



ISSN: 2785-2997

Review Article

Journal of Human, Earth, and Future

Vol. 7, No. 1, March, 2026



AI-Driven Information Systems for Sustainable Tourism: A Review of IoT and Big Data Applications

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Received 05 May 2025; Revised 23 January 2026; Accepted 07 February 2026; Published 01 March 2026

Abstract

Background: Converging technologies of Big Data and Internet of Things (IoT) in sustainable tourism need systematic review of existing applications, efficacy, and implementation issues to enable evidence-based strategies for development. **Methods:** Systematic review in line with PRISMA guidelines of five principal databases across eight years searched peer-reviewed articles. Systematic screening was used to select studies with high inter-rater reliability, as confirmed during study selection. **Results:** Three main application fields appeared with different evidence profiles. Customer experience enhancement was well empirically supported by AI-enabled personalization systems utilizing neural networks, collaborative filtering techniques, and IoT-enabled infrastructure, including smart environmental controls, wearable device integration, and automated service delivery. Sustainability applications offered compelling proof through IoT sensor networks facilitating real-time environmental monitoring, predictive crowd control analytics, and intelligent resource optimization with substantial efficiency gains over traditional methods. Ethical concerns emerged in substantial implementation hurdles: though most research recognized privacy and data management issues, few suggested feasible agendas for ethical data stewardship. Geographical analysis offered extreme urban-bias with rural tourism environments represented far less. Explainable AI methods were not forthcoming even as transparency requirements increased. The key implementation obstacles were infrastructure expenses, technical interoperability issues, and lack of skilled personnel, mainly impacting resource-scarce settings. **Conclusions:** There is support for the effectiveness of IoT and Big Data technologies for enhancing customer experiences and environmental sustainability in tourism contexts. However, there are key deficiencies in ethical frameworks, rural tourism applications, and explainable AI implementations. Research agendas include the creation of scalable solutions in diverse geographical contexts, tourism-specific privacy frameworks, and participatory governance frameworks. These findings inform evidence-based approaches to responsible smart tourism development that reconcile technological innovation with ethical regard and fair application in varied tourism settings.

Keywords: Big Data Analytics; Internet of Things (IoT); Sustainable Tourism; Decision-Making; Tourism Technology; Hospitality Management; Tourism Information Systems; Intelligent Personalization; Predictive Analytics; Explainable AI.

1. Introduction

The rapid advancement of technology, particularly in data analytics and digital infrastructure, has fundamentally transformed numerous industries, with tourism emerging as one of the most significantly impacted sectors. The integration of Big Data and Internet of Things (IoT) technologies into tourism operations represents a paradigm shift that is reshaping how destinations are managed, how tourist experiences are delivered, and how sustainable practices

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<https://doi.org/10.28991/HEF-2026-07-01-015>

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are implemented across the industry [1, 2]. This technological convergence offers unprecedented opportunities for operational efficiency, enhanced customer experiences, optimized resource management, and the promotion of sustainable tourism practices. However, despite these promising developments, the comprehensive application of these technologies within sustainable tourism and hospitality contexts remains significantly underexplored, creating substantial research gaps concerning their holistic impact, implementation challenges, and ethical considerations [3, 4].

1.1. Technology Integration in Tourism: Current State and Evolution

Big Data, characterized by the extensive volumes of structured and unstructured data generated from diverse digital activities, including online searches, social media interactions, mobile applications, and IoT sensors, has emerged as a critical enabler for understanding complex tourism dynamics. Previous research has demonstrated that Big Data analytics facilitate the deciphering of consumer behaviors, forecasting of tourism trends, personalization of services, and enhancement of strategic decision-making processes [5-7]. Concurrently, IoT technology enhances tourism infrastructure by creating interconnected device ecosystems that enable real-time data collection, monitoring, and responsive service delivery. In practical applications, IoT deployments span smart cities, intelligent hotels, and heritage site management, where they support continuous monitoring of tourist activities, dynamic resource management, and proactive mitigation of overcrowding issues. The convergence of these technologies with artificial intelligence (AI) has further amplified their transformative potential [8, 9]. Sophisticated AI methodologies, including advanced machine learning algorithms, predictive analytics models, and intelligent recommendation engines, are increasingly employed to process and analyze the vast amounts of Big Data generated by tourists, service providers, and destination management platforms. This technological integration enables tourism operators to develop more responsive, context-aware, and adaptive decision-making environments that can predict trends, optimize resource allocation, and enhance overall tourist experiences through dynamic, data-driven service customization [10, 11].

1.2. Technology Integration in Tourism: Current State and Evolution

Recent scholarly investigations have provided valuable insights into the digital transformation of tourism through the adoption of IoT and Big Data. Researchers have offered comprehensive bibliometric analyses examining innovative tourism trends, with particular emphasis on service personalization and technological innovation within urban environments. Similarly, other researchers have provided critical sector-specific perspectives focused on hospitality applications while maintaining a narrower scope that leaves broader sustainability questions and cross-contextual applications largely unexplored [12-15]. However, critical gaps persist in the current literature that this study seeks to address. First, existing reviews inadequately address the complex interplay between AI, IoT, and Big Data, particularly in relation to sustainable tourism practices and ethical data governance frameworks. Second, there is a conspicuous absence of a comprehensive, up-to-date synthesis that spans both operational efficiency considerations and the ethical, practical, and infrastructural challenges associated with technology adoption across diverse tourism contexts. Third, rural and resource-constrained settings remain significantly underrepresented in current research, with most studies focusing predominantly on urban, technologically advanced destinations. Fourth, limited attention has been given to community engagement and participatory governance in the design and implementation of smart tourism systems. The lack of a holistic framework that integrates technical capabilities with sustainability imperatives, ethical considerations, and diverse geographical contexts constitutes a significant deficiency in the current academic discourse. This gap is particularly pronounced given the increasing global emphasis on sustainable development goals and responsible tourism practices [16-21].

1.3. Research Objectives and Contribution

This systematic literature review aims to bridge the identified knowledge gaps by providing a comprehensive synthesis of research on the integration of Big Data and IoT within sustainable hospitality and tourism contexts. Adhering rigorously to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol, this review synthesizes existing research to derive balanced insights into the potential advantages, limitations, and prospects of these technologies for enhancing sustainability across diverse tourism environments. The study makes several distinctive contributions to academic literature. First, it provides the first comprehensive systematic review that explicitly focuses on the intersection of Big Data, IoT, and sustainable tourism practices, offering a unified analytical framework that previous studies have not addressed. Second, it examines both urban and rural tourism contexts, providing insights into scalability and adaptability challenges across different resource environments. Third, it synthesizes technical, ethical, and practical considerations within a single analytical framework, offering actionable recommendations for diverse stakeholder groups. Fourth, it identifies emerging trends and future research directions that can guide both academic inquiry and practical implementation efforts.

1.4. Scope and Research Questions

This review addresses three primary research domains that capture the multifaceted nature of Big Data and IoT applications in sustainable tourism. The first domain examines the utilization of Big Data and IoT technologies for enhancing customer experience through personalized services and real-time engagement mechanisms. The second domain investigates the implications of these technologies for sustainable resource management, including environmental monitoring, energy optimization, and crowd control strategies at high-traffic destinations. The third domain examines the ethical and technical challenges that these technologies present to the tourism sector, with a particular focus on data privacy, security concerns, and governance frameworks.

Three specific research questions guide the research:

- RQ1:** How does the integration of Big Data and IoT enhance customer experience in tourism through personalized services and real-time engagement?
- RQ2:** In what ways does the integration of Big Data and IoT impact sustainable practices within tourism, particularly in resource management and crowd control at high-traffic destinations?
- RQ3:** What are the primary ethical concerns and privacy risks associated with Big Data and IoT usage in tourism, and how are these challenges addressed in current research?

1.5. Methodology and Significance

By synthesizing existing research across these thematic areas, this review establishes a comprehensive foundation for understanding current applications and identifies critical gaps that require further investigation. The findings will help industry stakeholders, policymakers, and tourism managers make informed decisions about implementing data-driven solutions for sustainable development. For technology providers, the review provides valuable insights into market needs and development priorities that can inform and guide innovation efforts. For academic researchers, it provides a roadmap for future investigations in this rapidly evolving interdisciplinary field.

1.6. Article Structure

The remainder of this paper is organized as follows: Section 2 provides a comprehensive overview of the relevant literature on IoT and Big Data applications in tourism, establishing the theoretical and practical foundations for the study. Section 3 describes the systematic review methodology, including database selection criteria, systematic search strategies, inclusion and exclusion criteria, and data extraction processes, all following the PRISMA guidelines. Section 4 presents and analyzes the main findings organized around the three research questions, examining personalization and customer experience, sustainability and resource management, and ethical and privacy considerations. Section 5 discusses the implications of these findings for both research and practice, presents actionable recommendations for stakeholders, and outlines directions for future research. Finally, Section 6 concludes the paper by synthesizing the main findings, providing specific recommendations for practitioners and policymakers, and presenting perspectives on future opportunities for integrating IoT, Big Data, and AI technologies in sustainable tourism development.

2. Literature Review

2.1. Internet of Things (IoT) and Big Data Technologies in Smart Tourism

The integration of the Internet of Things (IoT) and Big Data technologies into the tourism industry has fundamentally transformed how destinations are conceptualized, managed, and experienced by visitors. IoT encompasses a network of interconnected devices—ranging from environmental sensors to mobile devices—that communicate and exchange data through internet connectivity, creating seamless ecosystems where devices, people, and systems collaborate to enhance operational efficiency and service delivery. This technological convergence has become increasingly prevalent in tourism applications, with smart cities and destinations adopting these innovations to create enhanced tourist experiences while managing resources more sustainably. IoT technology serves as a foundational element in smart tourism, which fundamentally relies on real-time data collection and analysis to manage tourist activities, personalize experiences, and optimize service delivery [22-24]. According to researchers, the Internet of Things (IoT) enables transformative applications and services, including automated hotel check-ins, intelligent transportation systems, and AI-powered personalized recommendations for tourists, all of which are essential components for enhancing overall tourist satisfaction and operational efficiency. IoT devices continuously collect vast amounts of behavioral and preference data from tourists, which tourism managers then utilize to make informed decisions regarding tourist flow management, congestion reduction at popular sites, and dynamic resource optimization [25-27].

