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A Bibliometric Analysis of Internet of Things and Augmented Reality Applications in Agriculture: A Scopus-Based Review (2019–2026)

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***Abstract*—The integration of Internet of Things (IoT) and Augmented Reality (AR) technologies has emerged as a transformative approach in modern agriculture, enabling precision farming, real-time monitoring, and immersive decision-support systems. This study presents a bibliometric analysis of research trends related to IoT and AR applications in agriculture using data retrieved from the Scopus database. A total of 72 publications were gathered from 2020 to 2026. The metadata is then analyzed using bibliometric techniques to identify publication trends, document types, research themes, and emerging directions. The results reveal a steady increase in publications, with the highest number of records (20 documents) in 2024 and a slight drop to a total of 12 documents in 2025. Conference papers represent the largest proportion of publications (20 documents), followed by book chapters (17 documents), and reviews with 13 documents, reflecting the changing and experimental nature of this research area. Key research themes include precision agriculture, smart farming systems, digital twins, sensor networks, and real-time visualization for crop monitoring. The findings highlight the increasing role of AR interfaces integrated with IoT sensor data for enhanced agricultural decision-making. This study provides an inclusive overview of research developments and identifies potential future directions, including AI-driven AR visualization, digital agriculture ecosystems, and sustainable farming technologies.**

***Keywords*—Bibliometric analysis; Internet of Things; Augmented Reality; smart agriculture; precision farming; Scopus database**

I. INTRODUCTION

Agriculture is undergoing rapid transformation with the adoption of digital technologies designed to improve productivity, sustainability, and resource efficiency. Among these technologies, the Internet of Things (IoT) and Augmented Reality (AR) have attracted significant attention in recent years. IoT enables real-time data collection through networks of sensors, while AR provides interactive visualization that allows users to interpret complex data within a real-world environment.

IoT-based agricultural systems typically utilize sensors to monitor parameters such as soil moisture, temperature, humidity, nutrient levels, and crop health. These systems enable farmers to make data-driven decisions and automate agricultural processes. However, the visualization and interpretation of large volumes of sensor data remain challenging for farmers and agricultural practitioners.

Augmented Reality has emerged as a complementary technology capable of overlaying digital information onto the physical environment. When combined with IoT, AR can provide immersive visualization of farm data, enabling users to monitor crop conditions, analyze sensor readings, and manage agricultural systems more efficiently. The integration of AR and IoT in agriculture supports several applications, including:

1) Precision farming: Precision farming refers to a data-driven agricultural approach that uses IoT sensors, GPS, and analytics to monitor field variability and optimize farming practices. It enables farmers to apply water, fertilizers, and pesticides precisely where needed, improving efficiency and crop yield.

Recent studies show that IoT-enabled sensors provide real-time data on soil conditions, plant health, and environmental factors, allowing targeted interventions such as optimized irrigation and fertilization [1], [2]. This significantly reduces resource wastage and enhances productivity.

2) Crop monitoring: Crop monitoring involves continuous observation of crop conditions using IoT sensors, drones, and imaging technologies. It helps detect issues such as plant stress, diseases, and nutrient deficiencies at early stages.

IoT-based systems collect real-time environmental and crop data, enabling farmers to track crop growth and respond quickly to changes [1]. Advanced systems can monitor parameters like soil moisture, temperature, and pest activity, improving overall farm management.

3) Agricultural training and education: AR plays a major role in agricultural training by providing interactive and immersive learning environments. It allows farmers and students to visualize farming processes, machinery operations, and crop conditions without physical risks.

Recent studies highlight that AR-based training systems improve knowledge transfer, enhance understanding, and support skill development in agriculture by simulating real-world scenarios [3]. This is especially useful for training in modern farming technologies.

4) Smart irrigation management: Smart irrigation uses IoT sensors and automated systems to optimize water usage based on real-time environmental data. It ensures that crops receive the right amount of water at the right time.

Research shows that IoT-based irrigation systems can significantly reduce water consumption while maintaining optimal soil moisture levels through automated control mechanisms [2]. These systems are particularly important in addressing water scarcity and climate variability.

5) Digital twin farming environments: Digital twin technology creates a virtual replica of a physical farm using real-time data from IoT sensors. This allows farmers to simulate, monitor, and optimize agricultural processes. Recent studies indicate that digital twins integrate IoT, AI, and AR technologies to model crop growth, predict outcomes, and support decision-making [4], [5]. They enable advanced applications such as yield prediction, disease detection, and scenario simulation.

IoT and AR technologies support several applications in agriculture, including precision farming, crop monitoring, agricultural training, smart irrigation, and digital twin environments. Precision farming enables data-driven decision-making through real-time sensor data [1], [2], while crop monitoring improves early detection of environmental changes [1]. AR enhances agricultural training through immersive visualization [3], and smart irrigation optimizes water usage using automated systems [2]. Furthermore, digital twin technology enables simulation and predictive analysis for improved farm management [4], [5].

Despite the growing interest in this interdisciplinary field, comprehensive reviews focusing specifically on the convergence of IoT and AR in agriculture remain limited. Bibliometric analysis provides a systematic method for evaluating scientific publications, identifying research trends, and mapping the development of a research field.

The objectives of this study are:

- To analyze publication trends related to IoT and AR in agriculture.
- To identify the dominant document types and publication sources.
- To explore emerging research themes in this field.
- To identify potential research directions for future studies.

Therefore, this study aims to analyze global research trends related to IoT and AR in agriculture using bibliometric techniques based on publications indexed in the Scopus database.

The next section will focus on the literature on the digital transformation in agriculture, the usage of Internet of Things (IoT) in agriculture, the usage of Augmented Reality (AR) in agriculture, and the integration of both technologies in agriculture, followed by methodology, results, discussion, research challenges and future directions, and conclusion section.

