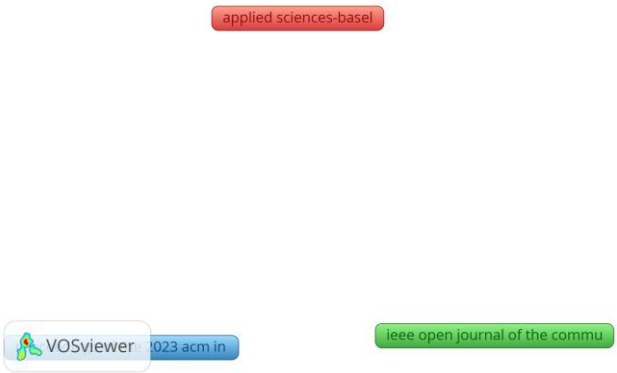

Figure 4. Graph generated with VosViewer for bibliographic coupling of sources

Table 4. Table for bibliographic coupling of sources

Source	Documents	Citations	Total link strength
applied sciences-basel	2	25	0
ieee open journal of the communications society	2	5	0
proceedings of the 2023 acm international conference on interactive	2	1	0

3.5 Bibliographic coupling of countries

While conducting the relevant analysis, the "lowest number of published documents in a country" was selected as 5. The "lowest number of citations of a country" was identified as 0. 5 out of 30 countries "meet the thresholds" Figure 5 and Table 5 shows the bibliographic coupling of countries.

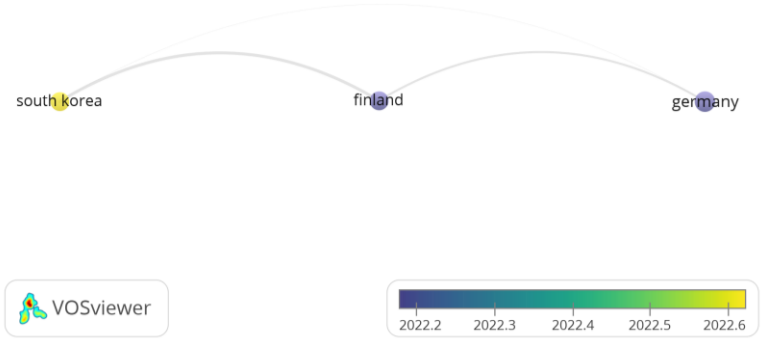

Figure 5. Graph generated with VosViewer for bibliographic coupling of countries

Table 5. Table for bibliographic coupling of countries

Country	Documents	Citations	Total link strength
finland	5	25	47
germany	6	27	19
italy	5	16	0
south korea	5	17	30
usa	7	34	0

4. Discussion

In this study, the bibliometric analysis of the studies scanned in Web of Science using the keyword “Extended Reality Applications” along with graphs and tables was given using VosViewer. When the findings are examined, it is seen that the authors of the studies most cited with the keyword “Extended Reality Applications” are “jungherr, andreas” (1 Document, 25 Citations) and “schlarb, damien b.” (1 Document, 25 Citations).

When “Co-occurrence-all keywords” are examined, the most used keywords in “Extended Reality Applications” studies are seen as virtual reality, augmented reality, mixed reality and virtual-reality, respectively. Extended reality (XR) is the general term used to cover virtual reality (VR), augmented reality (AR) and mixed reality (MR) (Vasarainen, Paavola & Vetoshkina, 2021). Therefore, it should not be surprising that research examining XR technology also addresses technologies in the virtual reality-reality continuum.

According to the keyword "Extended Reality Applications", the most cited study is "The Extended Reach of Game Engine Companies: How Companies Like Epic Games and Unity Technologies Provide Platforms for Extended Reality Applications and the Metaverse" by Jungherr and Schlarb (2022). The study investigated the products of game engine companies for extended reality and metaverse (Jungherr & Schlarb, 2022). Two pioners of game engine developers were considered in the examinations regarding three dimensions by the researchers.

The fact that the study has received the highest number of citations can be explained by the fact that it has guided other researchers. In addition, the most published journals are "applied sciences-basel" and "ieee open journal of the communications society". Within the scope of the study, the countries with the maximum number of publications in the relevant field are USA, Germany, Finland, Italy and South Korea. Since these countries are among the pioneers in technological developments, it should not be surprising that the number of studies on extended reality applications is the highest in these countries. Besides, extended reality technologies have been the subject of many studies due to their use in many fields. Cardenas-Robledo et. al (2022) revealed in their studies that extended reality

technologies are used in the fields of automotive, construction, energy, recreational, manufacturing, maritime, education and research, health and safety, aerospace, petrochemical, business, others.

5. Conclusions

In this study, articles in the Web of Science database were scanned with the title "Extended Reality Applications" in the scoop of bibliometric analysis. The VosViewer software was used in order to obtain data regarding the authors with the highest number of studies, journals which published the highest number of articles and countries where the highest number of studies were conducted on the extended reality applications.

The findings show that the works of Professor Andreas Jungherr at the University of Bamberg and Assistant Professor Damien B. Schlarb at the Johannes Gutenberg-University, Mainz are the most influential authors in the Extended Reality Applications literature. The countries with the highest number of citations in the field of study are the United States and Germany. The journal "Applied Sciences-Basel" contains the most important "Extended Reality Applications" studies. As a result, the keywords virtual reality, augmented reality and mixed reality are the most used in Extended Reality Applications studies. This study aimed to present current research on extended reality applications and to guide future studies.

REFERENCES

Alcañiz, M., Bigné, E. & Guixeres, J. (2019) Virtual reality in marketing: a framework, review, and research agenda. *Frontiers in psychology*. 10, 1530. doi:10.3389/fpsyg.2019.01530 .