A representative example involves the deployment of smart sensors throughout tourist destinations to monitor environmental conditions, tourist movement patterns, and location-specific capacity utilization. This real-time data collection enables proactive management of overcrowding while supporting sustainability initiatives by preventing

excessive strain on heritage sites and natural environments. In their case study examining innovative heritage management in historical centers, researchers demonstrate how IoT systems effectively monitor visitor flows and prevent over-tourism, which poses multiple risks to cultural heritage preservation and the quality of visitor experiences. Big Data, characterized by large-scale datasets sourced from diverse origins, including IoT devices, social media platforms, and tourism booking systems, plays a critical role in understanding complex tourism trends, predicting tourist behaviors, and enhancing strategic decision-making processes [28-31]. According to a research study, Big Data analytics empower tourism managers to collect, process, and analyze extensive information volumes, enabling accurate demand forecasting, dynamic pricing optimization, and service customization aligned with individual tourist preferences. In innovative tourism applications, Big Data analytics frequently support tourist experience management by delivering real-time updates regarding available services, current weather conditions, and personalized activity recommendations based on tourists' geographical location and expressed preferences. Within rural tourism contexts, researchers describe comprehensive applications of Big Data for analyzing tourist flow patterns and managing resources in rural destinations. Through predictive data analysis for identifying peak visitation periods and continuous monitoring of tourist behavior patterns, rural areas can enhance service delivery while maintaining environmental sustainability [32-36].

The convergence of IoT and Big Data technologies has fundamentally transformed traditional tourism management approaches. Historical crowd management and tourist flow monitoring relied primarily on manual estimation and basic counting methods. Contemporary IoT and Big Data integration enables automated, real-time execution with unprecedented accuracy levels. For instance, IoT-based sensor networks can continuously track visitor flows at popular attractions within smart tourism destinations. At the same time, Big Data analytics predict peak visitation periods, enabling managers to distribute visitors more effectively across time and space [37, 38]. This technological integration extends beyond practical tourism behavior management to encompass significant improvements in delivering personalized experiences. Other researchers demonstrated that integrating 5G networks with AI-driven IoT systems enables uninterrupted data transmission and real-time processing capabilities, creating more dynamic and responsive tourist management systems. This technological foundation enables tourism operators to provide real-time, personalized recommendations aligned with individual tourist interests while allowing for immediate service adjustments based on instantaneous demand fluctuations [39-41].

The Venn diagram below (Figure 1) illustrates the three primary applications of IoT and Big Data technologies in smart tourism: Connected Tourist Services (real-time information and navigation systems), Cultural Heritage Sites (visitor flow management and preservation technologies), and Smart Hotels & Accommodations (automated systems and personalization). The overlapping areas demonstrate synergistic applications: Cultural Navigation (AR-enhanced storytelling and interactive tours), Sustainable Tourism (resource optimization and environmental monitoring), and Enhanced Guest Experience (seamless service integration). The central intersection represents the core of AI-enhanced IoT and Big Data integration, enabling all applications. The diagram incorporates key technologies, including Neural Networks, IoT sensors, predictive analytics, and explainable AI techniques (SHAP, LIME) that support transparent decision-making in tourism management systems.

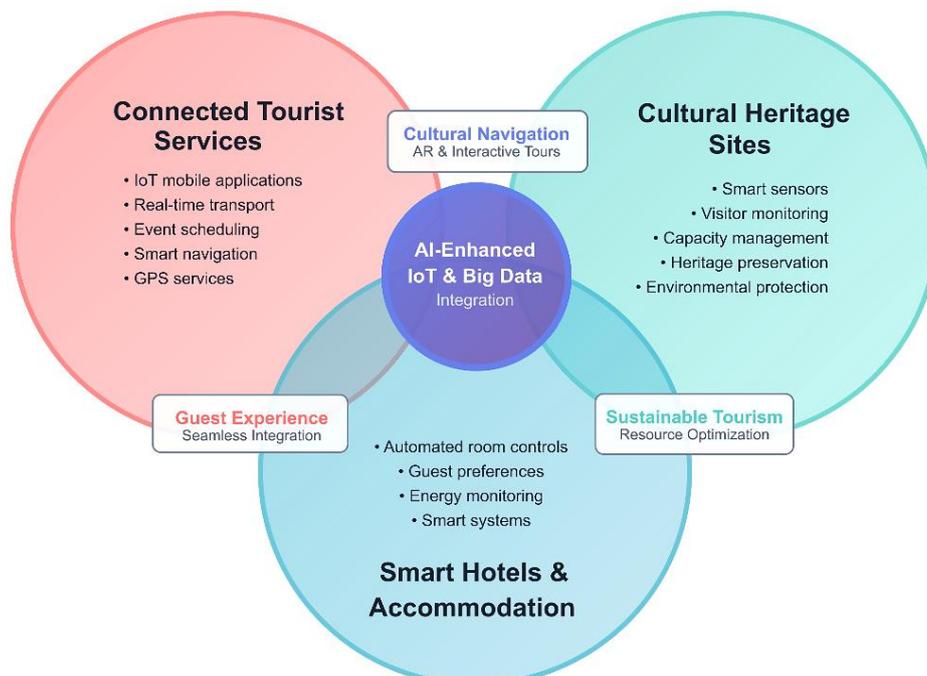


Figure 1. Smart Tourism Applications Venn Diagram

Furthermore, IoT and Big Data technologies provide substantial value in risk management within digital tourist ecosystems. Researchers establish that these technologies enable the prediction and prevention of potential risks associated with tourist flows, including overcrowding, security challenges, and environmental degradation, allowing tourism managers to implement proactive risk mitigation strategies. The integration of artificial intelligence with IoT and Big Data has introduced sophisticated analytical capabilities that enhance tourism service delivery through advanced personalization and predictive analytics. The current literature identifies several specific AI models and techniques commonly employed in tourism contexts [42-45]. Neural networks, particularly Convolutional Neural Networks (CNNs), are widely used for analyzing hotel review sentiment and processing visual content. At the same time, Deep Learning architectures support advanced personalization algorithms that analyze complex patterns of tourist behavior. Recurrent Neural Networks (RNNs) and Long Short-Term Memory (LSTM) networks prove particularly effective for time-series forecasting in tourism demand prediction [46-49].

Natural Language Processing (NLP) techniques are widely used for sentiment analysis on social media, review processing, and chatbot development. Advanced NLP models, including transformer-based architectures, enable real-time language translation services and intelligent virtual tourism assistants. Recommender systems utilize collaborative filtering algorithms, including both user-based and item-based approaches, which are fundamental to tourism recommendation engines. Trust-based collaborative filtering (Trust-CF) and matrix factorization techniques are commonly implemented for Point of Interest (POI) recommendation systems [50-54]. Additionally, machine learning algorithms such as Random Forest and Support Vector Machines are frequently employed for tourist classification and behavior prediction, while clustering algorithms, particularly K-means and hierarchical clustering, support tourist segmentation for targeted marketing strategies [55-58].

AI-powered IoT devices, combined with sophisticated Big Data analytics, have revolutionized personalized tourism through intelligent, real-time, data-driven services that precisely address individual traveler requirements. The integration of AI-enhanced IoT devices, including wearable technologies, mobile applications, and innovative environmental sensors, enables comprehensive data collection across the entire lifecycle of the tourist experience. These AI-powered systems generate extensive, diverse datasets that intelligent analytical platforms use to understand, predict, and respond to tourists' behavioral patterns and preferences [56-59]. Through AI-enabled IoT device networks, continuous real-time tracking of tourist activities enables intelligent recommendation engines to provide highly personalized suggestions regarding destinations, dining options, and exclusive experiences tailored to individual traveler profiles. AI-driven Big Data analytics complements IoT capabilities by analyzing vast volumes of collected data and translating them into actionable, context-aware insights that enhance decision-making processes [60-63].

Current research reveals a pronounced urban-centric bias in the literature, which can be attributed to several interconnected factors. Rural tourism destinations often lack the advanced digital infrastructure necessary for the comprehensive implementation of IoT and Big Data, including limited broadband connectivity, inconsistent cellular coverage, and inadequate technological support systems. Economic constraints further compound this issue, as rural tourism operations are frequently characterized by smaller-scale enterprises with limited financial resources for technology adoption [64-66]. The high initial investment costs associated with IoT infrastructure and Big Data analytics systems make these technologies less accessible to rural tourism operators. Additionally, academic research institutions and technology companies tend to concentrate their resources and partnerships in urban areas where they can achieve greater visibility, larger sample sizes, and more measurable economic impacts. To address this significant gap, future research should prioritize the development of low-cost, scalable solutions designed explicitly for resource-constrained rural environments. Public-private partnerships among government agencies, academic institutions, and technology providers could facilitate infrastructure development and research funding focused on rural tourism applications. Capacity-building programs and educational initiatives for rural tourism operators can enhance local expertise and create sustainable frameworks for technology adoption [67-69].

2.2. Practical Applications of IoT and Big Data in Sustainable Smart Tourism

The incorporation of IoT technology into tourism infrastructure offers significant opportunities to advance sustainability through enhanced environmental monitoring and efficient resource management systems. IoT sensors, smart meters, and real-time communication networks are strategically deployed throughout tourism infrastructure to continuously monitor resource utilization and environmental conditions, enabling tourism managers to make data-driven decisions that conserve natural resources while minimizing the environmental impact of tourism activities [70-76].