II. LITERATURE REVIEW

A. *Digital Transformation in Agriculture*

The agricultural sector is undergoing a significant transformation driven by digital technologies aimed at improving productivity, sustainability, and resource efficiency. Traditional farming methods, which rely heavily on manual labor and experience-based decision-making, often result in inefficient resource use and limited adaptability to environmental changes [6]. These limitations have accelerated the transition toward smart agriculture, where technologies such as the Internet of Things (IoT), Augmented Reality (AR), and artificial intelligence (AI) are increasingly adopted.

Recent studies highlight that smart agriculture systems integrate sensing, communication, and data analytics technologies to enable real-time monitoring and automation [7]. Among these technologies, IoT and AR play complementary roles in data acquisition and visualization, forming the foundation of modern precision agriculture systems.

B. *Internet of Things (IoT) in Agriculture*

The Internet of Things (IoT) has become a core component of smart agriculture by enabling real-time monitoring through interconnected sensors and devices. IoT systems collect environmental data such as soil moisture, temperature, and humidity, allowing farmers to make data-driven decisions and optimize resource utilization [6].

1) Usage of IoT in agriculture: IoT applications in agriculture cover a wide range of smart farming activities that help improve productivity and sustainability. For example, smart irrigation systems use sensor data to optimize water consumption by supplying water only when needed, reducing waste and improving efficiency. In addition, soil and environmental monitoring systems utilize wireless sensor networks to collect real-time data on factors such as soil moisture, temperature, humidity, and nutrient levels. IoT technology is also applied in livestock tracking and health monitoring, allowing farmers to monitor animal location, behavior, and health conditions more effectively. Furthermore, automated greenhouse management systems help control environmental conditions such as lighting, temperature, and ventilation to support optimal crop growth. IoT can also assist in crop disease detection and yield prediction through continuous data collection and analysis. Overall, these applications enable farmers to make more accurate data-driven decisions, leading to increased agricultural productivity, reduced resource wastage, and more sustainable farming practices.

2) Advantages of IoT: IoT offers several important benefits in agriculture by enabling smarter and more efficient farming practices. One of the main advantages is real-time monitoring and control of farming conditions, allowing farmers to continuously observe environmental factors such as temperature, humidity, soil moisture, and nutrient levels. This capability helps improve resource efficiency by reducing unnecessary use of water, fertilizers, and energy, ultimately minimizing wastage and operational costs. In addition, IoT technologies contribute to enhanced crop yield and quality through accurate data collection and timely interventions. IoT also supports the automation of repetitive agricultural tasks, such as irrigation, fertilization, and greenhouse management, reducing labor dependency and increasing productivity. Furthermore, these technologies play a significant role in supporting precision agriculture techniques, where farming activities are optimized based on real-time data and specific crop requirements.

3) Disadvantages of IoT: Despite its many advantages, the implementation of IoT in agriculture also faces several challenges. One of the major limitations is the high initial setup and maintenance costs, which can be difficult for small-scale farmers to afford. In addition, IoT systems heavily depend on reliable internet connectivity, particularly for real-time monitoring and data transmission, making deployment difficult in rural areas with limited network coverage. Data security and privacy concerns also arise due to the continuous collection and storage of sensitive agricultural data. Furthermore, the technical complexity of IoT systems requires users to possess certain technical skills and knowledge for effective operation and maintenance. Another challenge involves the integration of IoT technologies with existing farming systems and traditional agricultural practices, which may require additional infrastructure and adaptation efforts.

C. Augmented Reality (AR) in Agriculture

AR is emerging as a powerful tool for enhancing data interpretation in agriculture by overlaying digital information onto the physical environment. Recent research positions AR as an important interface that connects IoT, AI, and other smart farming technologies [8].

1) Usage of AR in agriculture: AR applications in agriculture provide interactive and immersive solutions that improve farm management, monitoring, and training processes. One important application is the real-time visualization of crop and soil data, where farmers can view information such as moisture levels, temperature, and crop conditions directly through AR interfaces. AR is also used in farm management systems through mobile devices or wearable technologies, enabling users to access agricultural data and control systems more efficiently in the field. In addition, AR supports agricultural training and simulation environments by creating realistic virtual experiences that help farmers and students learn farming techniques and equipment operations safely and effectively. Another application involves equipment maintenance guidance, where AR overlays provide step-by-step visual instructions for repairing and maintaining agricultural machinery. Furthermore, AR technology can be used for digital twin visualization of agricultural systems, allowing users to observe and interact with virtual representations of farms and farming processes in real-time.

AR allows users to interact with data directly in the field, improving situational awareness and decision-making.

2) Advantages of AR: AR offers several important benefits in agriculture by improving the way farmers interact with and interpret agricultural data. One major advantage is its ability to enhance understanding through visual and interactive data representation, allowing users to view farming information more clearly and intuitively. AR also improves efficiency in farm operations by providing real-time guidance and visual support during monitoring, maintenance, and management activities. In addition, AR facilitates training and knowledge transfer by creating immersive learning environments that help farmers and agricultural workers better understand farming techniques and equipment usage. Another important benefit is the reduction of cognitive load when interpreting complex datasets, as AR simplifies data visualization through interactive overlays and graphical representations. Furthermore, AR supports real-time decision-making by enabling farmers to access accurate information instantly, leading to faster and more effective agricultural management.

3) Disadvantages of AR: Despite its many advantages, the implementation of AR in agriculture also encounters several challenges. One of the primary limitations is the high development and deployment costs associated with AR applications and hardware, which may not be affordable for many farmers, especially small-scale agricultural operators. In addition, the limited availability of AR devices and supporting infrastructure in rural areas can restrict wider adoption. AR systems also face usability challenges in outdoor agricultural environments, where factors such as sunlight, weather conditions, and field terrain may affect visibility and system performance. Furthermore, AR applications heavily depend on device performance and battery life, which can limit continuous operation during farming activities. Another challenge is the need for user training and adaptation, as farmers and agricultural workers may require time and technical knowledge to effectively use AR technologies in daily agricultural practices.

