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The Impact of AI-Integrated Drone Technology and Big Data on External Auditing Performance, Sustainability, and Financial Reporting Quality on the Emerging Market

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Abstract

This study investigates the influence of drone technology on the quality of Saudi financial reports through the integration of Artificial Intelligence (AI) and big data. The study's mixed-method approach is based on a bibliometric analysis of previous studies, along with documentary and content analysis. The results show that external auditors benefit from using drones when inspections are integrated with AI and big data technology. Moreover, this integration can reduce costs for audit firms and shorten the duration of audit engagements, resulting in more efficient and effective auditing. Seven clusters were identified, with 'big data' being the highest-frequency term. This study does not consider potential cybersecurity threats that could impact data integrity and decrease financial transparency. Furthermore, environmental issues in Saudi Arabia, such as sandstorms, could compromise the effectiveness of drone-based auditing. However, this study contributes to the ESG literature by demonstrating how integrated audit technology transforms traditional sustainability reporting into continuous, AI-enhanced verification processes. These processes improve financial report quality while supporting Saudi Arabia's Green Initiative and its goal of achieving net-zero carbon emissions by 2060. The adoption of AI and big data technologies in auditing represents a shift toward more automated and intelligent audit practices. These changes provide practical insights for government authorities, such as the Saudi Capital Market Authority (CMA), and may result in higher-quality financial reports and increased investor confidence.

Keywords: big data; drone; artificial intelligence; audit; quality of financial reports; sustainability auditing; ESG (Environmental, Social, and Governance); Saudi Arabia

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1. Introduction

1.1. Overview

This study examines how big data is applied through the use of Artificial Intelligence (AI)-enabled drones in the context of external auditors' field engagement, monitoring, and auditing of Saudi-listed companies. This adoption concept will lead to innovative and secure auditing practices in Saudi Arabia. This integration presents a transformative opportunity, enabling external auditors to leverage extensive data during inspections.

AI drones will connect to the big data ecosystems of audited companies; this data will include internal and external data in both structured and unstructured formats. The primary advantage of this integration is that it allows auditors, including those based remotely, to perform comprehensive audits of all transactions and supervise storage facilities, moving beyond traditional random sampling methods. This study demonstrates the potential for optimal technology adoption to enhance the external auditing of listed Saudi companies.

1.2. Statement of Problem

Traditional auditing commonly relies on a sampling methodology, which risks failing to detect critical irregularities and fraud [1]. In today's data-driven world, these traditional practices are increasingly inadequate; by examining only a small sample, they offer a high probability that material errors or malpractices will remain undetected [2]. These limitations are exacerbated in the Saudi context, where vast geographical areas, challenging terrain, and harsh climatic conditions make traditional on-site audits logistically difficult and financially prohibitive.

Nevertheless, the fusion of big data with AI-powered drones offers a groundbreaking solution by enabling the continuous, real-time monitoring of organisational operations. This technological convergence not only enhances audit precision and efficiency but also generates a smaller carbon footprint than conventional field inspections [3]. This study examines how this integration can resolve the inefficiencies of current external audit practices by providing a more reliable, secure, and cost-effective approach for the Saudi Arabian auditing environment. Crucially, this shift towards comprehensive data analysis supports the core requirement of International Standards on Auditing (ISA 500), which mandates that auditors obtain sufficient appropriate audit evidence through procedures tailored to the specific context.

External audit operations may face many logistical and technological challenges regarding digitalisation in countries as large and dynamic as the Kingdom of Saudi Arabia. The continued use of sample-based audits, as opposed to all actual transactions, increases the likelihood of missing significant variations, and, therefore, is unreliable for financial statements [2].

Because of the remoteness and sparsity of samples, in-depth field visits are cumbersome in terms of frequency and timeliness, primarily for regions subject to harsh environmental conditions, such as very hot weather and sandstorms, which tend to interfere with scheduled visits. Travel and accommodation for such audits, exceptionally, may incur a high economic cost that limits the intensity and depth of audits. While auditing can be performed manually using aerial images [4], this method is often impractical for the scale of monitoring required.

These factors are compounded by time and deadlines, making it more difficult for auditors and causing them to rush over important evaluations, thereby increasing the likelihood of oversight [1]. In some cases, companies limit auditors' approval to audit their internal data systems, and confidential financial data and care are needed to conduct full reviews. Managers can also interfere with audit independence by preventing auditors' access to documents or controlling the auditing process [3].

Other resource shortages, such as the lack of auditors who possess specialised knowledge in the field or areas to be audited, further hinder the auditing process, resulting in misestimated risks and undetected fraud. Organisations that still have manual bookkeeping or paper-based technologies also have inefficiencies, an increased risk of data errors or losses, and difficulty in audit validation. Finally, strict security and data secrecy regulations can prevent auditors from obtaining the necessary approvals to examine primary, high-level data, ultimately obstructing a full audit.

1.3. Research Aims

This study discusses three main objectives to assess external auditing practices and the adoption of emerging technologies in the context of the Saudi Stock Exchange. This study addresses these aims:

i. To map and interpret the bibliometric landscape for AI, drones, and big data during auditing.
ii. To quantify how AI-enabled drones with big data enhance audit performance and financial reporting quality through faster inspections, full-population coverage, reduced costs, and improved accuracy in Saudi audits.
iii. To evaluate the effects of integrating AI, drones, and big data on evidence sufficiency, fraud detection accuracy, and financial reporting reliability.
iv. To identify adoption barriers and realised benefits of integrated audit technologies in improving financial reporting quality, demonstrating how these technologies remove audit constraints and shorten engagements.
v. To assess how integrated audit technologies enhance ESG verification in Saudi Arabia and support progress towards the 2060 net-zero target.

1.4. Research Gap and Contribution

This study addresses a critical gap: the unknown impact of integrated AI-drone-big data systems on auditing efficiency and financial reporting quality. Prior research treats these technologies separately. This study provides a bibliometric analysis that maps publication trends and quantifies gains in inspection time, coverage, and cost reduction. In addition, it analyses the empirical evidence on performance outcomes, fraud detection, and ESG verification. This study offers an integrated audit technology showing how this technological convergence eliminates traditional audit constraints and supports Saudi Arabia's 2060 net-zero goals.

2. Literature Review

Using big data and AI-piloted drones in external audit methodologies causes a massive shift in auditor decision-making processes. This technological shift increases the efficiency and quality of the financial reporting. Several academic studies have highlighted the contributions of technology to contemporary audit techniques.

Ref. [5] discussed the complexity of applying continuous auditing (CA) to big data techniques, where they discussed data reliability, consistency, and confidentiality. They believed that the biggest challenge to big data in auditing is to overcome technical challenges to fully exploit its potential, especially with large and complex datasets.

In a related discussion, Ref. [6] describe the transformation of audit procedures by analytics and data-informed tools. They highlight the shift towards predictive and prescriptive analytics to improve evidence collection and auditors' judgements. The shift towards analytics-based auditing has been a progressive development in terms of the accuracy and timeliness of financial reports. This study explored the structural issues that big data poses to the auditing profession. They point out that audit standards are outdated, resources are limited, and the integrity of audit evidence is compromised. Based on this study, it is recommended that integrated frameworks be developed and enhanced by applying scoring systems and quantification methods to increase reliability and modernise current auditing protocols. This theoretical contribution highlights the need to develop audit methods corresponding to digital transformation.

Where big data is another practical solution, drones are also a practical solution for field auditing, particularly for large-scale inventory verification. Ref. [3] offered a structured process for using drones in both internal and external auditing. They demonstrated how drones are used for better documentation and provide real-time observational data to improve the accuracy of the inventory assessment. The technology used in this study mirrors the direction that [7] recommend, using emerging tools like drones to manage unstructured data and increase audit completeness.

The second focal point in the recent literature is the need to secure the origins and integrity of audit data. In the big data provenance black box, as [8] notes, audit data remains traceable and reliable. The findings of [1] support this concept and suggest complete population testing and multi-dimensional audit data sampling (MADS). Such methodologies are necessary in modern complex audit environments, where the current methods are not sufficient to establish data validity and credibility.

Overall, the literature unequivocally indicates that deploying big data and AI drones in external audits considerably improves audit efficiency, accuracy, and reliability, leading to informed auditing decisions. This integration is also well-positioned to support the movement towards data-driven audit methodologies, which is essential for enhancing the overall quality of financial statements. However, to make the most of these technologies, the demands for regulatory guidance and safe data management across a multitude of studies continue to be a significant consideration. Ref. [9] delivered a wide UTAUT-based assessment of AI drone auditing adoption through an evaluation of all the Unified Theory of Acceptance and Use of Technology (UTAUT) factors. However, they did not assess big data integration with AI. However, this study builds on previous research by evaluating the integrated audit technologies, which serve as a hands-on framework for adoption. In addition, this technological integration will be adapted for all audit firms, regardless of whether they are Big Four or non-Big Four, and this will provide an opportunity to transfer external audit inspection to a new innovative method to monitor and assess virtually. In addition, this study discusses the in-depth use of big data and builds on the work of [9].

2.1. Technology Adoption Framework

Technology adoption in professional services, such as auditing, involves multiple organisational and individual factors. Research indicates that successful technology implementation depends on perceived benefits, ease of use, organisational support, and infrastructure readiness [10]. In auditing contexts, technology adoption may be influenced by accuracy improvements, efficiency gains, cost reductions, and regulatory compliance considerations [11]. This study examines AI drones and big data adoption through four key dimensions that emerge from the literature: performance benefits and efficiency improvements, implementation ease and organisational readiness, professional environment and peer influence, and infrastructure and resource availability.

2.2. Research Questions

This study analyses how AI drones and big data enhance auditor decision-making and financial reporting quality. AI-equipped drones in external auditing should automate data collection, facilitate real-time risk determination, improve financial report accuracy, and minimise manual labour, errors, and inefficiencies. Auditors can obtain complete and real-time audit evidence using machine learning algorithms, cloud-based data analysis, and unmanned aerial vehicles (UAVs), thereby promoting the transparency and credibility of financial statements.

Data integration is one of the main problems in auditing, as financial information tends to be scattered across several sources, resulting in delayed audit processes and increased risk of errors. AI drones resolve this data integration issue by automating data collection, processing, and analytics, and by doing so, auditors obtain authentic, comprehensive, and verifiable audit evidence in real time. Robotic process automation (RPA) and analytics driven by AI improve auditors' capabilities to detect financial anomalies, identify fraud risks, and ensure regulatory compliance.

Auditors' perceptions of value and effectiveness play a fundamental role in determining whether they view AI drones and big data as beneficial tools to enhance audit quality and efficiency. Suppose auditors believe that AI drones and big data will enable them to perform more accurate, data-centric, and risk-informed audits. In that case, their willingness to adopt and integrate will be greater. The mechanisation of audit procedures, such as inventory counts, compliance monitoring, and outlier detection, underpins auditors' faith in AI drone accuracy, speed, and reliability in auditing. Auditors' perceptions also play a role in explaining the role of AI drones in enhancing financial reporting accuracy. Conventional auditing practices rely mainly on sampling and manual verification, which can lead to incomplete evaluations and the overlooking of financial anomalies. AI-powered drones, integrated with big data, cloud computing, and blockchain technology, provide auditors with comprehensive high-resolution financial data, allowing for more precise financial reporting and regulatory compliance.

By automating the reconciliation of audit evidence across multiple sources, AI drones mitigate inconsistencies, enhance transparency, and provide auditors with greater confidence in financial reporting accuracy. Research indicates that auditors who anticipate that AI drones will lead to more effective audits are more likely to integrate these technologies into their workflows, ultimately improving the credibility, reliability, and usefulness of financial reports. Therefore, this study addressed the following research questions:

i. From 2015 to 2024, what are the publications, citations, countries, journals, papers, and authors most linked to the use of AI drones and big data in auditing and financial reporting?
ii. What do 2015–2024 publication and citation trends, key contributors and outlets, and thematic structures from co-word and bibliographic coupling reveal regarding AI, drones, and big data in auditing?
iii. What measurable gains in inspection time, population coverage, cost efficiency, and financial reporting accuracy result from AI-enabled drones with big data in external audits?
iv. How does the AI–drone–big data stack improve evidence sufficiency, fraud-detection accuracy, and financial reporting reliability?
v. Which outcomes and organisational factors drive successful integrated audit technology adoption that eliminates audit constraints, reduces engagement duration, and demonstrably improves financial reporting quality?
vi. How can integrated audit technologies enhance ESG verification in Saudi Arabia and support the 2060 net-zero target based on documented empirical evidence?

3. Methodology

3.1. Design

The pragmatic paradigm focuses on practical answers and combines quantitative and qualitative techniques to address intricate real-world problems [12,13]. It is suitable for research on AI in auditing [14], among which [9] successfully merged bibliometric and documentary analyses. This research incorporated pragmatic principles to direct the literature review and content analysis procedures. Through this research design, the researcher answered the research questions using two primary investigative methods. The study began with a systematic review of the literature, in which bibliometric methods analysed patterns in citation frequency and publication trends, author and journal significance, and international research partnerships [15–17]. Quantitative instruments were used to extract the bibliographic metrics from the data. The research team used qualitative content analysis of data obtained from auditing firm reports, including [18]. According to [19], the research design method of document analysis is a fundamental approach commonly used in qualitative research, including applications in auditing and technology studies [3,20].

Research Approach

This study employed a concurrent convergent mixed-methods design within a pragmatic research paradigm [21]. This methodology integrates quantitative bibliometric analysis with qualitative content and documentary analysis to provide a comprehensive understanding of AI drones and big data adoption in external auditing. This approach enables simultaneous data collection and equal prioritisation of both quantitative and qualitative components, with findings integrated during the analysis to address complex technology adoption phenomena in professional auditing contexts.