Anastasiou, E., Balafoutis, A. T. & Fountas, S. (2023) Applications of extended reality (XR) in agriculture, livestock farming, and aquaculture: A review. *Smart Agricultural Technology*. 3, 100105.

Arslan, A. G. Ö. (2023) *Fen Bilgisi Öğretiminde Genişletilmiş Gerçeklik Uygulamalarinin Etkililiği Üzerine Bir Meta-Analiz Çalişmasi*. Thesis.

Beşinci, E. (2023) *Metaverse'te pazarlama ve VRChat'te bir pazarlama deneyimi tasarımı* (Master's thesis, Işık Üniversitesi).

Cardenas-Robledo, L. A., Hernández-Uribe, Ó., Reta, C. & Cantoral-Ceballos, J. A. (2022) Extended reality applications in industry 4.0. – A systematic literature review. *Telematics and Informatics*. 73, 101863.

Choi, S., Jung, K. & Noh, S. D. (2015) Virtual reality applications in manufacturing industries: Past research, present findings, and future directions. *Concurrent Engineering*. 23(1), pp. 40-63.

Chuah, S. H. W. (2018) Why and who will adopt extended reality technology? Literature review, synthesis, and future research agenda. *Literature Review, Synthesis, and Future Research Agenda*.

Daskin, E. N. (2024) *Mekân Tasarimcilarinin Renovasyon Projelerinde Genişletilmiş Gerçeklik Teknolojileri Kullaniminin Araştirilmasi*. Thesis.

Glegg, S. M., Holsti, L., Stanton, S., Hanna, S., Velikonja, D., Ansley, B. Sartor, D. and Brum, C. (2017) Evaluating change in virtual reality adoption for brain injury rehabilitation following knowledge translation. *Disability and Rehabilitation: Assistive Technology*. 12(3), 217-226.

Jerald, J. (2015) *The VR Book: Human-Centered Design for Virtual Reality*. Morgan & Claypool Publishers.

Jung, T., Chung, N. & Leue, M.C. (2015) The determinants of recommendations to use augmented reality technologies: the case of a Korean theme park. *Tourism Management*. 49, 75-86.

Jungherr, A. & Schlarb, D. B. (2022) The extended reach of game engine companies: How companies like epic games and Unity technologies provide platforms for extended reality applications and the metaverse. *Social Media+ Society*. 8(2), 20563051221107641.

Jungherr, A. & Schlarb, D. B. (2022) The extended reach of game engine companies: How companies like epic games and Unity technologies provide platforms for extended reality applications and the metaverse. *Social Media+ Society*. 8(2), 20563051221107641.

Kerawalla, L., Luckin, R., Seljeflot, S. & Woolard, A. (2006) "Making it real": exploring the potential of augmented reality for teaching primary school science. *Virtual reality*. 10, 163-174.

Memmesheimer, V. M. & Ebert, A. (2022) Scalable extended reality: A future research agenda. *Big Data and Cognitive Computing*. 6(1), 12.

Milgram, P. & Kishino, F. (1994) A Taxonomy of Mixed Reality Visual Displays. *IEICE Trans. Information Systems*. E77-D(12), 1321–1329.

Milgram, P., Takemura, H., Utsumi, A. & Kishino, F. (1994) Augmented Reality: A class of displays on the reality-virtuality continuum. In *Proceedings of SPIE*. 2351. pp. 282-292. doi: 10.1117/12.197321.

O'Donnell, D. (2018) Driving immersive experiences in virtual and augmented reality. https://blog.westerndigital.com/driving-immersive-experience-virtual-augmented- reality/.

Rauschnabel, P. A., Rossmann, A., Andtom Dieck, M.C. (2017) An adoption framework for mobile augmented reality games: the case of Pokémon Go. *Computers in Human Behavior*. 76, 276-286.

Ro, Y.K., Brem, A. & Rauschnabel, P.A. (2018) Augmented Reality Smart Glasses: definition, concepts and impact on firm value creation. In Jung, T. and tom Dieck, M.C. (Eds.). *Augmented Reality and Virtual Reality – Empowering Human, Place and Business*. Springer, Cham, CH, pp. 169-181.

Salehi, M., Hooli, K., Hulkkonen, J. & Tölli, A. (2023) Enhancing next-generation extended reality applications with coded caching. *IEEE Open Journal of the Communications Society*. 4, 1371-1382.

Salmon, G. R., MacLeod, M., Claxton, J. R., Ciamarra, U. P., Robinson, T., Duncan, A. & Peters, A. R. (2020) Exploring the landscape of livestock 'Facts'. *Global food security*. 25, 100329.

Schaal, B. (2019) Plants and people: Our shared history and future. *Plants, People, Planet*. 1(1), 14-19.

Sheikh, K (2016) Beyond gaming: 10 other fascinating uses for virtual-reality tech. https://www.livescience.com/53392-virtual-reality-tech-uses-beyond- gaming.html [Accessed 27th July 2024].

Speicher, M., Hall, B. & Nebeling, M. (2019) *What is Mixed Reality?* doi:10.1145/ 3290605.3300767 .

Suh, A. & Prophet, J. (2018) The state of immersive technology research: a literature analysis. *Computers in Human Behavior*. 86, 77-90.

Vasarainen, M., Paavola, S. & Vetoshkina, L. (2021) A systematic literature review on extended reality: Virtual, augmented and mixed reality in working life. *International Journal of Virtual Reality*. 21(2), 1-28.

VosViewer Tool. (2024) *VOSviewer - Visualizing scientific landscapes*. https://www.vosviewer.com/ [Accessed 27 July 2024]

Yim, M.Y.C., Chu, S.C. & Sauer, P.L. (2017) Is augmented reality technology an effective tool for e-commerce? An interactivity and vividness perspective. *Journal of Interactive Marketing*. 39, 89-103.