D. Integration of IoT and AR in Agriculture

The integration of IoT and AR represents a major advancement in smart agriculture by combining real-time data collection with immersive visualization. IoT sensors continuously gather environmental data, while AR interfaces transform this data into interactive visual formats that enhance decision-making. Recent studies show that integrating IoT with AR and digital twin technologies improves monitoring, visualization, and farm management efficiency [1]. Furthermore, AR-based systems integrated with IoT sensors significantly enhance user interaction and support more effective agricultural decision-making [9].

These technologies support various advanced agricultural applications that improve farming efficiency and decision-making. One important application is precision farming with real-time visual analytics, where sensor data is combined with AR visualization to help farmers monitor and manage crops more accurately. This integration also supports smart irrigation monitoring and control by providing real-time information on water usage, soil moisture, and irrigation performance. In addition, IoT and AR technologies support crop health and disease visualization, allowing farmers to identify plant conditions and potential diseases more effectively through interactive visual displays. Another significant application is the development of digital twin farming environments, where virtual representations of farms are used for monitoring, simulation, and analysis. Furthermore, the integration of these technologies improves decision support systems by presenting real-time data and visual insights that support farmers in making faster and more informed agricultural decisions. By bridging the gap between data acquisition and interpretation, IoT-AR systems improve operational efficiency and enable proactive agricultural management.

E. Comparison with Traditional Farming

Traditional farming relies on manual observation and experience-based decisions, which often lead to inefficiencies and delayed responses to environmental changes [6]. The transition from traditional farming to IoT and AR-based agriculture highlights significant improvements in efficiency, accuracy, and sustainability. IoT and AR-based systems enable real-time monitoring, automation, and data-driven decision-making for users (see Table I).

TABLE I. COMPARISON WITH TRADITIONAL FARMING

Aspect	Traditional Farming	IoT & AR-Based Agriculture
Decision Making	Experience-based	Data-driven
Monitoring	Manual	Real-time
Resource Use	Inefficient	Optimized
Technology	Minimal	Advanced
Productivity	Moderate	High
Labor	High	Reduced
Data Interpretation	Limited	Visual & interactive

F. Research Gap

Although IoT and AR technologies have been widely studied individually, research focusing on their integration in agriculture remains limited. Most existing studies emphasize IoT-based monitoring systems or AR visualization independently, with fewer addressing their combined application. Recent studies emphasize the need for better integration of IoT, AR, and AI to develop scalable and intelligent farming systems [7]. Additionally, challenges such as system interoperability, cost, and user adoption continue to hinder widespread implementation.

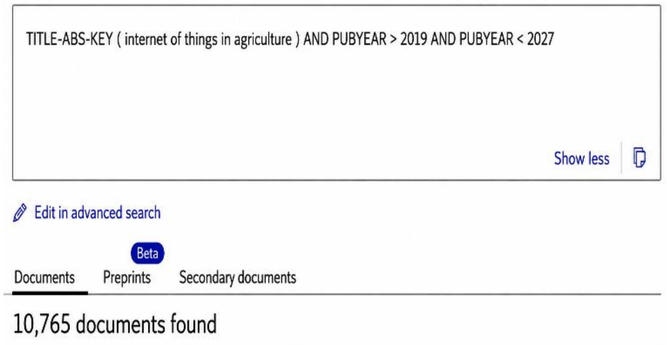
Additionally, several gaps remain in the implementation of IoT and AR technologies in agriculture. One of the major issues is the limited adoption among small-scale farmers, mainly due to financial and technical constraints. There is also a lack of cost-effective and scalable solutions that can be easily implemented across different farming environments and agricultural scales. Furthermore, the integration of these technologies with AI and predictive analytics is still insufficient, limiting the ability to perform advanced forecasting and intelligent decision-making. Usability and user experience challenges also continue to affect adoption, as some systems are complex and difficult for farmers to operate effectively without proper training and technical support. Here, it can be stated that IoT and AR technologies play a crucial role in converting agriculture into a more efficient and sustainable system.

Addressing these gaps is essential for advancing the practical implementation of IoT-AR systems in agriculture.

Despite the increasing interest in the application of IoT and AR in agriculture, the existing body of literature remains fragmented and lacks a comprehensive synthesis. Many studies focus on specific applications or technologies in isolation, resulting in a limited understanding of the overall research landscape. In such emerging and interdisciplinary domains, bibliometric analysis is particularly valuable, as it enables researchers to systematically analyze large volumes of scientific publications, identify research trends, and uncover knowledge gaps [10], [11]. Furthermore, bibliometric methods provide a structured approach to mapping the intellectual, conceptual, and social structure of a research field, which is often difficult to achieve through traditional literature reviews alone [10]. As highlighted in previous studies, bibliometric analysis is especially useful in areas where research is still developing or dispersed, as it offers a comprehensive overview and helps establish a foundation for future research directions [10], [12]. Therefore, given the limited and scattered literature on the integration of IoT and AR in agriculture, a bibliometric analysis is necessary to systematically evaluate existing research, identify emerging themes, and guide future studies.

III. METHODOLOGY

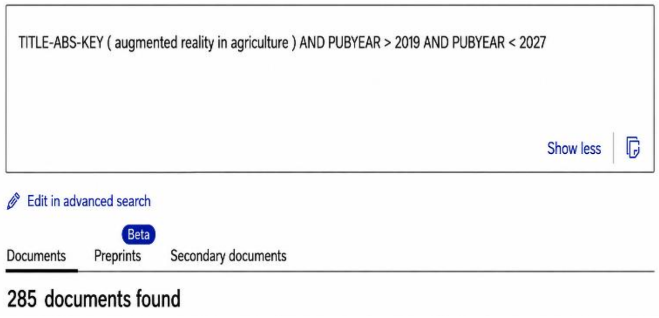
This section provides the systematic approach used to retrieve, filter, and analyze the bibliometric data related to IoT and AR in agriculture, limited to publications from 2020 to 2026. This analysis examined the publications collected from the Elsevier Scopus database based on documents categorized by conference papers, article papers, book chapters, and other related document types, as in Fig. 1.