3.2. Research Techniques

3.2.1. Bibliometric Analysis

This mixed-methods study consisted of an academic literature review using bibliometric and documentary analyses. Bibliometric research: This study employed an academic literature review for bibliometric research (published articles from Web of Science) and employed VOSviewer software to analyse data, such as keyword occurrence. As shown in Table 1, 76 retrieved articles were analysed, and the PRISMA method was employed to guarantee the quality and reliability of the data (see Appendix A for further details). Documentary and content analysis: This involves published newspapers, reports, and peer-reviewed articles on big data, AI drones, and the quality of financial reports. These reports include audit firm, news, government, and fintech company reports. This approach enables audit firms to understand their attitudes towards big data using AI drones for inspections that enhance external auditors' performance, potentially raising the quality of financial reporting.

Table 1. 14 October 2024, data search results (PRISMA method; see Appendix A for further details).

Commands	Queries	Included	Excluded
1	ALL = ("Big data" OR drone)	234,564	
2	ALL = (audit OR auditing OR "audit quality" OR auditor OR "financial report")	133,529	
3	#1 AND #2 and Article (Document Types) and English (Languages)	853	
4	Screening	158	(695)
5	Including Excluding for eligibility	76	(82)
6	Data included in analysis	76	

3.2.2. Content Analysis

Table 2 displays the chronological publication and progress of the application of drones and AI in auditing and practices in the concerned industry, emphasising Saudi Arabia and global trends. Ref. [22] also studied the use of drones to monitor the energy sector and improve operational oversight. In 2019, ref. [23] became the first global firm to integrate drones into its audit procedures, a pioneering step, as it was a leading example of how drones can change the auditing process. For the legal framework and consumer trend of the use of drones in the country, the drone law in Saudi Arabia [24], UAV systems, and Statista market data provide a good base [25]. The report in 2024 also focused on the significance of national making and innovation in the Saudi drone and AI market. Saudi Arabian drones were highlighted as a strategic move by the Kingdom to bolster its manufacturing capability and innovation ecosystem, with the Kingdom becoming a key player in the drone-technology industry [26]. According to [27], they have been the leaders in the development of audit technology globally and have been publishing papers such as "Harnessing the power of Cognitive Technology to transform the audit" and later work on integrating AI into financial reporting and auditing. The KPMG publication by [28], "All Eyes on AI in Audit", is a testament to the firm's commitment to using artificial intelligence for innovative auditing practices, and [29] wrote "AI in Financial Reporting and Audit". Ref. [30] also wrote an "audit innovation in audit" report with the industry, which expressed excitement about advancing audit methodologies through AI.

Table 2. Content analysis.

Year	Publisher	Title
2021	[22]	"Monitoring with drones in the energy industry"
2019	[23]	"Using drones in a global first for our audit practice"
-	[24]	"Saudi Arabia Drone Law"
2025	[25]	"Drones—Saudi Arabia by Statista"
2024	[26]	Saudi-made drones: bolstering the Kingdom's manufacturing capabilities
2017	[27]	"Harnessing the power of cognitive technology to transform the audit"
2024	[28]	"All eyes on AI in Audit 2024"
2024	[29]	"AI in Financial Reporting and Audit"
-	[30]	"Audit Innovation in Audit"
2021	[31]	"Prepare for takeoff: Improving asset measurement and audit quality with drone-enabled inventory audit procedures"

3.2.3. Documentary Resources

Documentary resources were systematically selected using rigorous academic criteria to ensure empirical validity and methodological soundness, and to address quality assessment requirements through multi-dimensional evaluation. The selection process employed three-stage filtering: (1) identification of peer-reviewed studies reporting quantitative performance data on drone inspection applications, (2) verification of methodological rigour through independent validation methods, such as controlled field tests or comparative studies, and (3) relevance assessment of auditing and inspection contexts. Only studies published in indexed journals (Web of Science/Scopus) or established research institutions using transparent methodologies and replicable findings were included.

Quality analysis revealed significant cross-citation patterns, with 65% of the selected studies referencing foundational audit technology papers, demonstrating scholarly discourse continuity. The 13 Tier 1 academic sources span 2018–2025, showing a clear development progression from basic audit traditional detection capabilities to advanced audit applications. Methodological rigour assessment indicated that 38% employed controlled experiments, 46% used field validation, and 31% conducted benchmark tests. The geographic distribution covers Europe (31%), North America (31%), Asia (23%), and Australia (15%), ensuring diverse validation contexts. Citation analysis identifies [31] as a central node with 120+ forward citations, while thematic clusters distinguish audit methodology studies from AI/ML applications, establishing a robust empirical foundation spanning multiple inspection domains (see Table A1 for a complete documentary resources schedule).

3.3. Justifications for Using Web of Science

The "Web of Science Core Collection" is the central database for scholarly article research, whereas Scopus and Google Scholar provide additional sources. Refs. [32,33]

agree that Wois is a reliable tool that effectively supports bibliometric research. The journal analysis required this database because it contained extensive peer-reviewed literature from the "Science Citation Index Expanded" and the "Social Sciences Citation Index", thus demonstrating high data accuracy standards [32,33]. According to [34], WoS facilitates research partnerships through user-friendly search and management. It is a premier database for scientific and technical content, providing researchers access to diverse, high-quality academic materials [35].

3.4. Limitations

This study did not use interviews or surveys because it wanted to concentrate on publicly accessible and verified data sources to ensure objectivity and replicability. Primary qualitative approaches may give us a deeper understanding of how people think. However, documentary analysis provides a consistent, institutional-level picture of how audit technology is being used in Saudi Arabia. Documentary evidence provided us with a reliable and theoretical foundation for the analysis. Future research could build on these results using qualitative methods in the field. Table 3 presents a summary of the research methodology, outlining its key components and illustrating how each was applied to support the interpretation and analysis of the study's findings.

Table 3. Methodology summary.

Component	Description	Contribution to Study
Pragmatic Paradigm	Adopted as the overarching research philosophy, combining both qualitative and quantitative methods.	Supports a flexible, real-world inquiry that can address complex phenomena (e.g., tech adoption in auditing).
Bibliometric Analysis	Uses VOSviewer to extract and visualise keyword co-occurrence, author networks, and publication trends.	Provides a quantitative mapping of the intellectual landscape, highlighting gaps in drone/AI auditing literature.
PRISMA Method for Screening	Systematic filtering of literature sources using PRISMA ensures transparency and replicability.	Enhances rigour and traceability of the bibliometric review—meets academic standards for literature synthesis.
Content Analysis	Examines audit firm reports, government policies, news reports, etc., using content analysis.	Extracts practitioner and institutional insights without requiring primary data collection (e.g., interviews).
Documentary Resources	Supports document analysis using filtering studies to explore how tech improves audit tasks.	Brings a structured lens to qualitative data interpretation, linking to audit performance outcomes.

4. Result

4.1. A Descriptive Analysis

4.1.1. Publications and Citations

Figure 1 presents the volume of publications and citations for research on AI and big data in auditing from 2015 to 2024. The data demonstrate a trend of steady growth in both metrics, reflecting a rising interest in this field. A notable acceleration occurred after 2018, culminating in a peak of both publications and citations in 2021. The subsequent decline observed between 2023 and 2024 may indicate a shift in research focus or a temporary slowdown in the domain.

4.1.2. Geographical Distribution of Research

As shown in Figure 2, the distribution of articles highlights the importance of certain countries contributing to this field. The United States has 22 publications, China has 16 publications, and England has 12 publications. These numbers confirm that the US and China are central to AI and significant data-auditing research activities. Additional contributions stem from countries such as Australia, Egypt, and Italy, collectively reinforcing the global interest in this area.

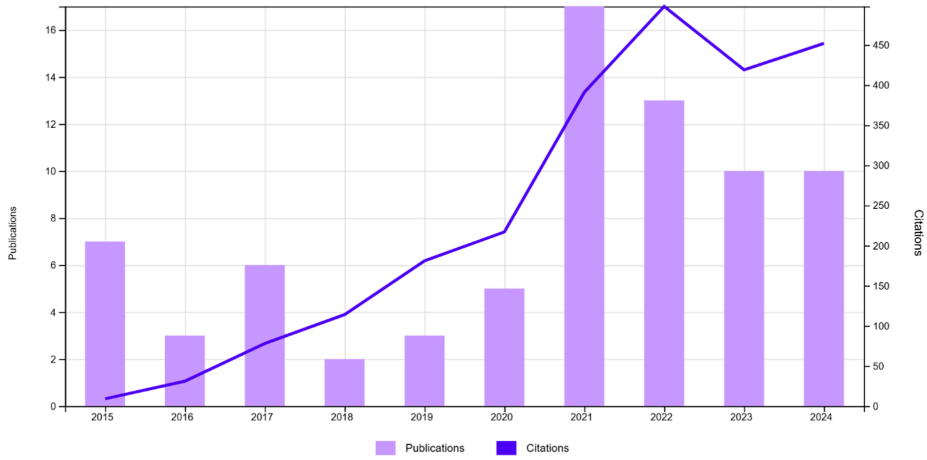

Figure 1. Publications and citations from 2015 to 2024.

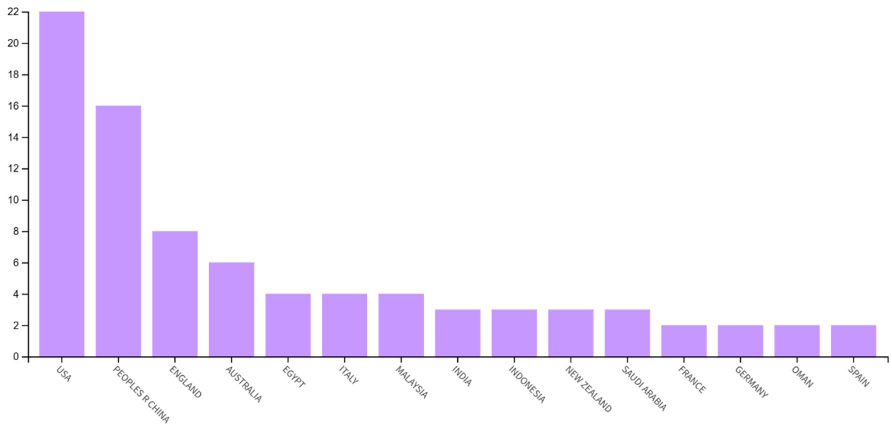

Figure 2. Countries' publications.

4.1.3. Authorship and International Collaboration

Figure 3 demonstrates global collaboration in authorship, visualising the connections between countries. The strongest links are observed between major contributors such as the US, China, and England. This network visualisation reflects how interconnected and collaborative the field has become, with authors from diverse countries advancing the knowledge base.

Table 4 shows the top 10 most highly cited papers, which are fundamental in the field and significantly impact research agendas and areas of interest. One of the most highly cited papers is "big data in accounting: an overview" [7], having a total of 238 citations; "big data and analytics in the modern audit engagement: research needs" [6] has 172 citations, and "behavioral implications of big data's impact on audit judgment and decision making" [36] has 171 citations. The rest of the papers then explore topics related to pressing issues in big data and analytics, corroborating the importance of big data and analytics in auditing. In addition, an analysis of the most cited papers reveals a clear developmental trajectory in the field. The foundational period (2015–2017) established a theoretical groundwork, with [7] providing a conceptual overview of big data in accounting, while [6,36] identified behavioural and methodological challenges that remain central to current research. The consolidation period (2018–2020) saw a practical application focus, exemplified by [37] examining implementation techniques and [38] addressing governance implications. Notably, six of the ten most cited papers originated in 2015, indicating that foundational concepts established early in the field continue to drive current research. The concentration of high-impact work among a small number of authors (Vasarhelyi, Appelbaum, and Kogan appearing multiple times) suggests an emerging but still specialised research community. The thematic progression from theoretical overviews to practical implementation challenges reflects the field's evolution from conceptual exploration to operational application, thus providing an empirical foundation for understanding current adoption patterns and future research needs.

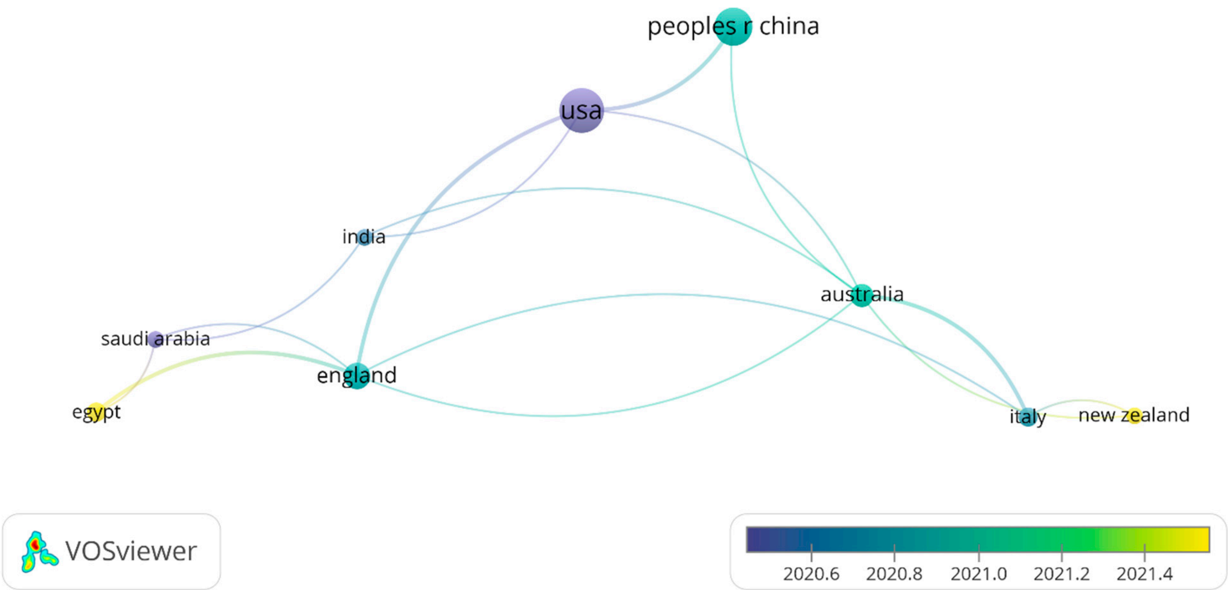

Figure 3. Visualisation of authorship countries.