IoT technology makes one of its most significant contributions to sustainable tourism through real-time environmental condition monitoring. IoT sensors can be strategically positioned in natural reserves, national parks,

and tourist destinations to continuously track air quality parameters, water quality indicators, temperature fluctuations, and humidity levels. These sensors provide tourism managers with precise, continuously updated information, enabling rapid responses when environmental thresholds approach critical levels. For instance, in fragile ecosystems, IoT sensors can monitor changes in water and soil quality, warning managers when conditions risk disrupting the area's natural equilibrium. With real-time information on environmental status, managers can limit visitor numbers or temporarily close specific zones to prevent further ecological damage [77-79].

In addition to environmental monitoring, the Internet of Things (IoT) plays a significant role in resource management within tourism infrastructure, particularly in hotels, resorts, and restaurants. Smart meters monitor water, electricity, and gas consumption in these establishments, providing real-time data that helps managers identify inefficiencies and implement energy-saving measures. This real-time tracking enables quick interventions to optimize resource use and minimize waste. Hotels and resorts, which are often significant consumers of water and energy, can significantly benefit from implementing the Internet of Things (IoT). IoT-enabled smart thermostats and lighting systems automatically adjust according to occupancy levels, helping reduce energy consumption while enhancing the guest experience through personalized environmental settings [80-82].

IoT systems have demonstrated effectiveness in encouraging renewable energy adoption and reducing the overall environmental footprint of tourism operations. By monitoring resource consumption comprehensively, IoT systems provide critical insights into areas that require improvement and optimization. Smart grids integrated with IoT devices enable tourism establishments to monitor energy consumption from renewable sources, including solar panels and wind turbines. In locations with sustainable energy systems, IoT technology tracks the performance and output of renewable energy installations, ensuring optimal, efficient operation. Beyond individual tourist establishments, the Internet of Things (IoT) plays a vital role in promoting sustainability on broader urban scales through intelligent transportation systems. In many smart cities, IoT sensors monitor traffic flows, congestion levels, and emissions, enabling more efficient and eco-friendly urban mobility solutions. IoT-enabled traffic management systems use real-time data to regulate traffic lights, optimize public transport routes, and reduce congestion in tourist-heavy areas, thereby minimizing the carbon footprint of tourism-related transportation while encouraging public transit and shared mobility options [83-86].

An emerging trend in sustainable smart tourism involves creating personalized, environmentally responsible experiences for tourists by strategically integrating IoT and Big Data. These technologies enable tourism providers to deliver customized services that align with individual traveller preferences while actively encouraging environmentally responsible behaviors [87, 88]. In smart hotels and tourist accommodations, IoT systems offer opportunities to enhance the visitor experience and promote sustainable practices. Smart meters and sensors installed in hotel rooms allow guests to monitor their energy and water consumption in real time, helping them become more aware of their resource use and encouraging the adoption of sustainable behaviors [89-91].

Big Data analytics play a crucial role in developing personalized itineraries that simultaneously fulfil tourist preferences and sustainability objectives. By analyzing extensive data from social media platforms, booking websites, and IoT sensors, Big Data systems can predict tourist interest in specific activities, including local cultural tours, eco-tourism experiences, cycling, and hiking [92-94]. This analytical capability enables tourism companies to recommend more sustainable activities, such as visits to less-visited natural parks or eco-certified accommodations. By promoting green options through personalized itineraries, Big Data empowers tourists to make sustainable choices that support destination sustainability [95-97].

Despite the significant benefits IoT and Big Data offer for promoting tourism sustainability, several challenges persist, particularly in developing regions and rural contexts. Energy consumption poses a considerable challenge, as IoT devices often operate continuously in remote or inaccessible locations, and many rely on battery power, which limits their operational lifespan. The vast volumes of data generated by IoT devices present significant challenges for storage, processing, and analysis, requiring effective data filtering mechanisms to extract actionable insights while reducing storage and processing resource burdens. As IoT systems expand, infrastructure requirements increase substantially, necessitating robust networks, extensive data storage capabilities, and substantial processing power to handle the growing number of devices and data volumes. Additionally, devices from different manufacturers often employ varied communication protocols, resulting in compatibility issues within multi-vendor ecosystems (Figure 2) [98-100].

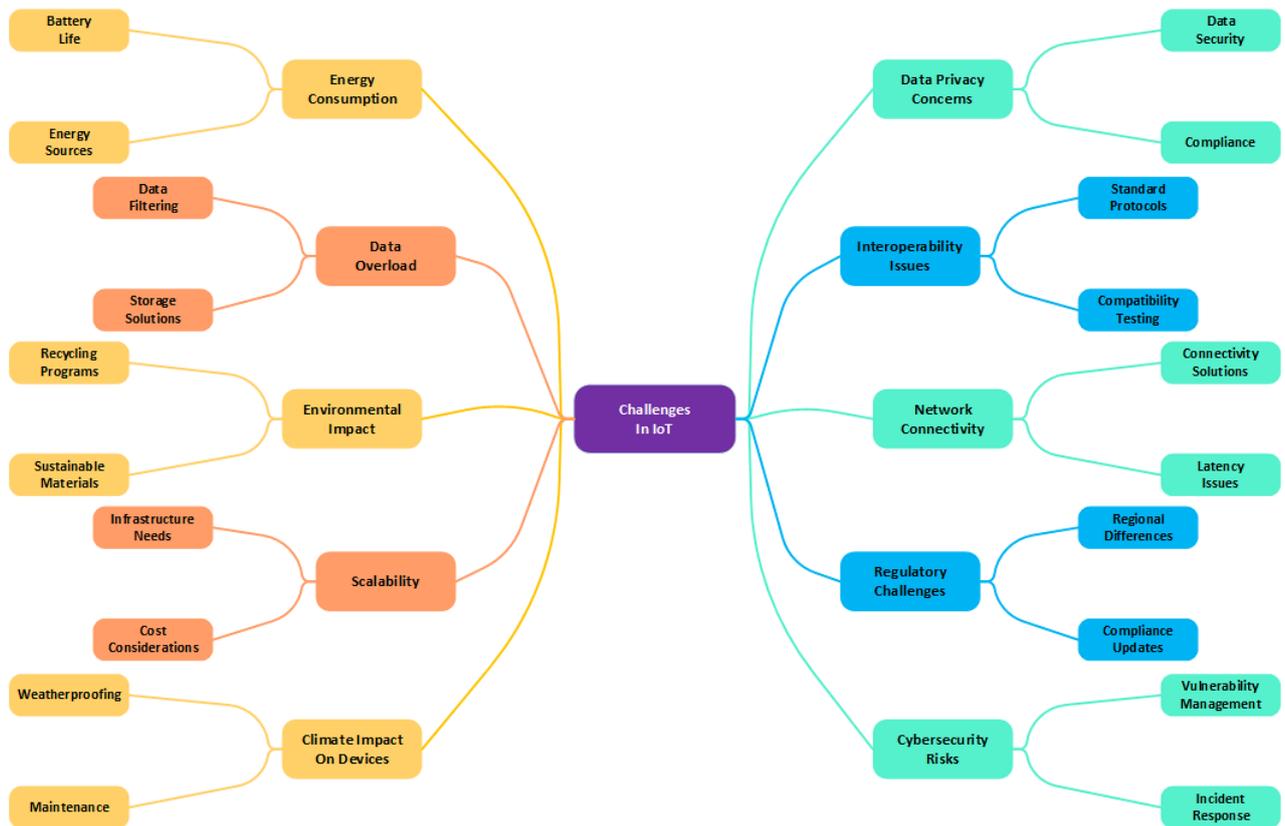


Figure 2. Overview of the challenges in implementing IoT in Tourism

The implementation of explainable AI in tourism contexts addresses critical needs for transparency and trust in algorithmic decision-making. SHAP (SHapley Additive exPlanations) values are particularly effective in tourism recommendation systems, enabling explanations of why specific destinations, accommodations, or activities were recommended to individual tourists. LIME (Local Interpretable Model-Agnostic Explanations) techniques prove valuable for explaining individual predictions in tourism demand forecasting models, helping tourism managers understand which factors contributed to predicted visitor numbers. Attention mechanisms in neural network-based tourism applications can highlight which aspects of tourist behavior or destination characteristics are most influential in prediction models. In contrast, decision trees and rule-based systems provide inherently interpretable models, making them suitable for dynamic pricing algorithms and resource allocation systems [101-104].

The continued advancement of IoT and Big Data technologies, enhanced by 5G networks and edge computing capabilities, will significantly influence sustainable, innovative tourism development. These innovations promise to revolutionize destination management approaches, tourist engagement methods, and community empowerment mechanisms, thereby contributing to sustainable development [105-107]. The establishment of 5G networks represents one of the most significant developments, propelling IoT and Big Data applications in tourism. With low-latency, high-speed data transmission capabilities, these networks enable enhanced communication between IoT devices, facilitating real-time monitoring and faster response times. This technological improvement is particularly crucial in high-traffic tourist destinations, where rapid data collection and analysis are essential for effective management of tourist flows and mitigating environmental impact [108-110].

Community-driven decision-making is another promising application area for integrating IoT and Big Data in sustainable tourism. Local communities, particularly in tourism-dependent regions, are often significantly impacted by tourism activities but typically have limited influence over their management. IoT and Big Data technologies can empower communities to actively shape sustainable tourism practices by providing residents with access to real-time data on tourist numbers, resource consumption, and environmental impacts. This data-driven community engagement approach ensures that tourism development aligns with local sustainability priorities while creating collaborative frameworks that benefit both the tourism industry and dependent communities (Figure 3) [111-113].