TITLE-ABS-KEY (internet of things in agriculture) AND PUBYEAR > 2019 AND PUBYEAR < 2027

10,765 documents found

Fig. 1. Internet of Things (IoT) in agriculture.

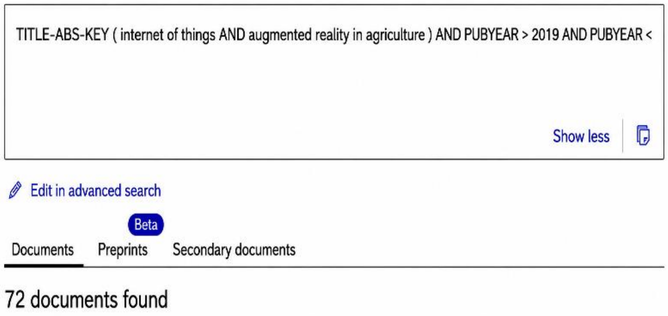
Based on the search done in Scopus using the keyword Internet of Things and Augmented Reality in agriculture, there are around 72 related documents being generated. These numbers are quite low as compared to only one technology search. A search for IoT in agriculture from 2020 to 2026 had resulted in 10615 documents generated, as shown in Fig. 1 and a search for AR in agriculture from 2020 to 2026 had produced 280 documents, as in Fig. 2. Here it can be seen that the integration of both technologies are still lacking in implementation and literatures, as in Fig. 3.



TITLE-ABS-KEY (augmented reality in agriculture) AND PUBYEAR > 2019 AND PUBYEAR < 2027

285 documents found

Fig. 2. Augmented Reality in agriculture.



TITLE-ABS-KEY (internet of things AND augmented reality in agriculture) AND PUBYEAR > 2019 AND PUBYEAR <

72 documents found

Fig. 3. Internet of Things and Augmented Reality in agriculture.

A detailed explanation of the search strategy is discussed in the following section. Fig. 4 below shows the distribution of all the 72 documents by year. The majority of the documents were published in 2024, with a total of 20 documents, followed by 2023 with 13 documents and in 2025 with 12 documents. Based on the graph, it can be seen that in 2026, the graph decreases with only 2 documents. This is due to the fact that during the search process, it is still in the third month (March) of 2026. There are still 9 months remaining, which will probably result in an increase in the number of documents later.

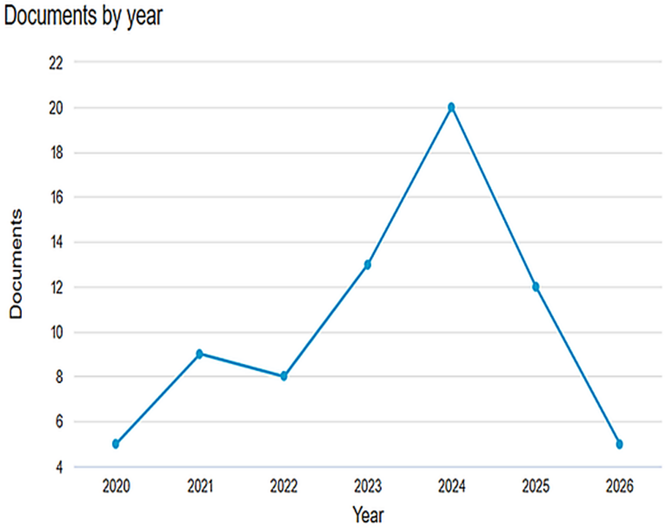


Fig. 4. Total number of documents by year.

A. Search Strategy

In order to retrieve relevant documents, a Boolean search string was developed that captured the intersection of data overload in real-time data processing. The query was applied to the title “Internet of Things and Augmented Reality in agriculture” with a filter of year from 2019 to 2026. Fig. 5 shows an illustration of a flowchart of the methodology used for conducting this bibliometric analysis using the Scopus database.

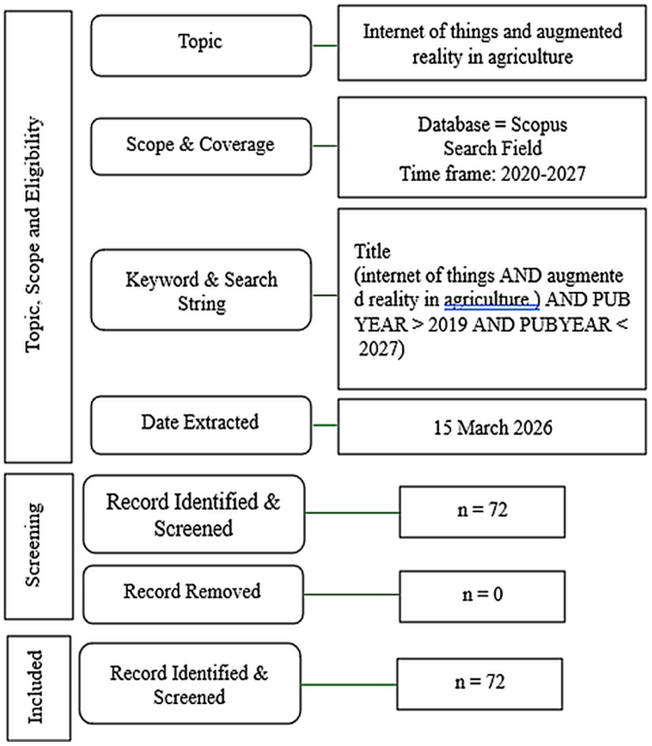


Fig. 5. Flow diagram of the strategy (Source: [13] as cited from [14]).