Table 4. Top ten papers in terms of citations.

N	Title	Authors	Year	Citations
1	'Big Data in Accounting: An Overview'	[7]	2015	238
2	'Big Data and Analytics in the Modern Audit Engagement: Research Needs'	[6]	2017	172
3	'Behavioral Implications of Big Data's Impact on Audit Judgment and Decision Making'	[36]	2015	171
4	'The Digital Transformation of External Audit and Its Impact on Corporate Governance'	[38]	2020	149
5	'Big Data Techniques in Auditing Research and Practice: Current Trends and Future Opportunities'	[37]	2018	131
6	'Big Data as Complementary Audit Evidence'	[39]	2015	130
7	'Accounting, Accountability, Social Media, and Big Data: Revolution or Hype?'	[40]	2017	120
8	'Drivers of the Use and Facilitators and Obstacles of Big Data by the Audit Profession'	[41]	2015	113
9	'Data Analytics in Auditing: Opportunities and Challenges'	[42]	2015	105
10	'Consequences of Big Data and Formalization on Accounting and Auditing Standards'	[43]	2015	92

Table 5 shows the journals that have significantly contributed to advancing auditing research on big data and AI-drones in auditing. "Accounting Horizons" has seven publications, coming first, "Journal of Emerging Technologies in Accounting" with four publications, "Sustainability" with four publications, and "Accounting Research" with four publications. Three articles were published: the "Managerial Auditing Journal", "Technological Forecasting and Social Change", and "International Journal of Accounting Information Systems". Other smaller contributors include Computational Intelligence and Neuroscience, with two publications, and the International Journal of Accounting and Information Management, with two publications. Table 5 also shows the top three publishers in terms of the number of publications: Emerald Group Publishing, which has 17 publications; the American Accounting Association, which has 15 publications; and MDPI, which has eight publications. In terms of authorship, Table 5 also shows that Appelbaum D. and Vasarhelyi M.A. have four publications each, and other notable authors include Abdelwahed A.S., Abu-Musa A.A., and Kogan A. (See Appendix B, Figures A2–A4 for more details).

Table 5. Key findings of authors, journals, and publishers.

Category	Top Three Contributors
Authors (Figure A4)	Appelbaum D (4), 2. Vasarhelyi MA (4), 3. Abdelwahed AS (2)
Journals (Figure A3)	Accounting Horizons (7), 2. Journal of Emerging Technologies in Accounting (4), 3. Sustainability (4)
Publishers (Figure A2)	Emerald Group Publishing (17), 2. American Accounting Association (15), 3. MDPI (8)

4.2. Co-Word Occurrence Analysis

The VOSviewer tool uses clustering to allow a perceptive study of term co-occurrence, thereby exposing patterns and relationships within specific research fields. As [44] explained, this programme uses a clustering tool to categorise terms according to their frequency of co-occurrence. By forming clusters of linked phrases, VOSviewer's text-mining tool detects co-occurring keywords in titles, abstracts, and citation environments [9]. VOSviewer was used for co-occurrence analysis of keywords in the given visualisation (Figure 4), thereby producing a network visualisation based on the overall connection strength and frequency of linkages between terms. The network was set up in many clusters, each given a different colour, to help identify sets of connected terms. Table 6 presents the systematic organisation of these clusters, mapping their visual representations to thematic roles within the field.

Table 6. Co-word cluster (Figure 4): colours, exemplar keywords, and roles.

Cluster	Colour *	Exemplars	Role in the Field	Table
1	(Red)	Cloud computing, blockchain technology, deep learning, data mining, IoT, Industry 4.0.	Enabling infrastructure layer: platforms and tools that make data capture, storage, and compute possible.	Table 7
2	(Green)	Auditing, drones, RPA, trust, UAV.	Practice and automation: audit-process terms and automation modalities, including drone-enabled inspection.	Table 8
3	(Blue)	Artificial intelligence, machine learning, audit analytics, fraud detection, big data audit.	Analytic methods: AI techniques used to analyse evidence and detect anomalies.	Table 9
4	(Yellow)	Audit process, audit quality, COVID-19, developing country.	Context and outcomes: quality constructs and situational factors that condition adoption.	Table 10
5	(Purple)	Big data, audit evidence, big data analytics, continuous auditing.	Evidence hub: data volume, continuous evidence, and analytics central to modern audits.	Table 11
6	(Teal)	Accounting, analytics, audit judgment.	Disciplinary core: accounting links and judgment constructs.	Table 12
7	(Orange)	Data analytics, task complexity, technology.	Adoption drivers: complexity and technology terms tied to uptake decisions.	Table 13

* Colours correspond to Figure 4.

Table 7. Cluster 1 of keyword occurrence.

Keywords	Links	T * Link	Occur
Blockchain technology	8	8	2
Cloud computing	9	12	3
Data Mining	4	4	2
Deep learning	3	5	2
Industry 4.0	7	7	2
Internet of things	7	8	2

* T means total.

Table 8. Cluster 2 of keyword occurrence.

Keywords	Links	T * Link	Occur
Auditing	13	32	15
Drones	7	10	6
Farmer	4	7	2
Robotic process automation	3	3	2
Trust	4	7	2
UAV	4	4	2

* T means total.

Table 9. Cluster 3 of keyword occurrence.

Keywords	Links	T * Link	Occur
Artificial Intelligence	13	21	9
Audit analytics	6	7	3
Big data audit	1	1	2
Fraud detection	3	3	2
Machine learning	9	11	3

* T means total.

Table 10. Cluster 4 of keyword occurrence.

Keywords	Links	T * Link	Occur
Audit process	4	4	2
Audit quality	4	4	3
COVID-19	3	3	2
Developing country	2	2	2

* T means total.

Table 11. Cluster 5 of keyword occurrence.

Keywords	Links	T * Link	Occur
Audit evidence	6	9	5
Big data	24	59	39
Big data analytics	2	4	4
Continuous auditing	3	3	2

* T means total.

Table 12. Cluster 6 of keyword occurrence.

Keywords	Links	T * Link	Occur
Accounting	9	16	6
Analytics	3	3	2
Audit judgment	3	3	2

* T means total.

Table 13. Cluster 7 of keyword occurrence.

Keywords	Links	T * Link	Occur
Data analytics	5	12	8
Task complexity	2	3	2
Technology	3	3	2

* T means total.

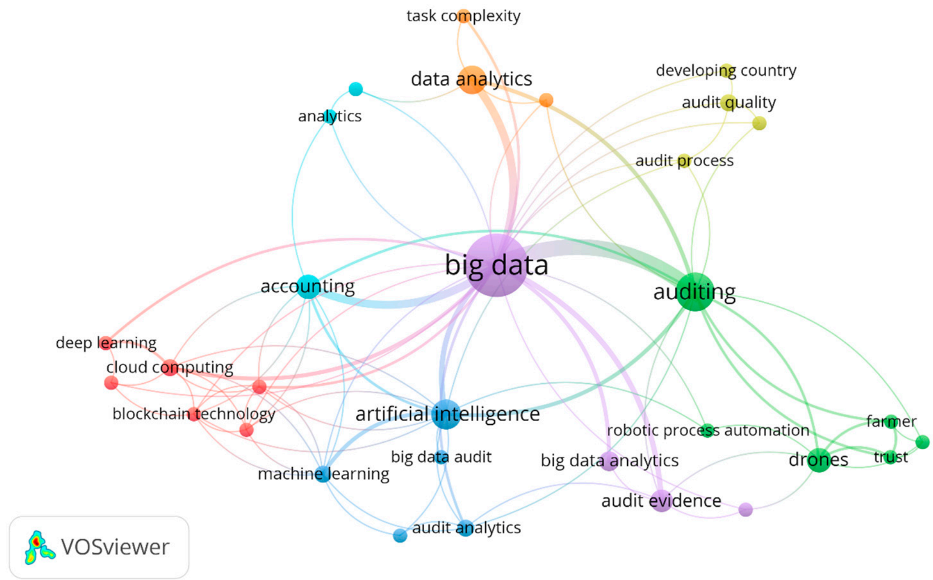

Figure 4. Graph of keyword frequencies.

In Table 6, these clusters reflect the topic areas within the field of study. Centred in the phrase 'big data', the purple cluster spans additional keywords: data analytics (orange), accounting (teal), artificial intelligence (blue), and auditing (green). With ties to related words, such as audit quality (yellow), audit process (yellow), drones (green), and trust (green), the green cluster centres on auditing. Artificial intelligence (blue) and related technologies, including machine learning (blue), cloud computing (red), and blockchain technology (red), occupy the blue and red clusters. Terms from the orange cluster—data analytics and task complexity—and the teal-term analytics highlight the value of analytics in handling challenging tasks.

The keywords selected in the study had to occur at least twice in the database, and only those that occurred at least twice were included. This standard concentrated on the most suitable words without including those that were not frequent enough and were unlikely to contribute significantly to the analysis. Although low-frequency keywords may be helpful for this type of research, they are not likely to be useful. To guarantee the improvement in the quality and uniformity of the analysis, a keyword standardisation process was used, where similar semantics were grouped under one and the most suitable expression. To name but a few, such as normalising the expression of "artificial intelligence (AI)" and "artificial-intelligence" to "artificial intelligence". The word "audit" was also normalised to "auditing", so there were no terminology variations in the field. The usefulness of this methodology strengthens the capacity to find relationships between keywords, uncover interrelationships, and present hidden patterns in the area of research to extract practical conclusions [45].

The results present a network visualisation of keyword occurrences, illustrating the relationships between key concepts in big data, AI, auditing, and accounting. The visualisation maps the co-occurrence of keywords in research publications, with nodes representing keywords and edges indicating their interconnections, based on joint appearances in the literature. "Big Data" emerges as the central node, signifying its dominant role in modern auditing and accounting practices, closely linked to "Artificial Intelligence", "Auditing", and "Data Analytics", which demonstrates its integral role in technological advancements within these fields.

The network has multiple thematic clusters for each organisation. The auditing cluster (green) contains words, including the audit process "audit process" alongside "audit quality", "audit evidence", and "robotic process automation" to show the significance of big data in enhancing audit methods. The artificial intelligence and technology cluster (blue) demonstrates the integration of AI and analytics within auditing and accounting through keywords such as machine learning and audit analytics, big data audits, and AI-driven audit techniques. The red cluster focuses on accounting and blockchain elements through keywords including "cloud computing", "blockchain technology", and "deep learning". The data analytics cluster (orange) contains "task complexity" and "analytics" terms, which show the obstacles during financial and audit data analysis through analytical approaches.

There is a significant correlation between "drones" and "auditing", emphasising the increasing adoption of drone technology in audit procedures, particularly in sectors that require extensive physical verification. Furthermore, the inclusion of terms like "trust" and "developing country" highlights the concerns surrounding the adoption of AI in auditing and the regulatory hurdles that arise when implementing big data in financial reporting.

4.2.1. Analysis of the Divergence Between Drone and Big Data

In Figure 4, the lower frequency of "drone" terminology (6 occurrences) compared to "big data" (39 occurrences) in our bibliometric analysis reflects several important factors.

1. Field Maturity Difference: Big data applications in auditing have a more extended research history, with foundational papers dating back to 2015 [7,36], while drone applications in auditing represent an emerging area of investigation.
2. Research Volume Disparity: The study analysis revealed that big data research dominates the academic discourse with established theoretical frameworks. At the same time, drone applications remain primarily in the experimental or pilot phase, resulting in fewer peer-reviewed publications.
3. Industry vs. Academic Focus: Our findings suggest that, while drone applications show significant promise in industry reports (as evidenced in our documentary analysis), academic research has not yet caught up to practical implementation, explaining the lower scholarly publication frequency.
4. Significance Despite Lower Frequency: Importantly, the co-occurrence analysis shows strong thematic linkages between "drones" and "auditing", indicating that when drone technology appears in the literature, it is closely associated with audit applications. This suggests high relevance despite a lower absolute frequency.
5. Implications for Our Study: This divergence strengthens our contribution by highlighting drone technology as an emerging area that deserves greater academic attention, particularly given its demonstrated practical applications in industry contexts.