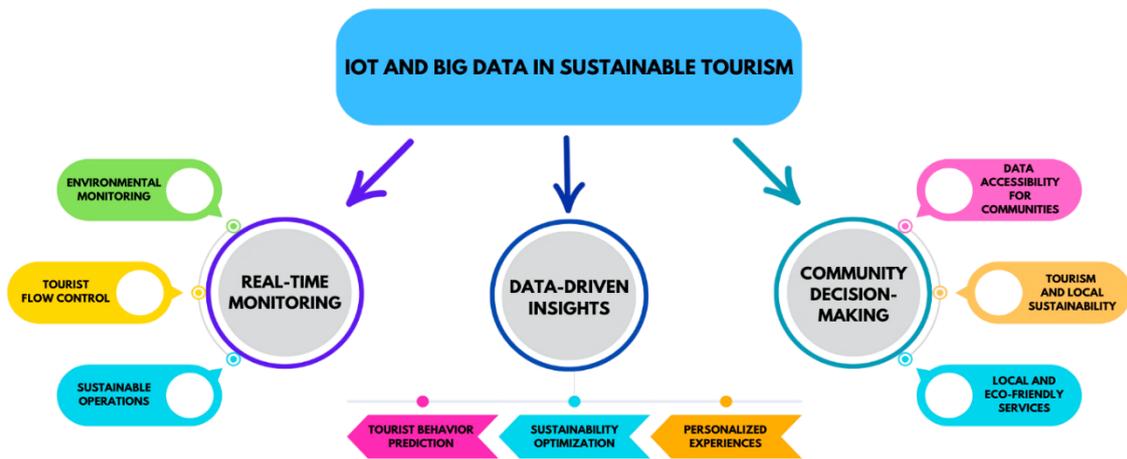


Figure 3. Overview of Big Data and IoT technologies in sustainable Tourism

3. Material and Methods

3.1. Scope

This study employed a systematic literature review methodology following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [114]. The systematic literature review is a methodologically rigorous approach for locating, evaluating, and synthesizing relevant research findings on a specific topic through transparent, replicable procedures. This methodology facilitates the identification of critical studies while fostering a comprehensive understanding of the knowledge base and conclusions across diverse research contexts. The review protocol was prospectively designed to examine the integration of Big Data and Internet of Things (IoT) technologies within the contexts of sustainable tourism and hospitality. The systematic approach ensures methodological transparency, reduces selection bias, and enhances the reproducibility of findings. The procedural framework underpinning this systematic review is illustrated in Figures 4 and 5, which delineate each sequential step of this structured research approach.

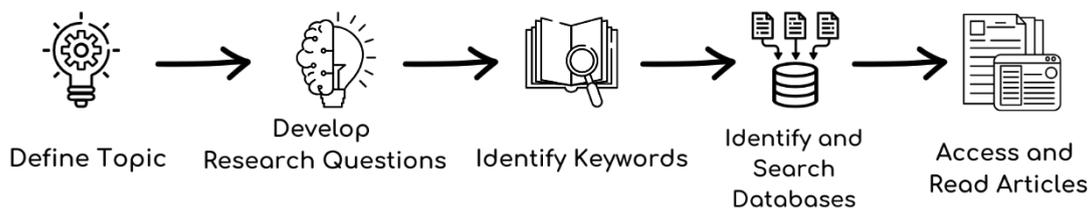


Figure 4. Steps of the Systematic Literature Review Process

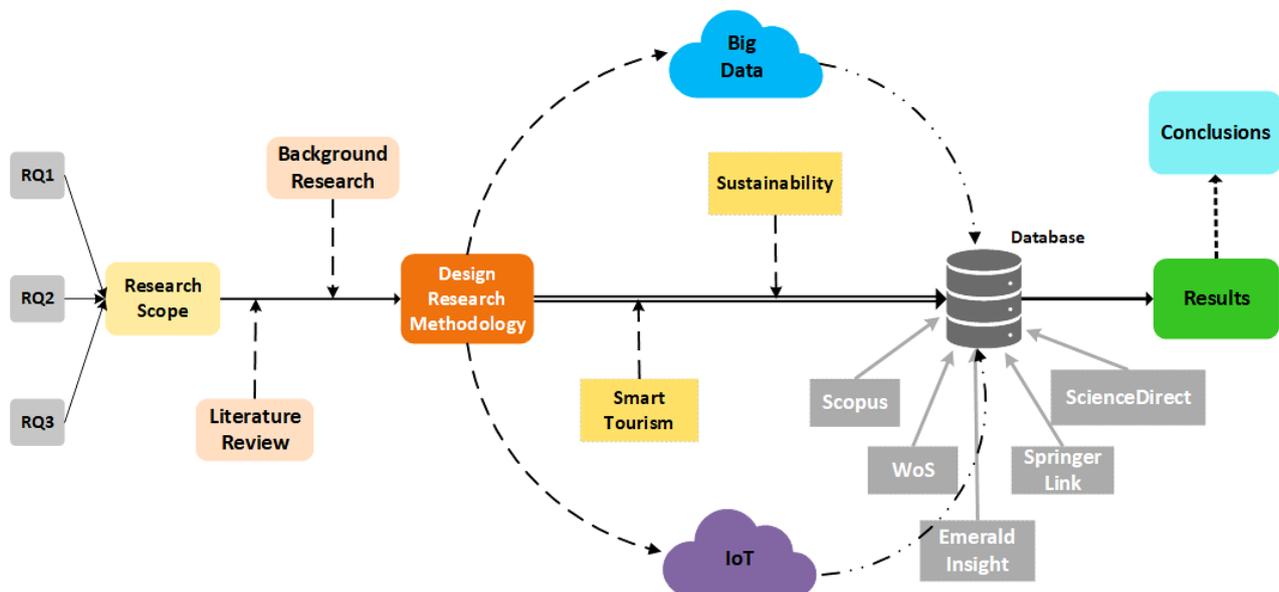


Figure 5. Methodology Flowchart

Moreover, this systematic review was guided by four specific research objectives designed to comprehensively examine the intersection of Big Data, IoT, and sustainable tourism: (1) to analyze how Big Data and IoT technologies can be leveraged for sustainable tourism development and implementation, (2) to evaluate the impact of Big Data and IoT on tourist experience enhancement through personalized services and real-time engagement, (3) to examine the influence of Big Data and IoT on sustainable practices within tourism, particularly regarding resource management and crowd control at high-traffic destinations, and (4) to identify and analyze the primary ethical concerns and privacy risks associated with Big Data and IoT usage in tourism contexts. These objectives informed the development of three primary research questions that served as the analytical framework for the systematic review.

- **RQ1** examines how the integration of Big Data and IoT enhances customer experience in tourism through personalized services and real-time engagement.
- **RQ2** investigates the ways in which Big Data and IoT integration impacts sustainable practices within tourism, particularly in resource management and crowd control at high-traffic destinations.
- **RQ3** explores the primary ethical concerns and privacy risks associated with Big Data and IoT usage in tourism and how these challenges are addressed in current research.

3.2. Search Strategy Development and Implementation

The search strategy was developed through a systematic three-phase approach to ensure comprehensive coverage of relevant literature. The preliminary keyword identification phase involved consulting seminal works in smart tourism and IoT literature, examining MeSH terms and subject headings in appropriate databases, and analyzing keyword frequencies in pilot searches. The identified core concepts included Big Data analytics, the Internet of Things, smart tourism, sustainable tourism, and hospitality management.

During the keyword expansion phase, each core concept was expanded to include synonyms, alternative spellings, and related terms. Big Data encompassed "big data", "data analytics", "data mining", and "predictive analytics". IoT included "IoT", "Internet of Things", "connected devices", and "smart sensors". Tourism incorporated "tourism", "travel", "hospitality", and "destination management". Smart tourism covered "smart tourism", "intelligent tourism", "digital tourism", and "e-tourism". Sustainability terms included "sustainable", "green tourism", "eco-tourism", and "environmental".

The search string optimization phase involved constructing the final search string using Boolean operators to ensure optimal recall while maintaining precision. The primary search string applied was:

("IoT" OR "Internet of Things" OR "smart sensors") AND ("big data" OR "data analytics" OR "predictive analytics") AND ("tourism" OR "smart tourism" OR "hospitality" OR "sustainable tourism") AND PUBYEAR > 2015 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (PUBSTAGE, "final"))

Five academic databases were selected based on their comprehensive coverage of computer science, tourism, and hospitality literature: Scopus for multidisciplinary coverage with extensive engineering and computer science content, Web of Science as a comprehensive citation database covering multiple disciplines, ScienceDirect for Elsevier's platform covering technology and social sciences, SpringerLink for computer science and tourism management literature, and Emerald Insight for business and management focus with hospitality specialization. Search strings were adapted for each database to accommodate syntactic differences while maintaining semantic equivalence. Searches were conducted in title, abstract, and keyword fields to ensure comprehensive coverage, with all searches completed in November 2024 and additional manual screening of reference lists from included studies.

3.3. Inclusion and Exclusion Criteria

The inclusion criteria were designed to ensure methodological rigor and topical relevance through seven specific requirements. Topical relevance requires articles that explicitly address Big Data and/or IoT applications in tourism, hospitality, or destination management contexts, ensuring direct relevance to the research questions. The temporal scope spanned publications from January 2016 to December 2024, capturing recent technological developments while ensuring a robust literature base. The language specification limited inclusion to articles published in English for accessibility and comprehensibility during analysis. Publication type restriction to peer-reviewed journal articles only ensured methodological quality and academic rigor.

Keyword coverage requires articles containing at least two specified keywords in the title, abstract, or author keywords to ensure sufficient topical overlap. Sustainability-focused articles were mandated to address environmental, social, or economic sustainability aspects, aligning with the research focus on sustainable tourism. Empirical or theoretical contribution required articles presenting original research, theoretical frameworks, or comprehensive reviews, excluding purely editorial or opinion pieces.