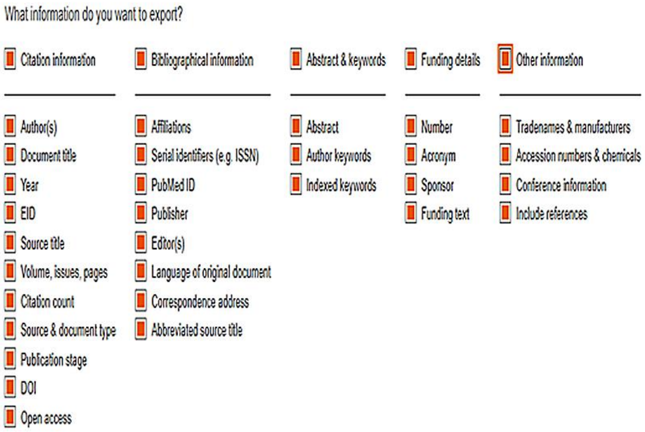
Fig. 5 consists of three main sections, which are: 1) Topic, Scope, and Eligibility, 2) Screening, and 3) Included. The first section outlines the foundational aspects of the research, where the topics used are stated, the scope and coverage of the study, the title of the search and also when the documents are extracted. It can be seen in the second section, Screening, where the total amount of documents was listed, which is 72 documents. In this search, there are no removed documents because the keywords are specifically filtered in the searching process on the Scopus database. The documents that have been searched are in detail already; therefore, there is no record removed and it indicates that all the records initially identified were considered relevant to the analysis. This analysis comprises three components listed below:

- The pattern in citations is examined to discover cited publications, influential authors, and related research groups.
- The themes and concepts on real-time data processing is analyzed based on co-occurring keywords.
- The emerging trends, areas and limitations of the area are discussed to offer a view of the research landscape and guidance.

This study offers insight into fundamental knowledge frameworks, research patterns, and trends of the technology used in visualizing real-time data.

B. Data Preparation Using VOSViewer

The Scopus-exported CSV file was converted to a format compatible with VOSviewer. The files were exported with metadata, as in Fig. 6:



What information do you want to export?

☑ Citation information
- ☑ Author(s)
- ☑ Document title
- ☑ Year
- ☑ EID
- ☑ Source title
- ☑ Volume, issues, pages
- ☑ Citation count
- ☑ Source & document type
- ☑ Publication stage
- ☑ DOI
- ☑ Open access

☑ Bibliographical information
- ☑ Affiliations
- ☑ Serial identifiers (e.g. ISSN)
- ☑ PubMed ID
- ☑ Publisher
- ☑ Editor(s)
- ☑ Language of original document
- ☑ Correspondence address
- ☑ Abbreviated source title

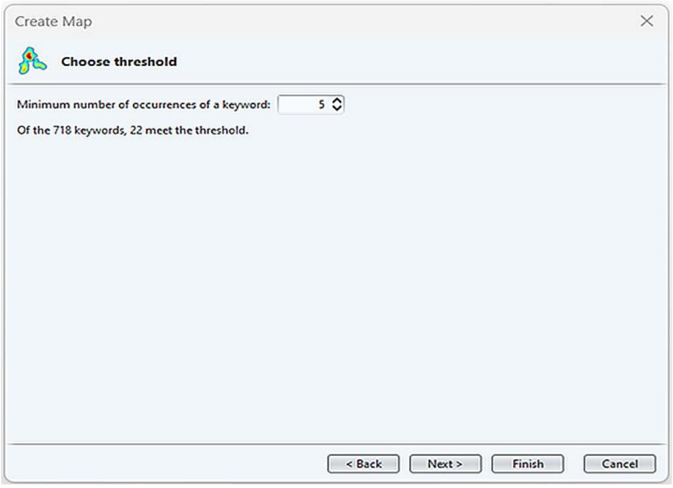
☑ Abstract & keywords
- ☑ Abstract
- ☑ Author keywords
- ☑ Indexed keywords

☑ Funding details
- ☑ Number
- ☑ Acronym
- ☑ Sponsor
- ☑ Funding text

☑ Other information
- ☑ Tradenames & manufacturers
- ☑ Accession numbers & chemicals
- ☑ Conference information
- ☑ Include references

Fig. 6. Metadata information exported from the Scopus database.

Fig. 6 shows various categories of metadata fields commonly used to represent a different type of bibliographic information that helps identify, classify, and analyze research outputs. These categories are important for researchers, especially when conducting literature reviews, citation analysis, or bibliometric studies. The following figures show the basic settings of threshold, number of keywords, and the selected keywords.



Create Map

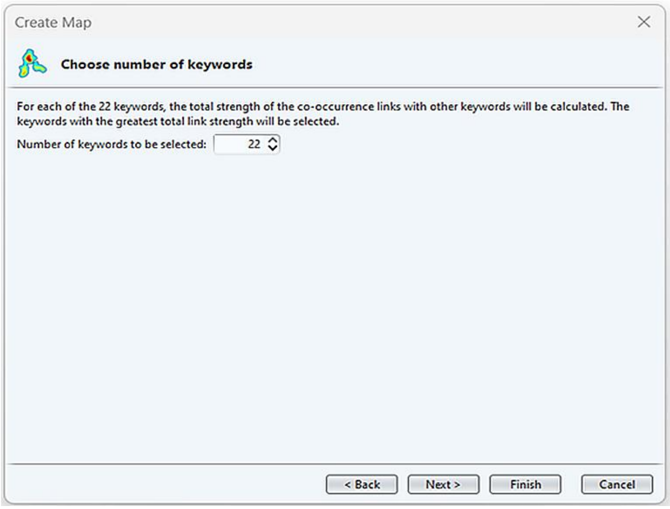
Choose threshold

Minimum number of occurrences of a keyword: 5

Of the 718 keywords, 22 meet the threshold.

Fig. 7. Default maximum number of occurrences.

Fig. 7 shows the selection of the minimum number of keyword occurrences. Here, the value is set to 5 and based on this value, from the total of 718 keywords, only 22 keywords met the threshold. Here, it can be seen that only keywords that appear at least 5 times are considered important enough to represent the research. This step is important because it removes low-frequency or irrelevant keywords and also ensure that the analysis provides significant and frequently studied topic field.