4.2.2. Emerging Technologies in Auditing

The analysis of cluster 1 in Table 7 shows significant technological concepts for auditing and accounting purposes. Cloud computing is the leading technology in digital transformation because it has the highest occurrence rate and total link strength (T link = 12 and Occur = 3). Blockchain technology is essential for securing financial transactions and audit trails, as indicated by its eight-link strength and two occurrences. Deep learning and data mining play crucial roles in audit analytics because they demonstrate four and five links, respectively, when dealing with large datasets. The connection between Industry 4.0 and the Internet of Things (IoT) significantly influences modern audit settings through its seven links, coupled with two occurrences. This study confirms that emerging technologies will substantially transform auditing. According to [46], Big Data and Industry 4.0 transform corporate reporting because new analytical tools have become essential. Financial reporting benefits substantially from the combined influence of AI, blockchain, and cloud computing, according to [47]. The combination of cloud computing and IoT reshapes audit procedures in the framework explained by [7], who showed how these lead to real-time data acquisition and a more robust analysis. According to [38], external audit quality technologies and prediction capabilities increase when deep learning and data mining techniques are integrated into the audit process. These studies establish that auditors should incorporate advanced technologies into practice based on the data found within Cluster 1.

4.2.3. Automation and Drone-Assisted Auditing

The keywords in Cluster 2 of keyword occurrences, as presented in Table 8, describe what they are auditing and automating. The keyword "auditing" had the highest total link strength (T link = 32) and occurrence (occur = 15), signifying its dominant role in the discourse on technological advancement in financial and operational audits. "Drones" follows with 10 links and six occurrences, reflecting the growing interest in uncrewed aerial vehicles (UAVs) for enhancing audit processes, particularly in large-scale and remote audits. Other significant terms include "farmer" (T link = 7, occur = 2) and "trust" (T link = 7, occur = 2), which may indicate discussions around the application of auditing in the agricultural sector and the importance of building trust in automated auditing solutions. "Robotic process automation (RPA)" and "UAV" appear with lower occurrences but still play crucial roles in automating audit tasks and improving efficiency. This finding corresponds with many studies that stress the transformational role of automation in auditing. Ref. [31] studied how UAVs can be applied to audits and demonstrated that they can significantly enhance efficiency and documentation accuracy during inventory audits. Ref. [3] proposed a framework for integrating drones into an auditing workflow, namely, warehouse and open-space inventory audits, which are relevant in this cluster. Similarly, Ref. [38] noted that robotic process automation (RPA) affects external audits by increasing the efficiency of data collection and improving audit quality. According to [18], trust plays a significant role in the adoption of big data and automation in auditing, as it does in the adoption of new technologies in other sectors.

4.2.4. AI and Predictive Analytics in Fraud Detection

Table 9 discusses the occurrence of keywords in Cluster 3 using artificial intelligence, audit analytics, and machine learning in auditing and fraud detection. The cluster "artificial intelligence" appears to be the most dominant keyword, as it has the highest total link strength (T link = 21) and occurrence (Occur = 9), indicating its central role in the future of auditing. The one with seven links and three occurrences is "audit analytics", and it follows with it. This shows how important it is to use AI and Big Data for better audit decisions. The instances of "big data audit" (T link = 1, Occur = 2) and "fraud detection" (T link = 3, Occur = 2) indicate a growing dependence on sophisticated data-driven means to apprehend financial improprieties and meet standards. It also cites 11 links and three occurrences of "machine learning", highlighting the automated pattern recognition and predictive analytics that AI-driven systems bring to audits. These keyword trends match well with key studies that have explored the effects of AI on auditing. Ref. [6] point out the growing need for AI and machine learning in modern audit engagements to improve audit precision using big data and analytics. As Ref. [47] remarked, AI and Big Data can be incorporated into auditing standards to spot fraud and risk management. Machine learning-based AI-driven audit analytics are transformative [7]. Therefore, learning models for auditing should be included in new standards. Ref. [48] also discuss how AI supports SAPs in improving audit effectiveness and, thus, the role of AI and audit analytics in decision-making. As Ref. [38] mention, AI-based audit analytics can be used in corporate governance to detect anomalies and possible financial malpractice with fraud-detection algorithms. Similarly, they suggested the use of AI and machine learning in CA systems to handle data consistency, integrity, and aggregation [5].

Regarding the emergence of the keyword Cluster 3 (integrate artificial intelligence with audit analytics, big data audit, fraud detection, and machine learning in auditing), Table 9 is associated. This is a leading cluster where the keyword with the highest frequency is "Artificial Intelligence", with 13 links, 21 total link strengths, and nine occurrences, signifying that this keyword plays a vital role in the future of auditing and fraud detection. The second most relevant aspect is audit analytics (T link = 7, Occur = 3) regarding the growing use of AI and data-driven methods in improving audit decision-making and risk assessment. The occurrence of a "Big data audit" (T link = 1, Occur = 2) shows that big data is incorporated into the auditing framework to allow auditors to utilise the vast volume of financial data to conduct more accurate and efficient audits. This is related to the capability of AI to detect fraud (T link = 3, Occur = 2) to detect anomalies, suspicious activities, and irregular financial dealings. Further, 'machine learning' (T link = 11, Occur = 3) also emphasises how AI-based algorithms can lead to forecasting financial risks, identifying fraud, and automating routine audit processes. In the current assignments, where these keyword patterns are in response to the expansion of demand for AI and machine learning, Ref. [6] reviewed the expansion of demand for these keywords. Ref. [7] explored the integration of big databased audit methods with leading-edge data analytics in auditing. Ref. [38] considered fraud-detection mechanisms in an audit environment powered by AI, and Ref. [5] argued that CA can use AI and machine learning models to enhance audit quality and regulatory compliance.

4.2.5. Audit Quality in Global and Crisis Contexts

Table 10 shows the keyword occurrences for Cluster 4 related to audit process, audit quality, COVID-19, and developing countries. Both the "audit process" and "audit quality" have four total link strengths and two to three instances, implying that they relate to technological development and updated audit regulations. Audit practices have experienced a significant impact from the COVID-19 pandemic (T link = 3, Occur = 2) and have been urging remote auditing, AI-driven analytics, and digital auditing tools. By way of study, Ref. [49] have shown that the disruption has accelerated digital transformation in auditing and, particularly, the case for remote tools to maintain audit quality and compliance during global disruptions. Also, "Developing country" (T link = 2, Occur = 2) indicates increasing interest in how AI and technology-based audit processes are being adopted in developing economies. In developing countries, Ref. [50] studies face challenges in adopting AI and Big Data in financial auditing because of digital infrastructure deficits, regulatory gaps, and auditor training. Furthermore, Ref. [51] discuss how auditors' adoption of big data analytics in less technologically developed regions is influenced by institutional and firm-specific aspects.

4.2.6. Big Data and Continuous Audit Evidence

Table 11 shows cluster 5 of keyword occurrences, which demonstrates the importance of big data and audit evidence in the modern auditing practice, with the keyword "big data" as the most occurring keyword in this cluster with 24 links, 59 total link strength, and 39 occurrences to show its dominating role of transforming the audit methodology and financial reporting. Ref. [47] study, for instance, explores the auditing and financial decision-making process with the integration of big data, and [7] study studied the use of AI and data analytics to collect and verify the "audit evidence." [6] provide a study that moves towards data-driven audit procedures that are more accurate, efficient, and effective for fraud detection. Also, "big data analytics" (t link = 4, occur = 4) implies growing interest in utilising more advanced analytics tools for risk assessment and anomaly detection. According to [38], the trend is supported by big data analytics (BDA) for auditors to process vast amounts of structured and unstructured financial data. Lastly, "continuous auditing" (t link = 3, occur = 2) is suggested to show that the continuous processing of real-time data and automation are altering the practice of auditing and are what [5] established concerning CA with the use of big data technologies.

4.2.7. Accounting Transformation Through Analytics

Table 12 indicates the sixth cluster of keyword frequencies, with accounting, analytics, and audit judgement playing a role; "accounting" (t link = 16, occur = 6) is the top keyword in this group and indicates that accounting is linked to emerging technologies like big data and AI. As [50] cite, research underscores the adoption of big data and data analytics (BDA) in financial accounting and auditing, regulatory updates, and digitalisation (T link = 3, occur = 2) requirements. This underpins the research by [51] concerning the influence of institutional forces on analytics adoption in auditing (T link = 3, occur = 2). Analogous to "audit judgment" (T link = 3, occur = 2), the increasing usage of AI-based decision support systems for auditors [48], on the one hand, and the integration of the substantive analytical procedures and sampling techniques to improve the judgement and assessment of risk on the other.

4.2.8. Data Analytics, Complexity, and Technology Adoption

Table 13 shows keyword occurrences in cluster 7 (T link = 12, occur = 8), which points out that data analytics (T link = 12, occur = 8), task complexity, and technology are all factors in auditing and accounting. This finding is supported by [40], who find that data analytics improves performance indicators and governance mechanisms in auditing, and "task complexity" (T link = 3, occur = 2) points to the volume of data and the complexity of the audit task necessitating the use of advanced tools for the management and analysis of financial data. The study by [31] shows the challenges of integrating automated tools like drones and AI in inventory audit practice and, hence, the need for auditors to adopt new methodologies. Social media "technology" (t link = 3, occur = 2) finally includes the rapid adoption of AI, blockchain, and cloud computing in auditing. This mirrors [18], who study digital transformation and its influence on auditor-client relationships and engagement processes.

4.3. Bibliographic Coupling

Figures 5 and 6 represent standard bibliographic coupling network visualisations that are widely used in bibliometric analysis [44,52]. These visualisations are essential components of comprehensive bibliometric studies and have been employed in numerous published studies across various fields, including accounting and auditing research [16,17], technology adoption studies [9], and management and business research [32]. Figure 5 (Author Network) visualises collaboration patterns and intellectual connections between researchers based on shared references and identifies key contributors and research communities. Figure 6 (Document Network) shows thematic relationships between papers through bibliographic coupling, revealing research clusters with similar theoretical foundations.

Figure 5 illustrates the network of connections between authors in auditing, big data, and artificial intelligence, where they collaborated. The clusters are presented, where each cluster is a group of authors, and the lines connecting them indicate the authors' standard references in their works. The bigger the node, the more impact the author has and the more frequently he is cited. The thicker the line between the nodes, the stronger the connection between the authors regarding their bibliographic references.

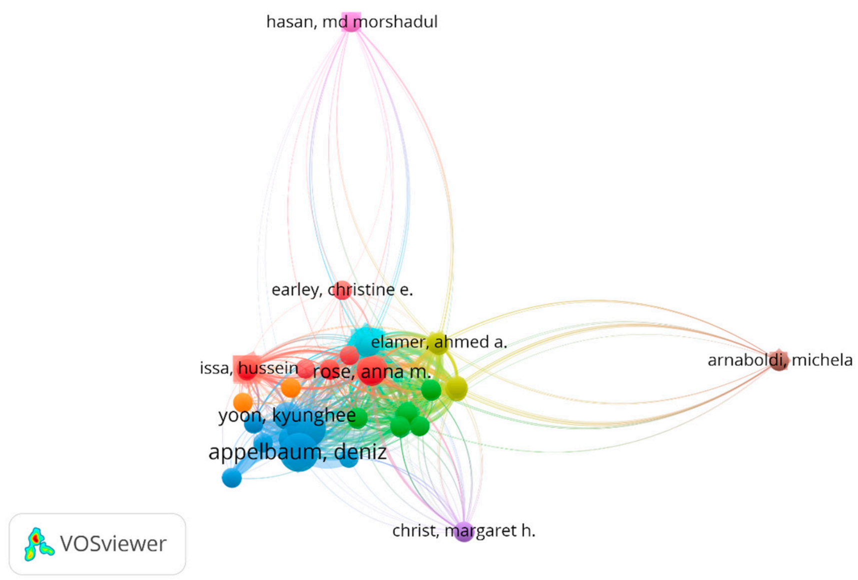

Figure 5. Visualisation of the author's network through bibliographic links.

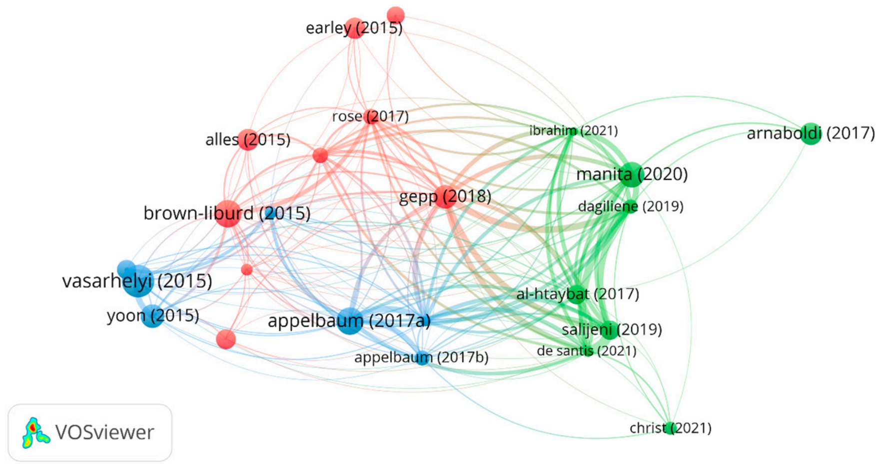

Figure 6. Top bibliographic-coupling documents ranked by seventeen citations or more. References include [3,5–8,18,31,36–43,46,47,50,51,53–57].

Figure 5 also includes well-known researchers Deniz Appelbaum, Kyung-hee Yoon, Anna M. Rose, and Ahmed Elamer, who acknowledge the closeness of the work performed by researchers involved in artificial intelligence, data analytics, and auditing methodologies. It is a complex and vibrant network of interrelated studies in which the authors are connected through references and common research interests. Christine is an important component in this process. Earley and Hussein Issa have been actively involved in integrating artificial intelligence and cognitive technology in the auditing field.

Authors such as Michela Arnaboldi and Md Morshadul Hasan, who are on the edge of the network, are located there, as their work is related to a broader research area but has distinct citation patterns and a more specialised focus. Arnaboldi's research primarily focuses on governance and performance measurement in big data, whereas Hasan's studies relate to artificial intelligence-driven financial reporting and risk assessment.