The exclusion criteria comprised six specific restrictions aimed at maintaining study quality and coherence. Publication-type exclusions eliminated conference papers, book chapters, dissertations, and reports that did not meet peer-reviewed journal standards. Language exclusions removed non-English publications due to practical limitations and consistency requirements. Temporal scope exclusions were applied to eliminate publications before 2016 or after 2024 to maintain contemporary relevance. Topical irrelevance exclusions removed articles that did not address Big Data or IoT in tourism contexts to ensure topical coherence. Insufficient detail exclusions eliminated articles lacking sufficient methodological or empirical detail to enable meaningful analysis. Duplicate publication exclusions prevented multiple publications of the same study to avoid bias from over-representation.

3.4. Study Selection and Quality Assessment

The study selection process followed a systematic four-stage approach, beginning with initial database searches conducted across all five databases using the developed search strings, yielding an initial pool of 1,247 records. The second stage involved duplicate removal and initial screening, during which duplicate records were identified using EndNote reference management software and manually verified, yielding 892 unique records. Initial screening involved examination of titles and abstracts against inclusion/exclusion criteria (Figure 6).

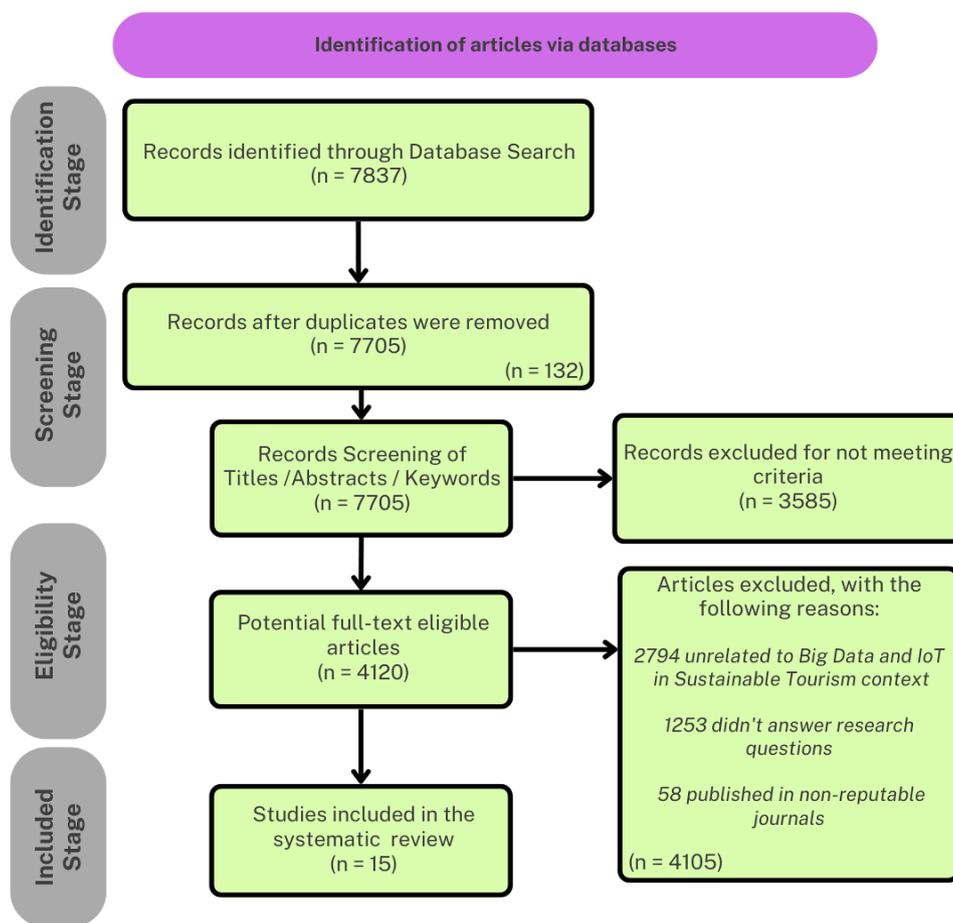


Figure 6. Flowchart of PRISMA Methodology

The third stage involved a full-text assessment, where articles that passed the initial screening underwent a full-text review by two independent reviewers. Disagreements were resolved through discussion and, when necessary, consultation with a third reviewer. The final stage involved final selection and quality assessment using adapted criteria from the Critical Appraisal Skills Program (CASP) for different study types.

Data extraction was performed using a standardized form developed specifically for this review, which captured bibliographic information, including author(s), year, journal, and country of origin. Study characteristics encompassed research objectives, methodology, sample size, and data collection methods. Technological focus examined specific IoT applications, Big Data techniques, and AI/ML methods employed. The tourism context encompasses the tourism sector (urban or rural), application domain, and stakeholder groups. Key findings included primary outcomes, benefits

identified, and challenges reported. Sustainability aspects addressed environmental, social, and economic sustainability measures. Limitations were captured as reported by the authors, while quality indicators assessed sample size, methodological rigor, and theoretical grounding.

To ensure consistency in data extraction, two reviewers independently extracted data from 20% of the included studies. Inter-rater reliability was assessed using Cohen's kappa coefficient, achieving $\kappa = 0.87$, indicating substantial agreement. Discrepancies were resolved through discussion and consensus.

3.5. Thematic Synthesis and Coding Framework

Thematic synthesis was conducted following the framework proposed by Thomas and Harden, involving three stages: free line-by-line coding, organizing free codes into descriptive themes, and developing analytical themes. This approach enables the systematic identification of patterns while maintaining methodological transparency.

The coding process began with open coding conducted using NVivo 12 software, where two researchers independently coded all included studies. Free codes were assigned to capture specific concepts, technologies, applications, benefits, and challenges mentioned in the literature. The second stage involved axial coding, in which free codes were organized into descriptive themes aligned with the three research questions: Theme 1 addressed personalization and customer experience enhancement; Theme 2 examined sustainable resource management and environmental impact; and Theme 3 explored ethical considerations and privacy challenges.

The final stage involved selective coding, where analytical themes were developed through iterative analysis, identifying relationships between descriptive themes and refining higher-order concepts that addressed the research questions. Beyond the predefined thematic framework, inductive coding was employed to identify emergent themes not anticipated in the original research design, ensuring a comprehensive capture of novel insights while maintaining systematic rigor.

Emergent themes identified included the urban-rural divide in technology adoption, community engagement, and participatory governance, as well as explainable AI requirements in tourism contexts and scalability challenges in resource-constrained environments. Coding reliability was ensured through dual coding of 30% of studies by two researchers, regular consensus-building meetings to discuss coding decisions and resolve disagreements, detailed audit trail documentation of coding decisions and theme development, and member-checking validation of themes through comparison with original study findings.

3.6. Study Characteristics and Methodological Considerations

The final selection yielded 15 high-quality studies meeting all inclusion criteria, distributed across publishers as follows: MDPI (4 articles, 26.7%), Emerald Insight (3 articles, 20.0%), Elsevier/IEEE (2 articles, 13.3%), Wiley/Hindawi (2 articles, 13.3%), and other publishers (4 articles, 26.7%). While the final sample of 15 studies may appear modest, this reflects several factors consistent with systematic review best practices (Table 1).

The emerging research area represents the specific intersection of Big Data, IoT, and sustainable tourism as a relatively nascent field with limited dedicated research. Rigorous selection criteria prioritized methodological quality over quantity, while the 2016-2024 timeframe captured contemporary technological developments. The quality-over-quantity approach emphasizes in-depth analysis of high-quality studies to provide more valuable insights than superficial coverage of numerous lower-quality publications.

Several limitations were acknowledged in the methodology, including language bias through the exclusion of non-English publications that may limit geographical representativeness, database coverage focus on academic databases that may exclude relevant grey literature, temporal constraints where rapid technological evolution may render older studies less relevant, and publication bias reflecting the tendency toward positive results in published literature. These limitations were addressed through transparent reporting and acknowledgment of their potential impact on findings. This systematic review involved the analysis of published literature only. It did not require ethical approval, as all included studies were appropriately cited and copyright considerations were observed in the presentation of findings.

Table 1. Research Papers included in the Systematic Review (n=15)