Create Map

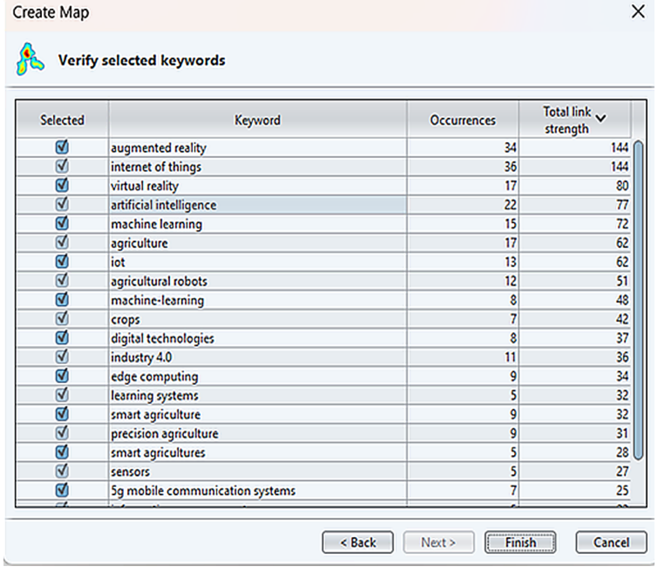
Choose number of keywords

For each of the 22 keywords, the total strength of the co-occurrence links with other keywords will be calculated. The keywords with the greatest total link strength will be selected.

Number of keywords to be selected: 22

Fig. 8. Default number of keywords.

In Fig. 8, the selection of the 22 keywords is based on the total link strength. This total link strength measures how strongly a keyword is connected to other keywords and also measures the frequency of co-occurrence relationships of the keywords. Therefore, keywords with stronger connections represent core concepts and relationships within the specified research domains.



Create Map

Verify selected keywords

Selected	Keyword	Occurrences	Total link strength
☑	augmented reality	34	144
☑	internet of things	36	144
☑	virtual reality	17	80
☑	artificial intelligence	22	77
☑	machine learning	15	72
☑	agriculture	17	62
☑	iot	13	62
☑	agricultural robots	12	51
☑	machine-learning	8	48
☑	crops	7	42
☑	digital technologies	8	37
☑	industry 4.0	11	36
☑	edge computing	9	34
☑	learning systems	5	32
☑	smart agriculture	9	32
☑	precision agriculture	9	31
☑	smart agricultures	5	28
☑	sensors	5	27
☑	5g mobile communication systems	7	25

Fig. 9. Selected keywords.

Fig. 9 shows all of the keywords that are selected based on the setting in Fig. 7 and Fig. 8. Internet of things, augmented reality, and virtual reality are the three tops keywords with the highest occurrences and total link strength. Occurrences are defined as how often each keyword appears and total link strength is defined as how strongly it connects with others.

By applying a minimum occurrence threshold of five, the dataset was refined from 718 to 22 significant keywords, improving the clarity and reliability of the visualization.

The selected keywords demonstrate strong interconnections, with “Internet of Things” and “Augmented Reality” emerging as the most influential terms based on both occurrence and total link strength. This indicates that these technologies form the core of the research domain. Additionally, the presence of keywords, such as artificial intelligence, machine learning, and edge computing, highlights the interdisciplinary nature and evolving trends in smart agriculture research.

To explore the intellectual structure and research evolution of IoT and AR applications in agriculture, VOSviewer was employed to generate three complementary visualization types: Network Visualization, Overlay Visualization, and Density Visualization. Each visualization provides a different perspective on the relationships and development of research topics within the selected literature, which is discussed in the following section.

IV. RESULTS

Keywords play an important role in bibliometric studies, as they reflect the main concepts, research interests, and thematic focus of a particular field. By examining the relationships among keywords, it is possible to identify the dominant research topics and understand how different concepts are connected within the literature. In this study, keyword co-occurrence analysis (Fig. 10) was conducted using VOSviewer to explore the research landscape of IoT and AR applications in agriculture. The resulting visualization provides insights into the major research themes, their interrelationships, and the emerging areas that have attracted increasing attention from researchers.

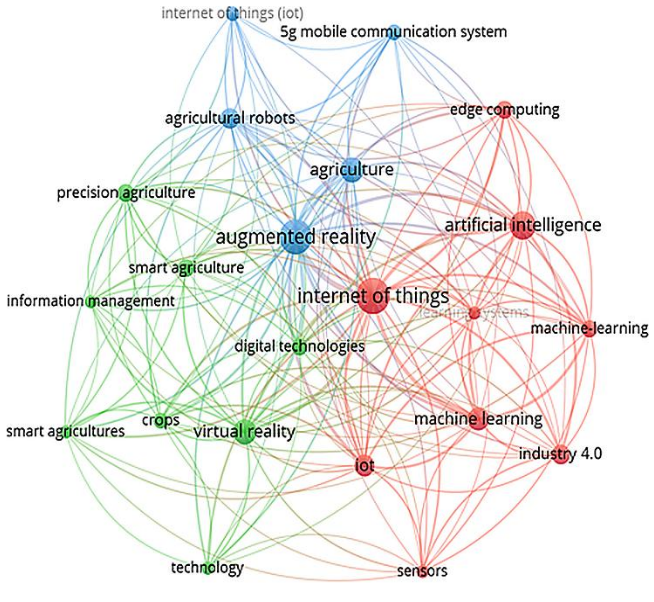


Fig. 10. Network visualization

The keyword co-occurrence network generated using VOSviewer reveals the conceptual structure of research on the integration of IoT and AR in agriculture. The analysis identifies several highly interconnected keywords, with “internet of things”, “augmented reality”, and “agriculture” emerging as the most prominent nodes, indicating their central role in the research domain.