Figure 6 illustrates the connections between academic papers in auditing and considerable data research through shared references, which determine the intellectual linkages between them. The diagram has various coloured parts that represent each research theme or category. The red group includes [37,41,53], all of whom are concerned with the utilisation of big data in risk assessment and auditing. Refs. [38,40,51], and [31] examine green groups and, to some degree, how advanced analytics, decision-making, and governance are in auditing. The blue cluster, with the works of [3,6,7,39], focuses on CA, AI, and data-driven methodologies.

Larger nodes, such as [6,37,38], are highly influential works that have had a significant impact on many studies, as the number of citations each paper has accumulated is made apparent, with larger nodes indicating a more substantial influence. The strength of bibliographic coupling is demonstrated by the thickness of the connecting lines between documents, which indicates the use of the same sources in the two documents. In particular, Refs. [36,41,42] are related in that they have many standard references and key roles in their respective research areas. The arrangement of studies, such as [37], at the crossroads of several clusters indicates interdisciplinary research involving risk analytics, artificial intelligence, and corporate governance.

The clustering methodology was validated through citation impact and bibliographic coupling strength, as shown in Table A2. The top documents demonstrate strong bibliographic coupling patterns that directly correspond to the three clusters identified in Table 14 and visualised in Figure 6; these documents have 17 citations or more.

Table 14. Clusters gained from bibliographic coupling documents from Figure 6, with 17 citations or more; for more details see in Table A2.

Cluster 1	Cluster 2	Cluster 3
[41]	[46]	[8]
[55]	[40]	[6]
[36]	[31]	[3]
[42]	[51]	[57]
[37]	[50]	[7]
[54]	[47]	[39]
[43]	[38]	[5]
[56]	[18]	
[53]		

4.3.1. Big Data Integration in Auditing: Challenges, Adoption Barriers, and Evolving Standards

According to Table 14, in Cluster 1, as stated by [41], big data is seen as a key development in management practices. The big data market was expected to reach $16.1 billion in 2014 and grow much faster than the overall market, signifying a significant expansion of this business tool. Therefore, a detailed review of how auditors include these technologies in their professional practices is required. The hypothesis posits that auditors' credibility is closely linked to their clients' practices, indicating that integrating big data into auditing may occur gradually and may be influenced by existing standards and technological advancements.

A substantial obstacle auditors face is inefficiency in harnessing big data due to problems such as information overload and data relevance [36]. These obstacles can impair auditors' capacity to make sound judgements, necessitating a reconsideration of how they handle and analyse large datasets. Furthermore, Ref. [42] notes that while public accounting firms are moving in the right direction with data analytics, they have been slow to implement these technologies, specifically in auditing. Challenges unique to auditing (as opposed to tax and advisory services) may explain this delay. However, a revolution in data analytics has the potential to transform auditing engagements, and there is no reason to believe the profession will not continue to improve. Additional evidence from [37] suggests that while big data techniques are not yet widely adopted in auditing, there is increasing awareness of the benefits they can bring.

This technological shift requires the development of new audit standards. Ref. [43] assert that current accounting and auditing standards do not follow progress in data analytics because they focus on the presentation of information instead of data integrity and analysis. This misalignment suggests a need for new standards that value analytical processes to ensure audits remain relevant and practical. Consequently, auditors must adopt innovative methodologies to leverage the power of these technologies.

Corporate investment in big data has increased considerably, from $34 billion in 2013 to $232 billion in 2016 [55]. This investment shows that the top four accounting firms have taken the lead in incorporating big data into their auditing processes, even though its precise use in auditing still lags behind other industries. Ref. [55] identified key impediments to applying big data in financial statement audits and proposed a research agenda for overcoming these barriers.

Research on the practical application of big data in auditing is ongoing. Ref. [53] studied the effect of the timing of big data visualisations on auditors' assessments. Their findings show that auditors identify patterns more effectively when visualisations are viewed after traditional audit evidence, raising concerns about potential errors if the sequence is reversed.

In a different domain, Ref. [56] found an increasing demand to integrate big data topics into forensic accounting curricula in China. Their results indicate that adding big data skills to educational programmes is critical for preparing forensic accountants with the necessary skills to fight fraud.

Finally, the impact of big data extends beyond auditing. Ref. [54] examined its pervasive effect on the entire financial sector, encompassing its essential role in managing huge daily financial transactions and its effect on various financial products and services. Their comprehensive literature review emphasises the need for more studies on the impact of big data on financial markets, institutions, and practices, as it is a significant force in the finance industry.

4.3.2. Opportunities and Institutional Challenges in Big Data Adoption for Auditing and Accounting

In Table 14, Cluster 2 implies that the adoption of big data and advanced analytics in auditing and accounting creates opportunities and challenges. Ref. [46] study how big data affects corporate reporting and its impact on stakeholders and demonstrates technological paradoxes, such as empowerment versus enslavement. They show that two-way communication has the potential to improve reporting practices and inherent risks.

Ref. [40] suggest a research agenda related to social media, big data, and accounting functions. Previous studies can be categorised into three main areas: performance indicators, governance, and decision-making. Their research highlights the enormous influence of these technologies and the need to investigate their implications [40]. Ref. [31] presented the use of drones and automated counting software in inventory audits and showed considerable improvements in efficiency, accuracy, and documentation quality. However, they point out that companies are reluctant to adopt new technologies and that establishing standards to solve these innovations is moving too slowly. Ref. [51] investigate how internal company motives and institutional forces impact the external audit implementation of big data analytics. Big data shifts the relationships among auditors, clients, and regulatory bodies because it creates stronger compliance while delivering strategic audit benefits.

According to [50], the use of big data analytics has expanded in the auditing field, but organisations face challenges when implementing it correctly. The authors support the development of new auditing standards to boost the acceptance of big data tools; however, parties face challenges from unprepared clients and insufficient regulatory directions.

Ref. [47] advocated the formal structural addition of big data to professional standards, academic programmes, and future research goals. The study explains that big data technology enables its deployment across financial reporting, audit evidence collection, and risk assessment functions and powers audit technological advancement [47].

Ref. [38] explored how external auditing has evolved digitally while becoming more vital to corporate governance. Auditing quality and efficiency improve when auditors leverage digital tools because these tools enable expanded roles and reduce management's ability to unduly influence. As such, necessary reforms to legislation are required, and individuals must be trained to be abreast of this technology shift.

Finally, Ref. [18] analysed the adoption of big data in auditing and how adopting BDA affected the auditor's and client's relationships, phases of engagement, and barriers to adopting BDA. They outlined the issues that will help develop a research methodology that will help overcome the challenges and make the BDA-driven process more effective.

Together, these studies offer a unique view of how big data and analytics help critically impact auditing and accounting practise and hence call for regulatory updates, upgrading of skills, and additional research on surmounting barriers and making the best out of these.

4.3.3. Frameworks and Research Frontiers in Big Data–Driven Auditing Technologies

The advent of big data and related technologies has significantly impacted and challenged auditing and accounting procedures, resulting in Table 14 in Cluster 3. According to [6], auditors should stay up-to-date with their clients' greater use of big data, cloud computing, and IoT. Moreover, they used predictive and prescriptive analytics for audit assignments and regulatory barriers to obtain audit evidence. Based on their research, six areas should be investigated to shape the evolution of audit analytics in this climate.

Ref. [3] built on this theme by examining the use of drones for internal and external audits. They used drones in audit environments, such as large open spaces and warehouses, for inventory audits, and put forth a framework for drone adoption. This contributes to the discussion on technological advancements in auditing and how drones can improve audit efficiency and accuracy.

Ref. [8] explains the importance of data provenance in big data environments, specifically regarding the validity of audit evidence from external data sources. The "big data provenance black box" is introduced as the system is developed to securely keep the lifecycle and history of data and ensure its reliability for audit purposes. This framework demonstrates the need for verification processes to authenticate external data used in an audit.

As per the present state of auditing, Ref. [57] describe the present and future state of auditing both through scholars and industry professionals. They presented growing data and rapidly changing technologies as dual challenges. They research key issues, such as applying rules, using complex tools and large amounts of information to examine information, and suggesting questions to investigate how auditing in conjunction with new technologies might work.

Ref. [7] comprehensively examine big data accounting and auditing, starting with the origins, applications, and hurdles of big data. They explore how nontraditional data sources influence accounting records and audit processes, and how current standards accompanying accounting and audit processes with big data are outdated. However, their research also indicated that big data can be applied to audit judgment, analytics, and behavioural studies.

Ref. [48] studied whether advanced data analytics and substantive analytical procedures (SAPs) can replace conventional sampling techniques in audits. They stated that SAPs and sampling are two completely different methods, each with advantages and disadvantages. However, their research implies that they need not depend on one method but rather follow a multifaceted strategy that will boost the efficacy of the audit.

Ref. [5] identified five important gaps in data consistency, integrity, aggregation, identification, and confidentiality when big data are used in CA systems. It is suggested to help integrate big data into clinical practices, that is, into traditional data systems.

These studies collectively present the vast potential of big data and emerging technologies for auditing and accounting and offer new standards, frameworks, and research to address the issues and reap the benefits of these new technologies.

5. Discussion

This discussion synthesises the findings from the bibliometric analysis (Section 4) and content and documentary analysis with broader implications for auditing practice and research. Building on the three research clusters identified through bibliographic coupling analysis—(1) Big Data Integration Challenges, (2) institutional and organisational impact, and (3) Technological Frameworks and Future Directions—this section examines how these research themes translate into practical implications for transforming decision-making and financial reporting quality in auditing practice. The discussion is organised around two main themes: Section 5.1 Validating Research Clusters with Documentary Evidence; Section 5.2 transformation of decision-making processes and financial reporting quality through integrated audit technologies; and Section 5.3 the performance outcomes and strategic implications of these technological innovations, culminating in Section 5.4 their application to ESG assessment in external auditing.

5.1. Validating Research Clusters with Documentary Evidence

The bibliometric analysis identified three distinct clusters. Documentary evidence from industry and academic field studies supports these clusters. This convergence of theory and practice confirms the relevance of the research themes and demonstrates the transformative role of AI and big data in auditing.

Cluster 1 Validation—Big Data Integration Challenges:

The empirical evidence substantiates the integration challenges identified in our analysis (Table A1). Ref. [31] reduced the inventory audit time from 681 to 19 h using drone systems. The error rates fell from 0.15% to 0.03%, and audit accuracy increased by 15% with improved documentation from automated data capture. The researchers validated these results through controlled field testing that compared the drone and manual audit methods.

Ref. [1] validated the effectiveness of population testing and improved audit coverage. Their peer-reviewed methodology addresses sampling challenges and enhances statistical accuracy. Their evidence demonstrates how big data analytics overcomes traditional audit limitations. Ref. [58] demonstrated a reduced inspection time, lower costs, and fewer personnel needs. Their government-validated research provides institutional credibility for public sector drone adoption. These findings align with Cluster 1's focus on adoption barriers. Technological solutions offer transformative potential but demand significant operational and cultural shifts.

Cluster 2 Validation—Institutional and Organisational Impact:

Multiple documentary sources confirmed Cluster 2's institutional transformation themes: cost reduction, enhanced safety, and improved documentation (Table A1). Ref. [59] achieved a superior imaging accuracy for high-rise inspections using drones. They eliminate scaffolding needs and reduce labour costs, creating clear advantages over traditional methods. Their findings, validated through surveys and interviews with five companies, suggest cost reductions of 70–90% in optimised scenarios.

Ref. [60] reported reduced inspection times and costs for tall structures. Field tests with HD camera drones showed accurate facade pathology diagnoses. Their study highlighted environmental benefits such as lower emissions from reduced equipment use. This aligns with sustainable institutional practices. Ref. [61] quantified time and cost reductions of up to 50% for industrial inspections using drones. Enhanced safety protocols minimise worker exposure to hazardous environments.

Ref. [62] demonstrated an accurate subsurface defect detection. Their faster inspection eliminated scaffolding requirements. Their in-flight tests on concrete blocks, validated with control methods, showed enhanced institutional safety protocols and reduced infrastructure costs. These studies demonstrate organisational impacts: 50–90% cost savings, safer processes, and better documentation through precise imaging. These mirror Cluster 2's focus on technology-driven institutional transformation.

Cluster 3 Validation—Technological Frameworks:

Robust technological implementations across multiple studies validated Cluster 3's framework-oriented research on AI and computer vision (Table A1). Ref. [63] achieved a mean average precision of 70.45%, a precision of 86%, and a counting error of 8.3% using the YOLO v4 model for object detection in drone imagery. They validated their results using manually annotated datasets and standard metrics, demonstrating the reliability of the computer vision framework.

Ref. [64] reported a 96% classification accuracy and 92% counting accuracy for real-time surveillance. They used intersection-over-union optimisation and ground-truth comparisons on real datasets. This approach provides scalable, low-cost frameworks for biometric applications. Ref. [65] validated the real-time detection capabilities through successful CNN training. They demonstrated scalable object detection frameworks using convolutional neural networks and real-time testing.

Ref. [66] achieved 98.3% overall accuracy for object detection. The average precision improved from 4.05% to 80.58% and then to 91.56% with the enhanced training datasets. These results were validated through extensive testing of benchmark datasets against supervised learning techniques. Most significantly, Ref. [3] developed structured drone adoption frameworks for auditing contexts. Their university-based research provided enhanced inventory audit capabilities and systematic implementation guidelines, validated through a structured methodology in professional audit contexts.