No.	Author(s)	Year	Study Objectives	Study Design	Population / Sample	Methods	Outcomes / Measures	Key Findings	Limitations
[115]	Car et al.	2019	To analyze the opportunities and challenges of IoT in tourism and hospitality, with emphasis on improving customer satisfaction and operational efficiency.	Case Study and Literature Review	Various IoT applications in tourism and hospitality	Case studies, analysis of existing IoT solutions	Insights into IoT's potential for enhancing customer satisfaction and operational efficiency through examples like geo-location and virtual concierge services.	IoT offers substantial benefits in efficiency, personalization, and cost reduction, but faces challenges such as scalability, interoperability, and data privacy.	Limited focus on future technological advancements; more empirical research needed to understand IoT's impact fully.
[116]	Elkhwesky & Elkhwesky	2023	To critically review IoT applications in hospitality, focusing on Big Data's role in enabling smart tourism.	Systematic Review	78 articles from Web of Science	Literature Review	IoT's impact on smart tourism, covering benefits like enhanced customer experience and efficiency.	IoT integration enhances smart tourism by improving data collection and analysis for tailored customer experiences. Key challenges include privacy issues and implementation costs.	Scope limited to hospitality sector within tourism; findings predominantly based on articles from 2015 to 2022, potentially limiting insights into emerging technologies.
[117]	Huang et al.	2022	To evaluate a wisdom tourism management model using Big Data and IoT, comparing it with traditional tourism models.	Comparative Experimental Study	180 participants from various age groups and tourism locations	Cross-sectional survey, data analysis	Compared smart and traditional tourism models on resource development, economic impact, and tourist experience.	The wisdom tourism model outperformed the traditional model in tourism resource utilization (82.8% vs. 70.1%), economic impact (1.4x growth), and tourist satisfaction, especially among younger users.	Limited to specific tourist sites; focus on comparing models without a deep dive into practical implementation challenges.
[118]	Kumar et al.	2022	To analyze the bibliometric trends in IoT and Smart Tourism research using Big Data applications.	Bibliometric Analysis	340 articles from Scopus Database	VOSviewer software for visualization	Trends and keyword analysis on IoT and Big Data applications in tourism and smart tourism	IoT and Big Data applications are essential for smart tourism, facilitating sustainable development, improved tourist experiences, and new business models. Challenges include data privacy and integration issues.	Limited to Scopus database; analysis spans from 2013-2021 and includes only English-language articles, which may limit representation of other significant research contributions.
[119]	Kurniawan & Nugraha	2022	To analyze the role of IoT and big data through social media in enhancing tourism services and customer engagement.	Social Media Content Analysis	Instagram accounts of top travel companies	Content analysis of Instagram posts using social analytics tool	Examines engagement metrics (likes, comments) on tourism-related posts, identifying effective marketing strategies.	Social media, powered by IoT and big data, enhances brand visibility and customer interaction in tourism.	Limited to Instagram data; results may not generalize across other social media platforms.
[120]	Li	2023	To develop a model for rural smart tourism that integrates IoT and big data to enhance tourism services	Case Study and Conceptual Model	N/A	Literature review, statistical survey, and analysis of rural tourism using big data and IoT for service improvement	Development of a smart tourism platform that collects and analyzes big data to optimize services, improve safety, and personalize tourist experiences	IoT and big data can transform rural tourism by enhancing management, safety, and visitor satisfaction through data-driven strategies	Focuses on rural tourism only, lacking empirical data from urban settings or broader tourism sectors
[121]	Nadkarni et al.	2020	To explore how IoT applications in hospitality relate to Big Data, using a conceptual approach to discuss convergence and impacts on hospitality.	Conceptual Paper	Various IoT applications in hospitality	Input-Process-Output Model, Big Data Vs	Impact of IoT on hospitality, through Big Data analytics and real-world examples like RFID and smart door locks.	IoT enables significant Big Data generation, influencing hospitality with enhanced customer experience, efficiency, and safety. Implementation challenges include privacy and interoperability issues.	Limited empirical data; conceptual focus with examples may not generalize across all hospitality sectors or geographic regions.
[122]	Novera et al.	2022	To explore the role of IoT and big data in enhancing smart tourism, focusing on improving tourism services and attracting visitors.	Bibliometric and Text Mining Analysis	469 papers from Scopus database, 36 for text mining	R Programming, VOSviewer for bibliometric analysis	Identification of key themes, topic clusters, and sentiment trends related to IoT in smart tourism.	IoT plays a significant role in smart tourism, enhancing tourist experience and sector growth. Key challenges include privacy issues and the need for scalable solutions. The study identifies trending themes like AI and Big Data.	Limited to Scopus-indexed publications; text mining limited to a subset of documents due to time constraints.

[123]	Ordóñez-Martínez et al	2023	To analyze the potential of Tourism Data Spaces (TDS) in Europe, focusing on Big Data and IoT integration to enhance smart and sustainable tourism.	Documentary and bibliographical analysis, DPSIR framework	Tourism Data Spaces across Europe	Empirical data from the EU's DATES project, DPSIR model	Highlights how TDS can transform traditional tourism into smarter, more sustainable models. Explores benefits such as improved decision-making and enhanced tourism experiences.	TDS offers significant potential to improve tourism management through data sharing but faces challenges with governance, data standardization, and diverse stakeholder interests.	Limited focus on non-EU tourism initiatives; requires further empirical validation to assess long-term impact of TDS.
[124]	Popova et al.	2023	To explore how IoT and Big Data Analytics can manage risks in digital tourism ecosystems (DTEs) through a systematic review.	Systematic Literature Review	Digital tourism ecosystems (general)	SLR and thematic analysis	Identification and classification of risks within DTEs; examination of IoT and BDA applications for risk management.	IoT and BDA help address risks such as operational, strategic, and socio-cultural risks in DTEs. Challenges include data interoperability, privacy, and infrastructure needs.	Primarily theoretical; lacks empirical data on the implementation of these technologies in real-world DTE scenarios.
[125]	Sun et al.	2016	To explore how IoT and big data analytics can support smart tourism and sustainable cultural heritage.	Case Study of Trento, Italy	City of Trento	IoT sensor data analysis and crowdsensing	Development of TreSight, a context-aware recommendation system for tourism based on big data from IoT sensors.	IoT and big data enable personalized tourism experiences and sustainable management of cultural heritage sites.	Focuses on a single case study; additional validation needed for broader application in different contexts.
[126]	Rosário & Carmo Dias	2024	Explore the transformative impact of IoT and big data on smart tourism, focusing on enhancing operational efficiency and traveler experience.	Systematic Literature Review with Bibliometric Analysis	83 studies indexed in Scopus	PRISMA for data filtering, VOSviewer for bibliometric analysis	Analyzes IoT applications in smart tourism, including payment systems, recommender systems, and smart cities.	IoT technologies present many opportunities to boost efficiency and performance within the tourism industry. In smart tourism environments enabled by IoT, various advanced tools—like big data contribute significantly to enhancing the traveler experience.	Restricted to Scopus database, limiting access to non-English studies and insights from other databases like Web of Science.
[127]	Wang et al.	2020	To outline how IoT, empowered by 5G and AI, can enhance smart tourism through efficient data transmission and intelligent processing, with a case study on POI recommendation.	Conceptual & Experimental	Real-world location-based social network data (Foursquare: 2,321 tourists, 5,596 POIs, 194,108 check-ins)	Proposal of a framework; heterogeneous network representation learning (meta-path-based random walk, heterogeneous skip-gram model) for POI recommendation	Efficiency and effectiveness of 5G- and AI-powered IoT for smart tourism (measured via POI recommendation accuracy and data rate).	5G and AI-enabled IoT significantly improve real-time data transmission and POI recommendation accuracy in smart tourism scenarios; demonstrates a practical, scalable framework.	Case study limited to POI recommendation; empirical validation based on simulated 5G transmission; other smart tourism applications not experimentally validated.
[128]	Weng & Zhang	2023	To analyze a smart tourism management model that leverages Big Data and IoT for enhanced tourism services.	Case Study and Survey Analysis	1,000 managers and technical personnel from 50 tourism enterprises	Questionnaire, Statistical Analysis	Evaluated IoT and Big Data resources' impact on tourism marketing, IT infrastructure, and technical talent training.	The model reveals a need for improved IoT resources and technical training in tourism. Effective IoT and Big Data use improves operational efficiency, marketing accuracy, and service quality.	Limited to Chinese tourism enterprises; findings may not apply globally. Focuses mainly on theoretical analysis with limited empirical data.
[129]	Zubiaga et al.	2019	To apply IoT, big data, and GIS for monitoring tourist flows and promoting sustainable tourism in historic centers.	Case study: Historic centre of Ávila (Spain)	Tourists visiting Ávila's historic center	IoT-based sensors, people-counting cameras, GIS analysis	Visitor occupancy levels, tourism flow, carrying capacity	The use of IoT and big data provided real-time monitoring of visitor flows, helping city managers make informed decisions to avoid overcrowding and overtourism	Counting errors due to weather conditions (e.g., snowfall affecting sensors), expensive infrastructure, and legal hurdles with permissions.

4. Results

This section synthesizes the key findings of the 15 reviewed articles concerning the three research questions. The insights reflect current trends, applications, and challenges in integrating Big Data and IoT into sustainable tourism and hospitality.

4.1. RQ1 – Enhancing Customer Experience: Personalized Services and Real-Time Engagement

Findings across 13 of 15 studies consistently support the transformative role of IoT and Big Data in enhancing customer experiences through personalization and immediacy.

- Personalization through Big Data analytics was a dominant theme (12/15 papers). Platforms analyzed customer behavior using booking history, social media activity, geolocation, and reviews (e.g., [118, 124, 126]), enabling highly customized experiences.
- IoT-enabled services—such as smart room adjustments, wearable devices, mobile tourism apps, and virtual concierge systems—were highlighted in 9 studies (e.g., [116, 121]). These services offer real-time, context-aware interactions that respond to user preferences.
- AI-driven recommendation systems (6/15 studies) integrated with IoT devices provided predictive service offerings, such as suggesting off-peak visits, custom itineraries, or eco-friendly choices based on current location and historical behavior (e.g., [125]).
- Operational Efficiency was also tied to customer satisfaction, with studies reporting that smart check-ins, cashless payments, and automated issue resolution improved the perceived service quality (e.g., [115, 127]).

The convergence of IoT, AI, and Big Data creates an ecosystem of anticipatory, real-time, and hyper-personalized customer engagement. 87% of reviewed studies recognize its contribution to increased satisfaction and brand loyalty. However, the implementation is skewed toward urban destinations and larger hotel chains, with rural applicability still underrepresented.

4.2. RQ2 – Supporting Sustainability: Resource Management and Crowd Control

Findings across 11 of the 15 studies reported sustainability-focused applications of Big Data and IoT, addressing environmental monitoring and operational optimization.

- IoT for real-time resource management was featured in 10 studies, including energy, water, and waste monitoring (e.g., [127, 128]). Smart meters and occupancy-based automation were used to reduce resource consumption in the accommodation and transport sectors.
- Crowd control and heritage site preservation appeared in 7 papers, notably Zubiaga et al. [129] and Ordóñez-Martínez et al. [123], where IoT sensors and GIS were used to monitor tourist flows and trigger interventions at overcapacity sites.
- Big Data for predictive analytics—forecasting tourist density, environmental impact, and peak demand—was used in 9 studies (e.g., [118, 125]). These insights enabled tourism managers to implement dynamic visitor management strategies.
- Eco-personalization emerged as a hybrid concept in five papers. It combines real-time environmental data with user profiles to recommend greener choices (e.g., alternative destinations or low-emission transport).