The network is grouped into three primary clusters representing distinct but interconnected research themes. The first cluster focuses on smart agriculture and precision farming, incorporating keywords such as precision agriculture, smart agriculture, crops, and information management. This cluster highlights the application of IoT technologies in monitoring and optimizing agricultural processes.

The second cluster represents intelligent systems and data-driven technologies, including artificial intelligence, machine learning, sensors, and Industry 4.0. This cluster reflects the growing integration of advanced computational methods to enhance agricultural decision-making and automation.

The third cluster emphasizes technological infrastructure and communication systems, consisting of keywords such as 5G mobile communication systems, edge computing, and agricultural robots. This cluster illustrates the enabling technologies that support real-time data transmission and system interoperability. The strong interconnections among these clusters indicate that research in this field is highly interdisciplinary, combining sensing technologies, immersive visualization, artificial intelligence, and communication networks to support smart agriculture.

While the keyword co-occurrence network provides an overview of the major research themes and their relationships, it does not reveal how these themes have evolved over time. To address this limitation, an overlay visualization (Fig. 11) was generated using VOSviewer. This visualization builds upon the keyword network by incorporating temporal information, allowing researchers to identify both established and emerging research topics within the field.

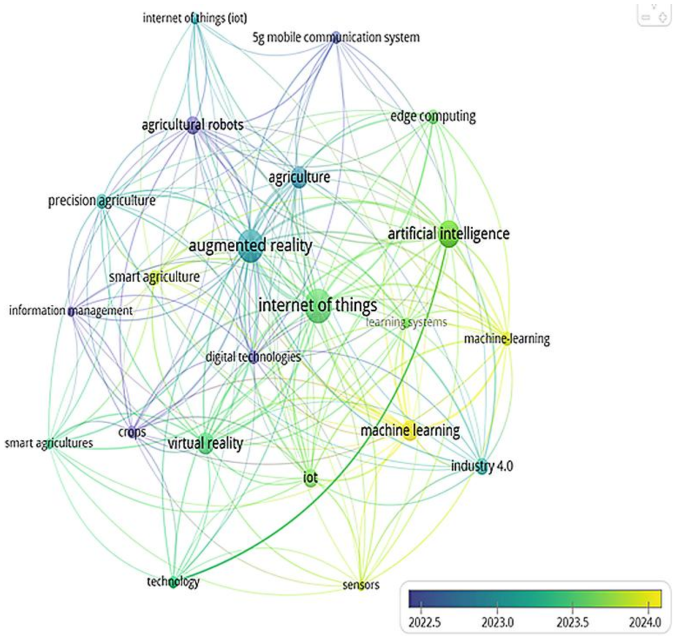


Fig. 11. Overlay visualization

The overlay visualization illustrates the temporal development of research topics in the field. Earlier studies (represented in blue tones) focused on foundational topics such as precision agriculture, information management, and agricultural robots, reflecting the initial phase of digital transformation in agriculture.

Subsequent research (green tones) shows a shift toward augmented reality, smart agriculture, and digital technologies, highlighting the increasing importance of interactive visualization and user-centered systems.

More recent studies (yellow tones) emphasize artificial intelligence, machine learning, and Industry 4.0, indicating a transition toward intelligent, autonomous, and data-driven agricultural systems. This temporal progression suggests that the field has evolved from basic monitoring and automation to more advanced systems that integrate AI with IoT and AR for predictive and real-time decision-making.

Following the overlay visualization analysis, a density visualization (Fig. 12) was generated to further examine the level of research attention received by different topics within the field. While the overlay visualization highlights the temporal evolution of research themes, it does not indicate the relative concentration or prominence of individual topics. Therefore, density visualization is included as a complementary analysis to identify the most intensively studied areas and reveal the overall research hotspots within the literature.

Fig. 12. Density visualization

The density visualization provides insight into the intensity of research focus within the field. Areas highlighted in bright yellow indicate highly researched topics, while green and blue areas represent moderate and emerging topics, respectively. The analysis shows that “internet of things”, “augmented reality”, “agriculture”, and “artificial intelligence” are the most intensively studied topics. These keywords form the core foundation of current research and indicate strong academic interest in integrating sensing technologies with immersive visualization.

Moderate-density areas include machine learning, smart agriculture, and digital technologies, suggesting that these topics are gaining traction but are still developing. In contrast, keywords such as edge computing, Industry 4.0, virtual reality, and sensors appear in lower-density regions, indicating that these areas are relatively underexplored and present opportunities for future research.

V. DISCUSSION

The findings of this bibliometric analysis demonstrate that the integration of IoT and AR in agriculture is rapidly evolving into a multidisciplinary research area. The dominance of core technologies such as IoT and AR reflects their critical role in enabling real-time data acquisition and immersive visualization.

The patterns identified in this study share several similarities with findings reported in earlier bibliometric research on smart farming, precision agriculture, and digital agriculture. Across these studies, IoT consistently appears as one of the core technologies driving agricultural digitalization. The keyword network generated in the present study reinforces this observation, with IoT emerging as one of the most influential and highly connected keywords. This suggests that IoT continues to serve as the technological foundation for collecting, transmitting, and managing agricultural data in modern farming environments.

Another notable observation is the growing presence of Artificial Intelligence (AI), Machine Learning (ML), and Industry 4.0-related concepts. Previous bibliometric studies have highlighted a gradual movement away from basic monitoring systems towards more intelligent and predictive agricultural solutions. A similar trend can be observed in the overlay visualization of this study, where AI and ML-related keywords appear among the more recent topics. This development indicates that researchers are increasingly interested in extracting meaningful insights from agricultural data rather than focusing solely on data collection.

While many studies in precision agriculture emphasize technologies such as IoT, remote sensing, drones, and artificial intelligence, the findings of this study reveal a growing interest in Augmented Reality (AR). The appearance of AR as a prominent keyword within the network suggests that researchers are beginning to explore new ways of presenting and interacting with agricultural information. As farming systems become increasingly data intensive, AR offers the potential to improve how users interpret and respond to real-time information by providing a more intuitive and interactive visualization environment.