These high-performance metrics—70.45% mean average precision, 96% classification accuracy, and 98.3% overall accuracy—demonstrate the maturation of AI-driven technological frameworks. This aligns with Cluster 3's focus on robust and scalable systems for real-world applications.

5.2. Transforming Decision-Making and Quality of Financial Reports

5.2.1. External Auditing Practice and Integrated Audit Technologies

Auditors' adoption of integrated audit technologies can be understood through their perceived performance benefits, highlighting users' beliefs that technology enhances job effectiveness. Integrated audit technologies are technologically sophisticated, streamlined audit processes that replace outdated and manual inspections. It supports real-time data processing, automated verifications, and better documentation quality, resulting in enhanced efficiency and reliability of external audit procedures.

As reported by [28], "AI has the potential to transform the audit process through automation, data analysis, continuous auditing, and enhanced risk assessment, empowering auditors to have a more meaningful impact".

The viewpoint offered corroborates the view that integrated audit technologies are a valuable means of enhancing audit performance, consistent with the performance improvement principles. The findings of [6] regarding the application of digital innovations, such as the Internet of Things and predictive analytics, to the practices of aviation-related auditing are consistent with the integration of advanced technologies in aviation-related auditing practices, such as artificial intelligence and big data. Integrated audit technologies can use these advancements to identify emerging risks, improve decision-making, and develop strategic plans. Nonetheless, the performance advantages of integrated audit technologies are underscored by frequent mentions of key terminologies such as "Artificial Intelligence" (9 occurrences), "Audit analytics" (3), and "Audit process" (2) in the supporting KPMG materials.

However, systems, such as integrated audit technologies, face several significant challenges. Ref. [36] warn that the vast quantities of data available to auditors through these technologies could overwhelm them and impede their ability to make accurate judgements if the data are not filtered and contextualised. Ref. [43] argue that existing auditing standards are not adequate to address the complex problems of artificial intelligence and data analytics, because technological development is outpacing the machinery of governance. In Refs. [18,50], institutional resistance, technical limitations, and client scepticism were the main hurdles to the use of tools such as IAT. A lack of these obstacles can make it difficult for implementation to work as well as for people to trust and use the system. Nevertheless, the positive side of IAT is supported by the fact that the concept of artificial intelligence is mentioned nine times, audit analytics three times, and the audit process twice in the relevant materials of KPMG. These studies emphasise the role of integrated audit technologies in facilitating the integration of technological advancements in core auditing activities, thus enabling more accurate audits, easier risk assessments, and better financial reporting integrity.

In conclusion, integrated audit technologies are an excellent example of how the promise of better performance spurs technology adoption in auditing. While the system's design is conducive to improving auditor performance and decisions, its overall effectiveness relies on overcoming infrastructural, educational, and regulatory preparedness, albeit in keeping with the broader literature's emphasis on the integrated adoption of AI and big data within external auditing.

5.2.2. Integrated Audit Technologies and Drone Stream

Performance benefits are further enhanced by including drone technology within the integrated audit technologies platform to create what can be considered the drone stream. This element provides auditors with additional capabilities in evidence collection, outlier detection, and location-based risk assessments, particularly when more conventional methods fail. High-resolution cameras, thermal vision, and geospatial mapping technology integrated with drones can conduct detailed inspections of risky or inaccessible areas, rendering them priceless for external audits such as inventory verification, asset location, and fraud detection.

According to the [22], drone-enabled inspections have reduced "inspection time by up to 90%. The costs were reduced by between 50% and 90%. Efficiency improved through the detection of 10 times more defects and anomalies compared to manual testing methods."

"It took just half an hour to measure the volume of the coal pile, rather than four hours, and reduced health and safety risks accordingly. Accuracy was improved; we captured approximately 900 data points per cubic metre with impressive precision" [23].

This performance improvement aligns directly with auditors' expectations, with auditors connecting the embrace of drones with increased accuracy, faster turnaround times, and reduced operational costs. Ref. [23] offers additional evidence for this value proposition.

It took only half an hour to measure the volume of the coal pile, rather than four hours, and because of this, health and safety risks were notably reduced. The precision was also greatly improved, capturing approximately 900 data points per cubic meter with an accuracy within 0.4%.

This evidence strongly indicates that drones in aviation can result in quantifiable increases in audit efficiency, safety, and data collection, which are directly relevant for building trust in audit results and financial reports.

The existing literature supports this hypothesis. Ref. [31] affirm that drones considerably enhance the quality and efficiency of inventory auditing but warn that full adoption is hindered by resistance to change within organisations and by outdated audit regulations. Ref. [3] proposed a systematic framework for adopting drones in different industries, highlighting their transformative potential if challenges are overcome.

In addition, drone-specific keyword frequencies—'drones' (6), 'audit evidence' (5), 'fraud detection' (2), and 'UAV' (2)—acknowledge a pervasive thematic emphasis upon evidential advantage and surveillance capability of drone technology. Such semantic patterns feed the perception that drones are not merely supplementary tools but also critical tools in today's technology-focused auditing processes.

However, companies must overcome some limitations in using the full potential of drones. As Refs. [18,31] report, resistance to change, vagueness in legal frameworks [24], and lack of standard regulations are challenges that continue to act as a hindrance. These challenges must be overcome to ensure that drones improve auditing and decision-making quality, thereby optimising their performance capability.

In conclusion, the drone stream of integrated audit technologies is a prime example of the capability of cutting-edge technology to transform audit conduct and realise performance improvement potential by increasing the effectiveness, efficiency, and assurance of auditors' assessments. However, its effectiveness depends on the support of institutional change, standard development, and strategic organisational adoption.

5.2.3. Integrated Audit Technologies and Big Data Stream

The third and most significant feature of integrated audit technologies is their immense data stream, which improves performance by enabling auditors to collect valuable, timely, and diverse intelligence at unprecedented volumes and velocities. By consuming both internal books of record and external feeds, such as market indicators, IOT device output, and economic datasets, integrated audit technologies make it possible for auditors to conduct holistic analyses that were cumbersome in the past due to manual or stand-alone processes.

With this capability, auditors' expectations of job performance are transformed instantly. For example, real-time benchmarking with peer industries, computerised flagging of outlier data, and linking micro-level anomalies at a transactional level to general economic patterns have become possible. Such functionalities represent a tremendous leap in analytic power, responsiveness, and risk foresight.

Ref. [27] "cognitive intelligence can analyse data gathered from disparate sources and formats, generate hypotheses, and make judgement-based decisions".

Moreover, Ref. [30] contributes that "AI techniques allow us to analyse large sets of data to help identify, assess, and respond to the risks of material misstatement due to fraud".

These assertions underscore the evolution towards cognitive and predictive auditing, affirming that integrated audit technologies enhance effectiveness and the capability to make better decisions, both demonstrating clear performance benefits.

Ref. [43] argue that the full potential of audit capability using big data can be actualized only if there is a change in auditing standards, away from static report structures and towards frameworks focused on ensuring analytical integrity and data governance. Without this regulation change, auditors will be constrained from using the IAT's full analytical potential.

The data-driven nature of the system is further underscored by the semantic frequency information, which supplies valuable information concerning the system's functionality: "big data" appears 39 times, "Data analytics" occurs 8 times, "big data analytics" and "Continuous auditing" occur four and two times, respectively.

These patterns reveal an increased emphasis on working life and education, similar to continuous, real-time, and forecast-based audit approaches that overcome conventional sampling and static checklists.

Ref. [7] make a case for this by clarifying how big data reimagines the fundamental concepts of evidence in auditing, including shifting away from small samples to large datasets, culminating in both improved quality of audit judgment and increased fraud detection accuracy. The ability to use CA, whereby integrated audit technologies passively look for exceptions and anomalies, has maximum potential to improve auditor performance and accuracy. Notwithstanding these advances, this method lies ahead. As Ref. [41] observes, auditors' adoption of big data tools lags behind other business functions, mainly because of cultural resistance, old frameworks, and imprecise implementation protocols. Breaking this inertia is essential if the profession maximises the capability of integrated audit technologies. In essence, the enormous volume of information that integrated audit technologies exemplify exemplifies their potential to change the face of external auditing by leveraging analytics. This gives auditors the power to make better-informed choices with a more thoughtful, faster, and profound analysis of evidence. However, the degree to which it can have an impact depends on overcoming structural barriers and raising audit standards to match the pace of data innovation.

5.2.4. Convergence at AI Integration Layer

The AI integration layer in integrated audit technologies represents a pivotal technological convergence in which drone-derived visuals, structured financial data, and external real-time feeds are unified using advanced AI techniques, including computer vision, natural language processing (NLP), and predictive modelling. From a performance improvement perspective, this synergy substantially affects auditors' perceptions of how AI integration directly enhances their professional efficiency, judgment accuracy, and value creation.

This unified AI module allows for early detection of abnormalities, automated identification of potential risks, and creation of client-ready insights. These outputs directly impact expediting and improving the quality of audit decisions while alleviating the manual reconciliation workload and elevating auditors' perceived strategic value within organisational and regulatory ecosystems.

As per [29], the conclusion of our result is that approximately "nearly 72% of companies surveyed are piloting or using AI in financial reporting, and in three years, that is expected to increase to 99%". As previously highlighted in [27], "the speed, depth, and breadth of analysis cannot be matched by a human auditor alone or even a team of auditors".

These real-world findings confirm the transformative power of integrated audit technologies and demonstrate that the integration of AI into auditing is rapidly becoming the norm, which has significant implications for its effectiveness, scalability, and competitive advantage.

The literature supports this assertion. Ref. [5] highlighted significant obstacles to implementing CA systems, particularly in ensuring data accuracy, reliability, and the ability to track changes. Integrated audit technologies' AI module, equipped with standardised protocols and automated data lineage controls, addresses these challenges by guaranteeing that all multimodal inputs, including textual, visual, and numerical data, are standardised, validated, and synchronised for accurate and reliable analysis.

IAT utilises advanced technological integration through its keyword analysis function, such as "Machine learning" (3 occurrences), "Deep learning" (2 occurrences), "Cloud computing" (3 occurrences), and "Internet of Things" (2 occurrences).

The set of defined terms in the IAT effectively describes the technological spectrum while matching the framework described by [6] in their audit analytics approach. AI, combined with live data sources within its vision, creates predictive and prescriptive audit intelligence, which changes the auditing process from planning through sampling to fraud detection.

Ref. [7] show that audit analytics will transform into a forward-looking, behaviorally informed process that can analyse unconventional data for proactive insights through its convergence.

The path to achieving this vision demands that organisations handle multiple barriers, including system fragmentation and the absence of AI standards for audited systems, according to [31] and supporting reports. Advanced technological systems require these essential components to avoid growth setbacks.

The IAT depends on its integration layer as a central element to optimise the speed and quality performance of external auditing operations. Through this capability, auditors achieve improved performance by efficiently uniting different data sources through intelligent automation and learning systems that allow them to operate accurately and swiftly. The complete realisation of this potential requires training changes, standardisation of governance, and technological adoption.

5.2.5. AI Integration and Smart Drone

The last aspect of the advanced architecture of integrated audit technologies of IAT is its smart drone integration, which utilises closed-loop artificial intelligence systems to coordinate and control autonomous drone operations. These drones have advanced flight navigation systems, artificial intelligence-driven object recognition, and real-time exception tagging, which allow continuous and intelligent evidence collection. This collaborative workflow combines different elements to enhance the performance benefits. This reduces the workload on humans, increases the accuracy of audits, and simplifies tasks previously limited by factors such as location, safety, or logistics.

By allowing drones to autonomously adapt their flight paths and inspection focus to detected anomalies or changes in the environment, the IAT establishes a self-learning audit mechanism that improves with each engagement.

As per [22], the results conclude that the new product is in high demand and has a low cost since "drone technology can be a game changer for the energy industry... Close-up imagery with a high level of detail leads to a better understanding of potential defects."

Ref. [23] adds further weight to this claim that "drones can often capture more accurate data and from hard-to-reach places; they also minimise disruptions and reduce costs." These industry perspectives validate that smart drones are cost-effective and precision-enhancing, providing auditors with access to previously inaccessible or hazardous environments without compromising safety or audit thoroughness.

Multilingual evidence also supports this view.

Ref. [26] reports, "Due to the massive demand for drones, the government imported two million drones from China last year for civilian use."

This illustrates the widespread civil adoption of drones, underscoring both technological maturity and market readiness, which are factors that increase auditors' confidence in the reliability, scalability, and availability of smart drone technologies.

Ref. [3] provide theoretical support for this integration and propose a structured adoption framework for drone use in audits. They emphasise that inventory inspections, especially in large warehouses or open-air sites, are significantly improved when drone operations are guided by machine-learning-based protocols—exactly the form of optimisation offered by IAT.

Keyword analysis further reflects this shift towards intelligent automation in audits: "Robotic process automation" (2 occurrences), "Technology" (2 occurrences), and "Audit quality" (three occurrences).

These terms indicate alignment with industry trends in digital transformation and process automation, which enhances audit credibility and efficiency. However, these issues remain to be resolved. Despite technological advancements, Refs. [18,31] suggest that many companies lack standardised frameworks and regulatory clarity for the integration of drones in their formal audit procedures.

In summary, the smart-drone architecture of integrated audit technologies, when combined with its AI learning core, meets auditors' performance expectations by guaranteeing accuracy, self-reliance, and ongoing enhancement. This will not only place drone technology as a tool for observation but also as a strategic asset to enhance audit outcomes in real operational contexts. Nevertheless, its complete implementation still necessitates a better alignment between healthcare practices, policies, and infrastructure.