Approximately 73% of the studies confirmed IoT and Big Data significantly enhance tourism's environmental and operational sustainability. However, success relies on infrastructure, investment, and cross-sector collaboration—resources not equally available across all geographic regions. Rural and ecologically fragile areas particularly require scalable, low-cost adaptations.

4.3. RQ3 – Ethical Concerns and Privacy Risks

Though depth and specificity varied, ethical and data privacy concerns were explicitly discussed in 10 of the 15 studies.

- Data privacy and consent were central concerns in 8 studies, particularly concerning IoT sensors capturing location, behavior, and even biometric data (e.g., [118, 124]). However, only 3 studies recommended user consent models or anonymization techniques.
- Six studies noted a lack of governance frameworks, pointing to a research gap in standardized protocols for ethical Big Data use in tourism contexts (e.g., [115, 122]).

- Five studies discussed security vulnerabilities in IoT ecosystems (e.g., hacking, surveillance), especially in the hospitality sector, where intelligent systems are integrated into customer environments.
- Balancing personalization with privacy was framed as a paradox in 4 papers. While customers expect tailored experiences, they are increasingly concerned about how much data is being tracked to enable them (e.g., [116, 126]).

While ethical concerns were frequently acknowledged (67% of studies), few proposed actionable solutions; the absence of tourism-specific privacy frameworks or regulatory alignment (e.g., GDPR compliance) underscores an urgent need for research and policy development.

4.4. Cross-Cutting Themes and Patterns

- Geographical Contexts: Most empirical applications focused on urban destinations in Europe and Asia; rural tourism settings were underrepresented, with Li (2023) [3] and Sun et al. [125] being rare exceptions addressing rural smart tourism.
- Technological Maturity: Only 4 studies referenced emerging infrastructure like 5G or edge computing, suggesting that real-time tourism personalization and sustainability still face scalability and latency challenges.
- Barriers to Adoption: Implementation costs, interoperability issues, and lack of skilled workforce were common challenges in 60% of the papers, particularly in developing contexts (e.g., [122, 128]).

The heatmap below (Figure 7) illustrates the extent to which each of the 15 reviewed studies addresses the three core research questions. Each cell is numerically coded to represent the depth of discussion on the respective theme: 0 = Not Mentioned, 1 = Brief Mention, 2 = Moderate Discussion, and 3 = In-Depth Analysis. This visualization reveals that personalization and real-time engagement (RQ1) are the most widely covered, with 10 studies scoring 2 or higher, indicating a strong research focus on enhancing the customer experience via Big Data and IoT. Sustainability applications (RQ2), including resource management and crowd control, are well-represented, with 9 studies offering moderate to in-depth discussion. Ethical and privacy concerns (RQ3), while acknowledged in two-thirds of the studies, show a shallower treatment overall, with only 3 studies providing a detailed analysis. The scoring framework enables a comparative assessment of thematic coverage, highlighting dominant research trends and areas requiring further exploration.

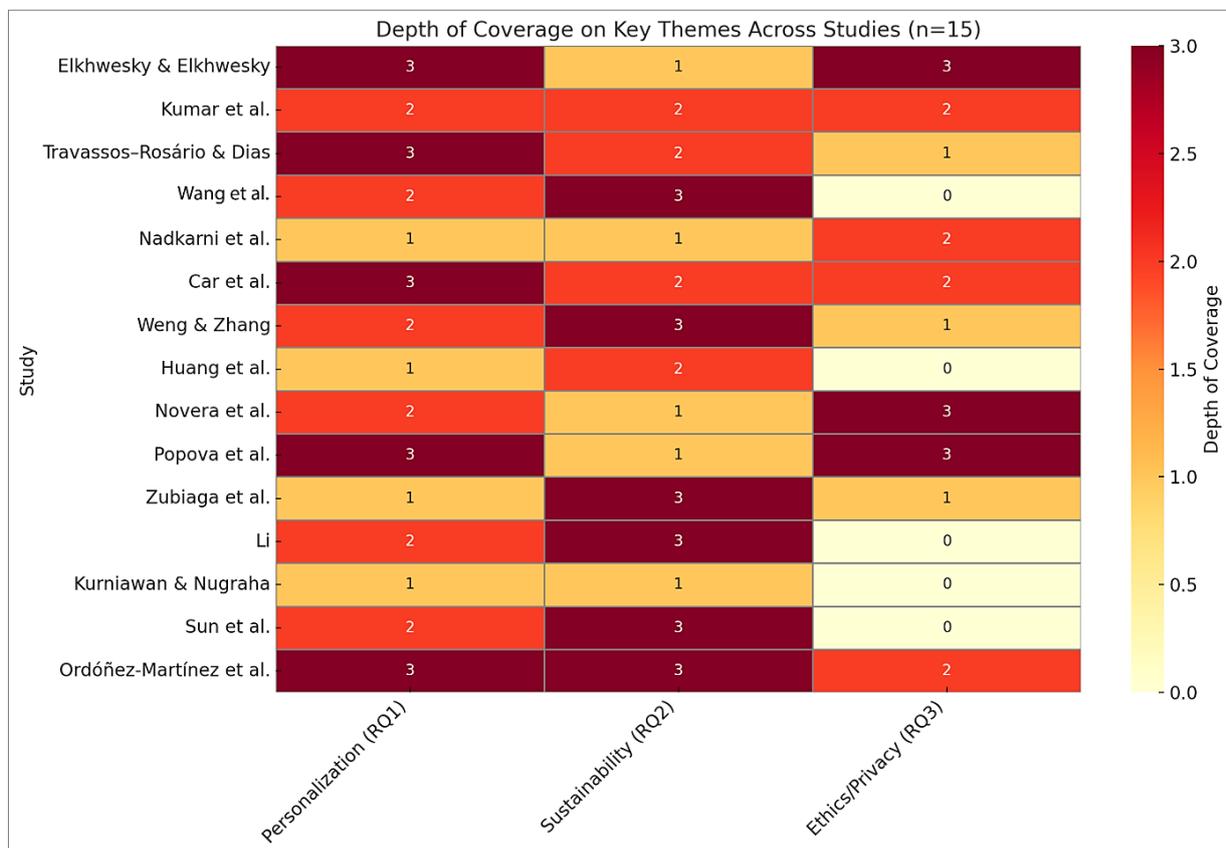


Figure 7. Depth of Coverage on Key Research Themes across Reviewed Studies (n = 15)

5. Discussion

The systematic review revealed several overarching themes and patterns in using Big Data and IoT within sustainable tourism and hospitality. These findings underscore the role of these technologies in operational efficiency, resource optimization, and enhancing customer experience. However, the review also highlighted notable challenges, including ethical concerns, infrastructure costs, and limited empirical research on their application in diverse tourism settings. Here, we discuss the insights gained from the review, drawing comparisons with established literature and identifying implications for future research and practice.

Table 2 summarizes the artificial intelligence (AI), machine learning (ML), and IoT/Big Data methods reported in each of the 15 studies included in this review. This table highlights the diversity (and, in some cases, the absence) of concrete AI models and techniques in the current literature, providing transparency for readers from both tourism and technology backgrounds.