The density visualization further supports this observation. Keywords related to IoT, AR, AI, and machine learning were concentrated within the most active areas of the map, indicating that these topics currently attract significant research attention. This finding is consistent with broader discussions in the digital agriculture literature, where the integration of sensing technologies, intelligent analytics, and advanced visualization tools is often described as an important step towards more efficient and sustainable farming practices.

Although previous bibliometric studies have provided valuable insights into smart agriculture as a whole, relatively few have specifically examined the relationship between IoT and AR in agricultural applications. In this regard, the present study contributes a more focused perspective by highlighting how immersive technologies are increasingly being combined with IoT-based systems. The findings suggest that AR is evolving beyond a supporting visualization tool and is becoming an important component of next-generation agricultural solutions. This creates opportunities for future research on real-time visualization, decision support, and user interaction within smart farming environments.

Furthermore, the presence of enabling technologies such as 5G and edge computing highlights the importance of communication infrastructure in supporting real-time agricultural applications. Despite these advancements, several areas remain underexplored, particularly the integration of virtual reality, advanced sensor networks, and scalable solutions for smallholder farmers. Addressing these gaps will be essential for the widespread adoption of smart agriculture technologies.

VI. RESEARCH CHALLENGES AND FUTURE DIRECTIONS

The growing number of publications identified in this study reflects the increasing interest in applying IoT and AR technologies within the agricultural sector. However, despite the promising developments reported in the literature, several challenges continue to limit the widespread adoption of these technologies in real farming environments.

One of the most frequently cited concerns is the cost of implementation. Although IoT sensors, cloud-based platforms, and AR applications can provide valuable insights for farm management, the initial investment required for hardware, software, and system maintenance may be beyond the reach of many small-scale farmers. As a result, the adoption of advanced digital farming technologies is often more feasible for larger agricultural enterprises with greater financial resources.

In addition to financial considerations, the successful use of IoT and AR technologies depends on users' ability to interact with digital systems and interpret the information provided. Farmers may face difficulties when dealing with unfamiliar technologies, particularly when systems are complex or require specialized technical knowledge. This highlights the importance of designing user-friendly solutions that simplify data interpretation and support practical decision-making in agricultural activities.

Infrastructure availability also plays a significant role in technology adoption. Many IoT-based applications rely on stable internet connectivity, reliable power sources, and access to cloud services. In rural and remote farming areas, these requirements may not always be fully available, creating barriers to implementation. Although emerging technologies such as edge computing and next-generation communication networks offer potential solutions, their accessibility remains uneven across different regions.

Beyond technical and economic factors, policy support is another important consideration. Government initiatives, funding schemes, and digital agriculture programs can help reduce adoption barriers by providing financial assistance, training opportunities, and infrastructure development. Without adequate policy support, the benefits of IoT and AR technologies may remain limited to a relatively small group of technology-ready users.

The findings of this study suggest that future research should extend beyond technological innovation alone. Greater attention should be given to understanding how economic constraints, user readiness, infrastructure availability, and policy support influence the adoption of smart agriculture technologies. Addressing these factors will be essential to ensure that the benefits of IoT and AR can be accessed by a wider range of agricultural stakeholders and contribute meaningfully to sustainable agricultural development.

VII. CONCLUSION

This study presents a comprehensive bibliometric analysis of research on the integration of Internet of Things (IoT) and Augmented Reality (AR) in agriculture based on Scopus-indexed publications from 2020 to 2026. The findings indicate a growing research interest in this interdisciplinary domain, with a notable increase in publications, particularly in recent years. This trend reflects the increasing importance of digital technologies in transforming traditional agricultural practices into more efficient and sustainable systems.

The VOSviewer analysis provides deeper insights into the intellectual structure and evolution of the research field. The keyword co-occurrence network reveals that Internet of Things, Augmented Reality, and agriculture serve as the central themes, supported by closely related concepts such as precision agriculture, artificial intelligence, and smart farming systems.

The clustering structure highlights the interdisciplinary nature of the field, integrating sensing technologies, data analytics, communication systems, and immersive visualization. The density visualization further confirms that IoT and AR are the dominant research hotspots, while emerging topics such as edge computing, virtual reality, and Industry 4.0 remain less explored. This suggests that while the core technologies are well established, there are still significant opportunities for expanding research into advanced and integrated systems.

In addition, the overlay visualization demonstrates a clear temporal evolution of the field. Early research primarily focused on data collection and monitoring through IoT, followed by the incorporation of AR for visualization and interaction. More recent studies emphasize the integration of artificial intelligence and machine learning, indicating a shift toward intelligent, predictive, and autonomous agricultural systems. This progression reflects the movement from basic digital agriculture toward fully integrated smart farming ecosystems.

The findings from the literature review further support this evolution, highlighting the complementary roles of IoT and AR in enabling real-time data acquisition and intuitive data visualization. While IoT enhances monitoring and automation, AR improves data interpretation and user interaction, thereby bridging the gap between complex data and practical decision-making. However, challenges such as high implementation costs, infrastructure limitations, and usability issues continue to hinder widespread adoption.

Overall, this study confirms that the integration of IoT and AR has significant potential to revolutionize agriculture by improving productivity, efficiency, and sustainability. Nevertheless, the bibliometric analysis also reveals that the research landscape remains fragmented, with limited studies focusing on the combined application of these technologies. This highlights the need for more comprehensive and integrated research efforts.

Future studies should focus on the development of scalable and cost-effective solutions, particularly for smallholder farmers, as well as the integration of emerging technologies such as artificial intelligence, digital twins, and advanced communication systems. In addition, further research is needed to improve system usability, enhance interoperability, and address practical implementation challenges.

In conclusion, this study provides a structured and comprehensive overview of the research landscape on IoT and AR in agriculture. It contributes to the existing body of knowledge by identifying key trends, themes, and research gaps, and offers valuable insights to guide future research toward the development of intelligent and sustainable agricultural systems.

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