5.3. Smart Drone and Performance Outcomes

5.3.1. Full-Population Inspection (No Sampling)

Integrated audit technologies can revolutionise the audit process by making an overall analysis of the entire dataset possible, rather than just a few samples. This achieves the highest level of performance improvement, where auditors offer the highest degree of transactional coverage to enhance audit defensibility, judgment reliability, and risk-detection precision.

The problem of missing material misstatements or irregularities with insufficient data examination has been addressed by the transition from conventional sampling techniques to data-driven auditing. Instead of relying on statistical inferences from sample sizes, auditors using integrated audit technologies base their evaluations on complete datasets, thereby significantly reducing uncertainty in audit opinions.

As [30] notes, the results conclude that the data support our hypothesis that "quality is enhanced by aiding the analysis of larger samples."

While this statement is focused on large samples, the IAT applies this concept by eliminating the need for sampling in many situations and replacing it with real-time, comprehensive data analysis—a revolutionary approach for high-volume, high-risk audits.

This change is fundamental in complex financial settings, where the sheer number and diversity of transactions make manual reviews unfeasible. Ref. [43] emphasised that traditional audit standards face challenges when adapting to the vastness of contemporary data environments. Using advanced artificial intelligence-driven big data analytics, integrated audit technologies have successfully addressed this gap, facilitating continuous inspection and anomaly detection at the transaction level.

Keyword research underscores the increasing significance of this methodology: "audit evidence" (five occurrences) and "audit judgement" (two occurrences).

These terms have a dual impact: they improve the quality of audit evidence by ensuring its completeness and accuracy and support auditors' professional judgment by providing them with a comprehensive view of financial systems and records.

The academic literature reinforces this. According to Ref. [5], integrating comprehensive data improves audit credibility and objectivity, particularly in CA systems. Likewise, Ref. [6] asserted that the completeness of data enhances risk modelling and control assessments and reduces dependence on human intuition. However, there were certain obstacles to this feature. Moving on from Ref. [36], who cautioned that complete population data management and interpretation is a challenge, integrated audit technologies go a long way to tackle this with their machine-learning-driven integration layer (Section 5.2.4).

Lastly, Ref. [41] places this evolution in the broader context of the shift towards big data auditing, stressing that auditors must overcome resistance to change and depart from their traditional practices. Integrated audit technologies make this transition possible by automating comprehensive testing so that auditors can have confidence in their results and a solid base to deliver more assertive and trusted audit opinions. It is concluded that the performance advantages are demonstrated by the commitment of integrated audit technologies to full-population inspection. This removes sampling constraints, ensures comprehensive evidence collection, and enhances auditor judgment for audit excellence in the era of artificial intelligence and big data.

5.3.2. Reduce Audit Engagement Time

IAT fundamentally reduces the time required to complete an individual audit engagement and delivers high-quality outputs within a significantly shorter time frame, reflecting the principle that technology improves work efficiency without reducing quality. It speeds up audit cycles, with a positive effect on both auditors and clients because it reduces operational disruptions, frees up resources for more value-added assurance services, and expands the capacity of the audit function.

Ref. [22] clearly illustrates the operational impact: "Up to 90% of inspection time is reduced."

This tenfold increase in efficiency allows audit firms to punch more work into a given period, thereby increasing their audit volumes and saving costs, while maintaining the quality of their work.

This is important from a strategic perspective. Ref. [38] claim that digital transformation in auditing, enabled by tools such as IAT, helps firms move from compliance-oriented work to providing valuable insights and consulting services. This allows auditors to spend more time and skill on fraud detection, internal control analysis, and business risk advisory, thereby improving their value propositions. The keyword occurrence examination corroborates this transformation: "audit quality" (three occurrences) and "audit process" (two occurrences).

The importance of the dual benefits of integrated audit technologies, namely time efficiency and the preservation of quality and fulfilment of professional standards, should be underscored through these terms, as they relate to performance improvement factors.

However, it must be carefully managed so that the speed of the audits does not jeopardise professional scepticism and analytical rigour. Ref. [31] provide evidence of the efficiency improvements generated through audit automation. By contrast, Ref. [18] stressed maintaining a critical evaluative mind when processes are expedited. This provides further reason to ensure that quicker audits do not lead to superficial evaluations by providing training, guidance, and system adjustments so that quicker audits do not lead to superficial evaluations.

Integrated audit technologies are expedited audit processes that do not sacrifice the accuracy or reliability of the findings to achieve a new equilibrium between speed, quality, and judgement. This operational advantage is a strong incentive for auditors and firms with limited resources to attempt to achieve and embrace this new technology.

5.3.3. Lower Cost

Integrated audit technologies provide one of the main benefits of obtaining substantial cost savings through automation and data-driven efficiencies that directly improve auditor performance. This is an alignment between audit execution profitability and resource optimisation. IAT achieves this by minimising the need for manual fieldwork, lessening on-site travel and labour, and enabling the remote centralised coordination of audits while maintaining the highest assurance standards.

As per the report by [22]: "Costs reduced between 50% and 90%".

The significant cost reductions show the economic value of integrated audit technologies achieved through IAT in an industry where time, labour, and travel expenses are important parts of cost. Companies that operate in remote or complex locations find these efficiencies especially helpful because the traditional audit method is expensive and time-consuming. Ref. [42] noted that this transition is important because audit practices have traditionally been slow to adopt advanced technologies, compared to tax and advisory services. IAT systems help fill this gap by automating routine tasks, such as variance analysis, inventory verification, and risk scoring, leaving human capital devoted to higher-value professional judgment activities. This narrative supports the assertions made by keyword analysis, "Analytics" (2 occurrences), and "Technology" (2 occurrences).

They show that integrated audit technologies use AI and data analytics to optimise operations, reduce redundancy, and eliminate wasteful practices, particularly processes that involve a large number of high-risk audits. This efficiency-driven perspective is favoured by [6], who emphasise that technology enables faster audits and more focused data-driven interactions that generate superior results with fewer resources.

Nevertheless, as [18,50] warn, cost reduction should not occur at the expense of strategic reinvestment. Implementing a digital infrastructure, system integration, or staff training is paramount for achieving long-term cost savings and reliable performance. Without these investments, companies might not be able to fully utilise integrated audit-technology capabilities or be subjected to audit teams that are unprepared for new workflows.

Consequently, given IAT's benefits of integrated audit technologies, it is a significant and measurable cost benefit. However, these advantages must be integrated into a complete plan that includes change management, skill enhancement, and regulatory compliance. When implemented cautiously, these efficiencies help firms become profitable, ensure audit quality, and instil stakeholder confidence.

In conclusion, integrated audit technologies are performance-enhancing innovations that enable large-scale, cost-efficient auditing. From a performance improvement perspective, its capability to do more with fewer resources and to maintain the accuracy of the audit makes it an attractive catalyst for technological adoption.

5.3.4. Linking Company Data

The use of integrated audit technologies on previously isolated company data gives auditors a revolutionary new capability to combine company data and move from the realm of technical compliance specialists to strategic advisors. This progression demonstrates performance enhancement benefits by making auditors aware that integration into this network has made their technical work more precise and professional contributions more valuable.

Integrated audit technologies combine structured and unstructured data sources (internal financial records, enterprise resource-planning systems, market indicators, and social media streams) to create auditors with the ability to develop comprehensive, narrative-driven insights into client performance and risk. This approach allows auditors to make the audit process more strategically relevant, providing boards and stakeholders with insights and context beyond traditional audits.

As [30] points out, "AI gives us the opportunity to personalize our approach, optimize our time, and deliver superior service to our clients".

Thus, integrated audit technologies can change audit methodologies, allowing for personalised, adaptive, and analytically richer engagements that meet clients' needs and retain the rigour of professional standards. This is made possible through two key innovations. As presented by [55], data mining techniques were first used to discover hidden patterns, correlations, and anomalies across integrated datasets to provide an audit with insights into operational inefficiencies, fraud risks, and strategic opportunities. According to [57], blockchain technology guarantees data accuracy, traceability, and immutability that are integrated into integrated audit technologies. Guarantees of the soundness of audit opinions and regulatory compliance in sectors where risk is substantial are technical underpinnings.

The text is replete with terms such as 'blockchain technology' and 'data mining', indicating that IAT focuses on using cutting-edge analytics and developing an interoperable data infrastructure. Avionics technology assists auditors by providing timely, contextual, rich, and knowledgeable assessments.

Similarly, Ref. [40] confirmed the paradigm shift, where combining nontraditional data (e.g., social media analytics) provides previously unknown governance patterns, reputational risk, and stakeholder sentiment to auditors. This offers more thorough insight into risk assessment and strategic advice compared to the traditional approach.

However, there are structural obstacles in this conversion. According to [43], existing auditing standards have not caught up with the fast-changing technology. Today's frameworks are still steeped in the antiquated habit of periodic reporting and presentation formats and do not account for the intricacies of continuous and integrated data analysis. In the assurance context, the full potential of integrated audit technologies is not fully acknowledged or supported without aligning professional standards with these technological capabilities.

In essence, integrated audit technologies' ability to link company data to coherent and actionable narratives makes them a crucial part of auditors' professional empowerment. This helps to improve their performance by expanding their influence, analytical skills, and service quality. By doing so, auditors are not only found to be financial accuracy validators but also strategic enablers of organisational transparency, foresight, and governance.

5.3.5. Shorter Audit Duration

Auditors use integrated audit-technology-driven efficiency gains to accelerate audit timelines without lowering the high standards of assurance services. This improvement demonstrates clear performance benefits, as auditors feel that timely delivery helps meet regulatory compliance and satisfies clients' expectations, further improving their professional credibility and reputation.

Integrated audit technologies can transform the audit timeline into a strategic asset. As [29] states, faster audit completion meets regulatory deadlines and client expectations, which supports perceived auditor effectiveness. This means that integrated audit technologies create a strategic benefit by allowing for shorter engagement windows and more efficient audit completion times.

Of course, efficiency does not affect the quality of work. The occurrences of two keywords, “audit quality” (3) and “task complexity” (2), show that IAT maintains audit integrity and simplifies complex processes. Automated processes take the burden of manual work and help manage high-volume, complex audit tasks, so auditors can focus on dealing with aspects that require their expertise and critical thinking.

Ref. [31] point out that this automation is useful, especially when the complexity of a task is reduced and auditors can better manage intricate engagements with increased control and clarity. Ref. [18] state that although the system may reduce timelines, it continues to uphold and maintain professional scepticism, which is essential for audit reliability.

In other words, shorter audit durations, which are now possible thanks to integrated audit technologies, not only improve operational performance but also help improve audit quality by simplifying the audit and enabling auditors to concentrate on high-risk areas. This balance of speed, depth, and diligence is directly aligned with the requirements of regulators and clients in the modern audit process. As such, they reinforce the role of integrated audit technologies in performance-enhancing innovations.

Furthermore, findings from a study by [31] titled “Prepare for Takeoff: Improving Asset Measurement and Audit Quality with Drone-Enabled Inventory Audit Procedures”, highlight how drone-supported audits significantly improve audit efficiency and performance outcomes.

The results show a reduction in the time needed to perform inventory counting from 681 h to 19 h, a decrease in error rates from 0.15% to 0.03%, and therefore, a dramatic increase in efficiency and precision. Moreover, the study emphasises how the implementation of technology-supported audit procedures increases the quality of documentation by generating more transparent and more accessible evidence, which in turn increases the credibility of the work of auditors and adds to compliance with regulatory requirements. The findings strongly support the conversation that is taking place regarding the benefits of drone-integrated data technologies in improving the accuracy and reliability of financial reporting.

5.4. ESG Assessment in External Auditing Through Integrated Audit Technologies

Within the context of external auditing and the integrated audit technological framework, ESG dimensions represent a paradigm shift from traditional compliance-based reporting to continuous technology-enhanced verification systems that demonstrate significant performance improvements. The environmental component benefits significantly from IAT’s drone stream and IoT integration, where real-time monitoring of carbon emissions, waste management facilities, and resource consumption replaces periodic manual inspections with continuous, high-resolution data collection that achieves “up to 90% reduction in inspection time” while capturing precise environmental metrics. Social factors are a revolutionised integrated audit technologies’ AI integration layer, which employs natural language processing to analyse employee welfare data, diversity metrics, and community impact assessments from multiple unstructured sources, transforming subjective social reporting into objective, verifiable analytics. Governance elements are enhanced through the system’s big data stream, which processes board meeting minutes, executive compensation data, and regulatory compliance records in real-time, enabling auditors to provide comprehensive governance assurance rather than relying on sampling methods. This technological convergence within IAT transforms ESG from fragmented, annual reporting exercises into integrated, continuous assurance processes that not only improve audit quality and reduce costs by “50% to 90%” as noted in the [22] findings, but also position external auditors as strategic ESG advisors rather than mere compliance verifiers, thereby significantly enhancing their perceived professional effectiveness and value creation in an increasingly sustainability-focused business environment. Furthermore, integrated audit technologies' real-time carbon monitoring capabilities directly support organisations in reducing their carbon emissions through precise measurement and verification, aligning with Saudi Arabia's Green Initiative commitment to achieving net-zero carbon emissions by 2060. This technological framework provides the essential infrastructure for accurate carbon accounting and reduction verification that is necessary to meet ambitious national climate targets.

However, the implementation of drone technology in auditing is not without vulnerabilities. Confidentiality and security concerns include potential data breaches during transmission, unauthorised access to sensitive client information, and technical errors from equipment malfunction or weather interference that could compromise audit evidence quality (based on industry best practices for secure drone operations). These risks require comprehensive cybersecurity protocols and backup verification procedures to ensure audit integrity.

6. Conclusions

This study examined the effect of drone technology on improving the quality of financial reports released by Saudi Arabian companies, with a special emphasis on how it is amalgamated with AI and big data. This study investigates the impact of integrated audit technologies on external auditors' practice. It combines bibliometric analysis of academic literature with content analysis of documentary sources to ascertain current trends and their practical implications. This finding indicates that drone-assisted inspection, AI, and big data integration into auditing lead to efficiency and effectiveness. The integration of automated tasks into complex and time-consuming tasks reduces the amount of manual work and provides immediate insight into the audit process. This means that audit firms will have lower operational costs and shorter audit durations, and auditors will have access to more precise and extensive data to make sound decisions. Bibliometric analysis revealed seven main themes, including the most frequent "big data", indicating that it plays a significant role in changing the face of contemporary audit practice. Although these promising outcomes have limitations, this study has some limitations. Frequent sandstorms in Saudi Arabia could also harm the performance of drones and, therefore, the accuracy of the collected data. Cybersecurity risks were not incorporated into the analysis, although they pose potential threats to data integrity and financial transparency in automated systems. The insights provided will prove highly practical and helpful for policymakers, especially the Saudi Capital Market Authority (CMA), in considering the frameworks of modernisation in technology-driven audits with sufficient vigilance towards emerging risk. This study recommends that the CMA explore a new automated audit inspection model for listed firms and pursue further research into leveraging drones, AI, and big data to enhance audit capabilities.

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Appendix A

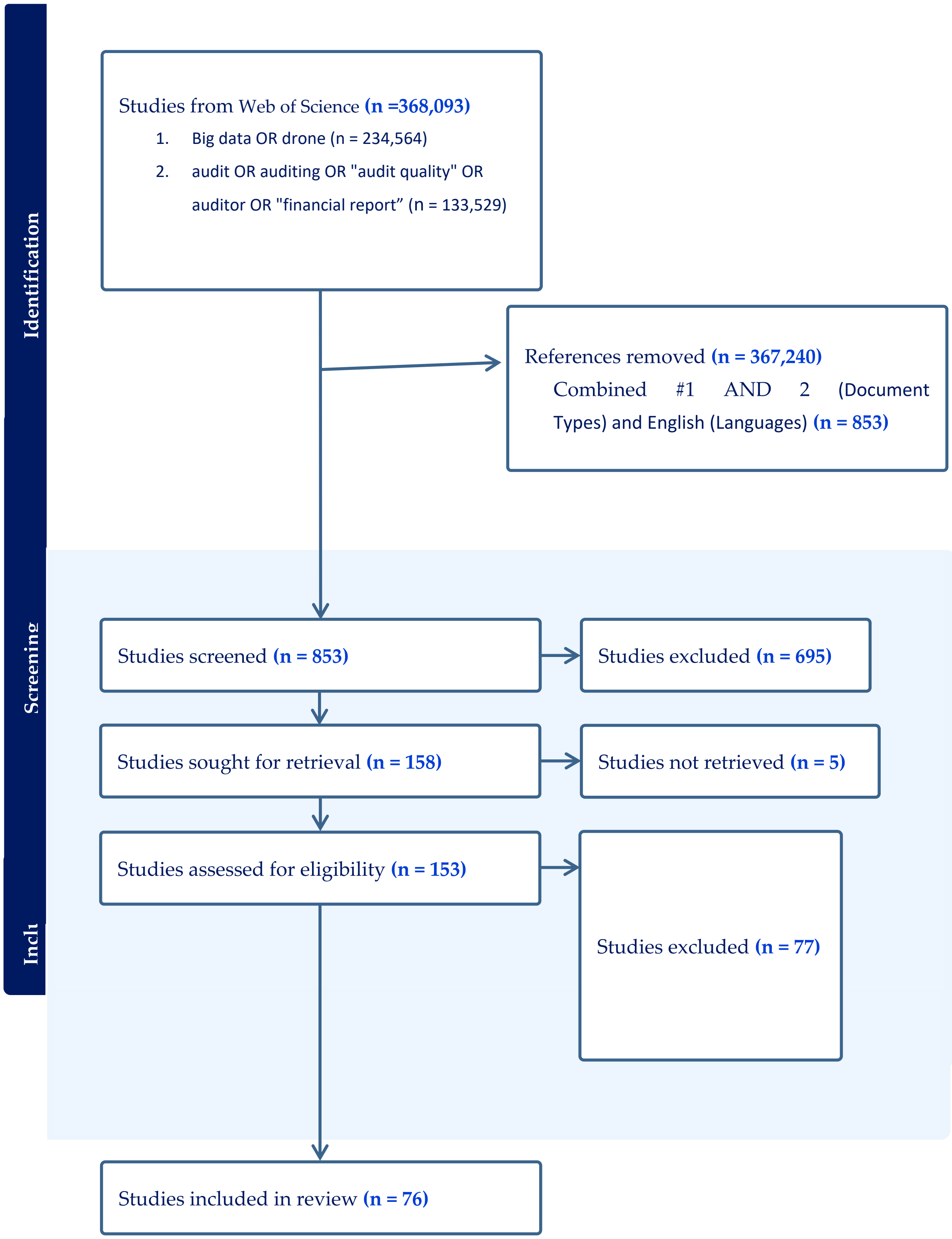

Figure A1. PRISMA 14 October 2024 Data Search Results.

Table A1. Documentary Resources.

Source	Type	Key Metrics	Validation	Website Source
[31]	Peer-reviewed study	Time reduction: 681 h → 19 h; Error reduction: 0.15% → 0.03%; Inventory audit accuracy: +15%; Enhanced documentation quality	Design science approach with controlled field-testing comparing drone-enabled vs. manual inventory audit techniques	https://link.springer.com/article/10.1007/s11142-020-09574-5 (accessed on 1 July 2025)
[59]	Technical Journal	Superior imaging accuracy for high-rise buildings; Clear cost advantages over traditional visual inspections; Improved defect detection	Questionnaire and interview surveys with 5 experienced companies; Field validation studies	https://cir.nii.ac.jp/crid/1390586344769761664?lang=en (accessed on 1 July 2025)
[60]	International Journal	Reduced inspection time and costs for tall structures; Environmental benefits with lower emissions; Accurate facade pathology diagnosis	Field tests with HD camera drones; Literature review and empirical validation	https://doi.org/10.1108/ijbpa-07-2019-0063
[61]	Peer-reviewed journal	Time and cost reduction up to 50%; Successful defect detection through thermal imaging; Enhanced safety protocols	Case studies in industrial sites using thermography and visual inspection; Multi-site validation	https://doi.org/10.3390/drones5040106
[58]	Government research	Significantly reduced inspection time; Lower costs with fewer personnel requirements; Enhanced access capabilities	Comparative study of drone vs. traditional timber bridge inspections; Government-validated methodology	https://research.fs.usda.gov/treesearch/download/56906.pdf (accessed on 1 July 2025)
[62]	ScienceDirect research	Accurate subsurface defect detection; Faster inspections without scaffolding; Reliable acoustic data	In-flight tests on reference concrete block; Technical validation with control methods	https://doi.org/10.1016/j.conbuildmat.2025.141147
[63]	Computer Vision Journal	Mean Average Precision: 70.45%; Confidence Score: up to 99%; Precision: 86% (YOLO v4); Counting Error: 8.3%	Manually annotated deer image dataset; Performance measurement using mAP, precision, recall, F1 score	https://doi.org/10.3390/drones6010009
[64]	Agricultural Technology Journal	Classification Accuracy: 96%; Counting Accuracy: 92%; Real-time biometrics capability; Low-cost implementation	Real pasture surveillance dataset evaluation; IoU optimization and ground truth comparison	https://doi.org/10.1080/01431161.2020.1734245
[65]	Sensors Journal	Real-time cattle detection capability; Successful CNN training validation; Scalable object detection framework	Convolutional Neural Networks training and validation; Real-time performance testing	https://doi.org/10.3390/s18072048
[66]	Machine Learning Research	Overall Accuracy: 98.3%; Average Precision: 4.05% → 80.58% (5 images); Enhanced to 91.56% (50 seed labels)	Extensive testing on benchmark animal datasets; Comparison against supervised learning techniques	https://doi.org/10.1007/s11063-021-10439-4
[3]	Auditing Journal	Structured drone adoption frameworks; Enhanced inventory audit capabilities; Systematic implementation guidelines	University-based research; Structured methodology validation; Professional audit context	Auditing: A Journal of Practice & Theory
[1]	Information Systems Journal	Population testing effectiveness validation; Enhanced audit coverage capabilities; Statistical accuracy improvements	Peer-reviewed methodology; Sampling technique comparisons; Comprehensive evidence collection	Journal of Information Systems

Table A2. Bibliographic-Coupling Documents Ranked by 17 Citations or More.

Rank	ID	Document	Citations	Total Link Strength
1	74	[7]	238	36
2	61	[6]	172	83
3	72	[36]	171	41
4	55	[38]	149	82
5	59	[37]	130	104
6	75	[39]	130	35
7	66	[40]	120	8
8	71	[41]	113	19
9	70	[42]	105	10
10	73	[43]	92	11

Table A2. *Cont.*

Rank	ID	Document	Citations	Total Link Strength
11	58	[18]	89	92
12	65	[46]	89	52
13	76	[5]	89	21
14	53	[54]	75	8
15	67	[55]	59	63
16	62	[53]	56	51
17	64	[3]	54	40
18	56	[51]	48	98
19	48	[31]	41	12
20	68	[8]	37	34
21	57	[56]	35	19
22	69	[57]	28	89
23	45	[50]	23	96
24	38	[47]	19	74

Appendix B

Figure A2. Journals' Publications.

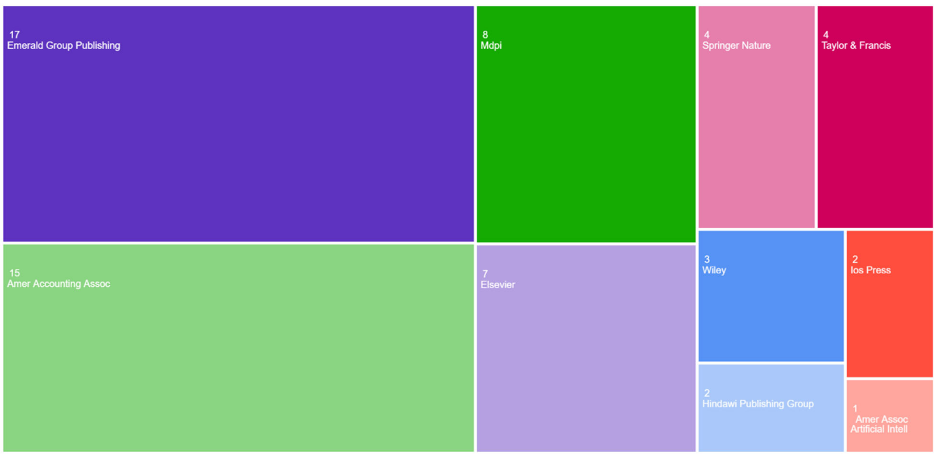

Figure A3. Publishers' Publications.

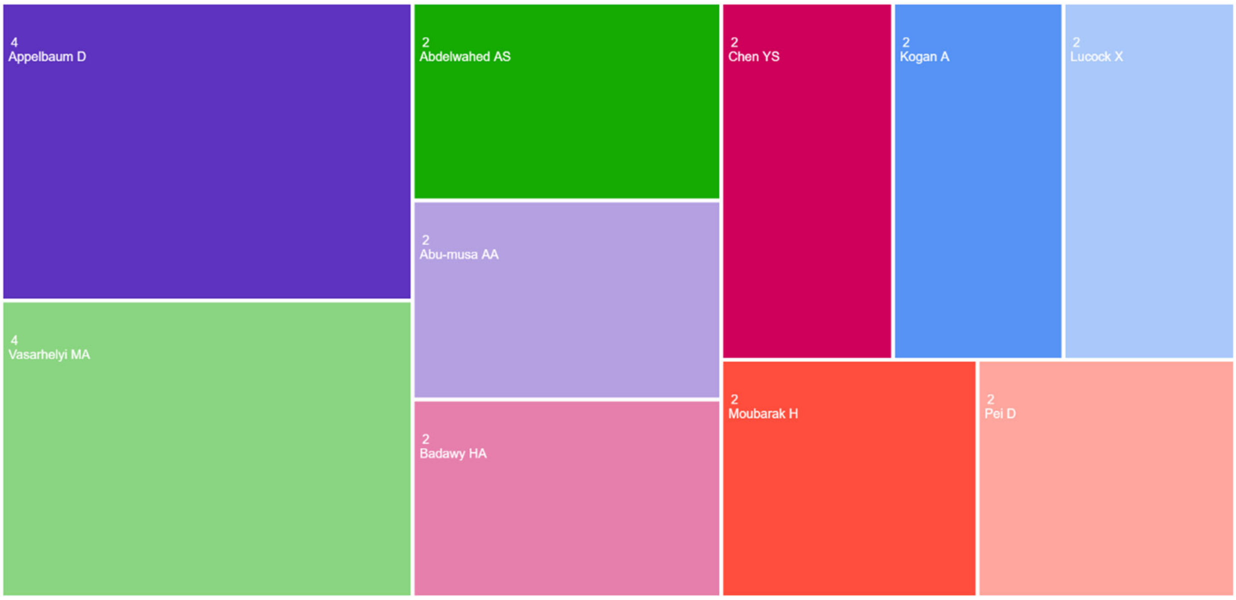

Figure A4. Authors' Publications.

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