Table 2. AI/ML Models & Techniques identified in the 15 papers of the PRISMA

Authors (Year)	AI/ML Models & Techniques	IoT/Big Data Methods and Context
Car et al. (2019) [115]	No specific AI/ML models detailed; general references to AI and automation in hotel/tourism services (e.g., predictive maintenance, voice-based interaction, virtual concierge, AR).	IoT: smart hotels, RFID, sensors, smart rooms, mobile integration, body sensors, location-based services, building automation, predictive maintenance, beacon tech, cloud computing, energy management.
Elkhwesky & Elkhwesky (2023) [116]	Convolutional Neural Networks (CNNs) for hotel review analysis, Deep Learning for personalization, Bayesian modeling for food quality, Machine Learning for smart hotel environments.	IoT: smart rooms, smart mirrors, RFID, wearable sensors, cloud/fog computing, wireless sensor networks; focus on hospitality and food service optimization.
Huang et al. (2022) [117]	BP (Back Propagation) Neural Network for data analysis and prediction in wisdom tourism; Ant Colony Algorithm for optimal travel route recommendation; data mining on Hadoop platform.	IoT: RFID, GPS, multi-layer architecture (perception, transport, service, application); Big Data: Hadoop, data mining, distributed storage and processing.
Kumar et al. (2022) [118]	General mention of AI and machine intelligence; no specific AI models detailed.	IoT: general adoption trends in tourism; Big Data and data mining discussed; VOSviewer used for bibliometric network analysis; no technical implementation focus.
Kurniawan & Nugraha (2022) [119]	Use of AI-powered social media analytics (analisa.io), content analysis, hashtag and sentiment tracking; AI mentioned for analytics but no details on underlying model.	Big Data: Social media (Instagram) data mining for tour/travel industry insights; IoT & AI discussed as critical for "Tourism 4.0" context.
Li (2022) [120]	No specific AI/ML models; uses SPSS for descriptive statistics, t-tests, correlation and regression analysis for survey data.	IoT: integration of sensing terminals, wireless sensor networks, mobile devices for real-time monitoring and tourist flow management; Big Data: data mining, panoramic analysis of tourist behavior, risk prevention, and development of rural smart tourism information platforms.
Nadkarni et al. (2020) [121]	Conceptual discussion of future integration: machine learning algorithms recommended for IoT deployment, mention of "embedding AI" for autonomous decisions (no empirical/technical AI model reported).	IoT in hospitality: RFID, smart rooms, wireless sensors, proximity beacons, context-aware automation, input-process-output model for applications; Big Data: cloud, fog/edge computing, IoT analytics, smart water/power/asset management.
Novera et al. (2022) [122]	Text mining using Latent Dirichlet Allocation (LDA) topic modeling, sentiment analysis (R programming); reference to AI and artificial intelligence in bibliometric clusters.	IoT: Literature review of IoT deployment in tourism; Big Data: bibliometric analysis, citation networks, R, VOSviewer; no direct application case studies.
Ordóñez-Martínez et al. (2024) [123]	No specific AI/ML model detailed; extensive conceptual discussion of data analytics, personalization, and decision support using Big Data.	IoT: Emphasis on "Tourism Data Spaces," data sharing/integration, context-aware smart tourism, and real-time personalization in the EU.
Popova et al. (2023) [124]	No explicit AI/ML model; focus on IoT and Big Data Analytics for risk prediction, resource optimization, and early warning systems.	IoT: real-time data collection, RFID, wireless sensors, electronic product codes, cloud computing; Big Data Analytics: predictive analytics, risk management, customer profiling, operational optimization; emphasis on integration in digital tourism ecosystems.
Sun et al. (2016) [125]	No explicit AI/ML algorithms detailed; discusses real-time control, cyber-physical systems, and mobile crowdsensing; technical focus is on architecture and opportunities/challenges.	IoT: Multi-layered architecture, mobile crowdsensing, cyber-physical cloud computing; Big Data analytics for smart tourism and smart heritage.
Rosário & Carmo Dias (2024) [126]	General reference to machine learning, AI, recommender systems, and predictive analytics; no specific AI models detailed.	Smart tourism: IoT sensors, wearables, mobile apps, cloud, data mining, big data analytics, smart destinations, personalization, operational efficiency, VOSviewer for bibliometric analysis.
Wang et al. (2020) [127]	Network representation learning for POI recommendation; collaborative filtering (Trust-CF); user-based collaborative filtering (UCF); deep learning for embeddings; machine learning for social network analysis; semantic analysis; NLP; text/image/video mining; reinforcement learning.	IoT: Integration with 5G for real-time data transmission; smart tourism applications—POI recommendation, self-guided tours, smart navigation, real-time monitoring; Big Data: Foursquare dataset, social network mining, cloud analytics.
Weng & Zhang (2023) [128]	Statistical algorithms for data analysis; no specific AI/ML models detailed; general emphasis on targeted marketing and personalized tourism through big data.	IoT: Smart tourism management platforms; sensors, transmitters, cloud; "four-end linkage" management; Big Data: data-driven marketing and resource planning.
Zubiaga et al. (2019) [129]	Associative and sequence analysis algorithms for pattern detection in occupancy and visitor flows; quantitative indicators for data analysis.	IoT: sensor networks, people-counting cameras, 3D urban models, interactive information panels; Big Data: cloud-based analytics platform, data mining for visitor flow management, predictive indicators for overtourism management.

As shown in Table 2, while a subset of studies employ specific AI/ML models—such as neural networks, collaborative filtering, ant colony optimization, and topic modeling—a majority discuss AI, machine learning, or predictive analytics in more general terms. Most technical implementations focus on IoT integration, data mining, and recommendation systems for personalization or operational efficiency. The relative scarcity of in-depth AI model application reflects both the emerging nature of this research area and a continuing trend toward conceptual and bibliometric analyses rather than large-scale empirical deployments.

5.1. Enhancing Customer Experience Through IoT and Big Data

Our study reveals that Big Data and the Internet of Things significantly impact the personalization of customer experiences in the tourism sector. The Internet of Things enables hotels to operate efficiently and adapt customer service quickly, thereby immediately boosting customer satisfaction. Internet of Things applications would allow guests to adjust hotel settings and receive personalized recommendations, thereby promoting a more responsive experience [118]. Big Data analytics expands IoT possibilities by analyzing large amounts of diverse data to predict consumer preferences and optimize service offerings. Moreover, our study reveals that the enhancement of data interpretation and the delivery of adaptive tourism services are increasingly driven by artificial intelligence (AI) as technology advances daily. Real-time adjustments to tourism services, informed by behavioral data, are enabled by AI-driven customization, anomaly detection, and intelligent decision support systems. This enhances both consumer happiness and operational efficiency. A common theme in prior studies is that this comprehensive customization approach has been demonstrated to increase consumer loyalty by improving the overall visitor experience. Conversely, our research broadens this perspective by recognizing the uses of the Internet of Things in rural areas [116], unlike previous studies that mostly emphasized the benefits of these technologies in urban and technologically sophisticated environments. The growing number of Internet of Things (IoT) applications suggests that tailored solutions could help overcome the infrastructure limitations noted in studies like [115], pointing to a new path for IoT implementation across various geographical areas.

5.2. Sustainable Resource Management and Environmental Monitoring

Our findings reinforce established knowledge regarding the potential of Big Data and IoT to optimize resource usage in tourism. In alignment with previous research, such as studies [123], this review highlights how smart sensors and data analytics facilitate the management of resources like water and energy, particularly in hotels and high-traffic tourist destinations. Monitoring visitor flows and environmental conditions in real-time, these technologies enable tourism operators to implement timely interventions that minimize ecological impact, a benefit also emphasized by Nadkarni et al. [121] in heritage management contexts. However, our review identified certain limitations in the current scope of environmental monitoring applications. While the existing literature often highlights the potential of IoT in urban centers, applications in ecologically sensitive rural areas remain scarce. This gap suggests a need for research focused on adaptable, low-cost IoT solutions that could benefit destinations in developing regions [125]. Our findings advocate for a balanced approach that scales technology according to environmental and infrastructural capacities, a recommendation that is not fully addressed in prior research but is necessary for broader application in sustainable tourism [126].

5.3. Ethical and Privacy Considerations

Ethical issues, particularly data privacy and security, were consistently mentioned across the reviewed research, aligning with current debates in the literature. With IoT and Big Data harvesting vast volumes of personal data from tourists, the ethical handling of such data remains essential for sustaining consumer and service provider trust. Despite such concerns, our review identified a limited number of frameworks or guidelines that discuss the ethical handling of data in tourism [121]. This deficit is consistent with the demands of previous research for stronger ethical foundations in ensuring data use responsibility. Given the increasing sensitivity of tourism data, which may encompass location, interests, and behavioral information, our findings underscore the need for policies addressing data protection and user consent. This aligns with the study by Wang et al. [127] call for ethics and transparency to be at the forefront as the utilization of IoT and Big Data becomes more widespread across tourism. Continuing this line of research has the potential to bridge the gap between technological innovation and moral responsibility, thereby driving further public trust in these technologies [129].

5.4. Addressing Infrastructure and Cost Challenges

A common challenge of conducting studies in our review was the expense and technical demands of introducing IoT and Big Data solutions, particularly in rural or low-resource environments. Previous research by Weng et al. [128] has consistently reported such barriers, and our review demonstrates that infrastructure expenses remain a significant limitation, most notably in environments lacking reliable connectivity or technical expertise. Despite the difficulties identified in the current literature, our synthesis also suggests potential solutions in current research, including the adoption of scalable IoT devices and collaboration with technology providers to distribute implementation costs. For instance, a research study Wang et al. [127] demonstrates the viability of modular IoT systems that can operate optimally with minimal infrastructure. Such a solution can enable smaller tourism operators to adopt these technologies without incurring exorbitant expenses. This scalability potential offers an encouraging avenue for future study, indicating that IoT tourism is not necessarily limited to high-spending, urbanized contexts.

5.5. Community Engagement in Smart Tourism Systems

The current literature indicates limited active participation of tourists and local communities in designing and governing smart tourism systems despite the growing emphasis on technological innovation. The TreSight project in Trento, Italy, stands as a notable exception, according to Sun et al. [125], because community members actively participated in mobile crowdsensing activities that provided real-time data for sustainable tourism and cultural heritage management. The research by Kurniawan & Nugraha [119] utilizes social media content analysis to understand tourists' perspectives, enabling industry stakeholders to modify their services based on user feedback. The reviewed literature lacks detailed documentation of participatory design methods, including co-creation workshops, community advisory boards, and collaborative system prototyping.

This gap suggests a significant opportunity for future research and practice. Drawing on best practices from the broader field of smart cities and urban informatics—such as Amsterdam's "Smart Citizen" projects [130]—future initiatives in smart tourism should prioritize inclusive design processes that actively involve both tourists and residents. Such engagement not only enhances the relevance and acceptance of new technologies but also ensures alignment with regional needs, values, and aspirations. Embedding community participation in smart tourism governance can foster greater trust, increase system effectiveness, and help balance innovation with social and ethical considerations.

5.6. Implications for Future Research

This review highlights gaps and provides directions for future research on the application of Big Data and IoT in sustainable tourism [115]. First, while personalization and resource management applications are well-documented, empirical research on low-cost IoT solutions suitable for rural and ecologically sensitive tourism destinations remains scarce. Addressing this gap would contribute to a more inclusive, sustainable tourism model that accommodates high-tech and resource-limited environments [121]. Second, there is a need for more comprehensive ethical frameworks to guide the collection, use, and protection of data in tourism. As IoT and Big Data continue to gather detailed customer information, future studies should prioritize the development of privacy-enhancing technologies and data protection protocols. Additionally, integrating 5G networks and AI could further enhance real-time data processing and predictive analytics, offering opportunities to dynamically manage tourist flows and deliver hyper-personalized services [117]. Also, a potential limitation of this review is the relatively small number of included studies. This is primarily due to the strict inclusion criteria, the focus on recent peer-reviewed journal articles, and the nascent state of the literature on IoT and Big Data in sustainable tourism. However, this selection strategy enhanced the review's rigor and ensured that only the most methodologically sound and relevant studies were synthesized.

The review confirms that current research on Big Data and IoT applications in tourism primarily focuses on urban areas, but rural areas remain underrepresented. The deployment and study of advanced tourism technologies in rural areas remain challenging because these regions typically lack sufficient digital infrastructure, including broadband internet, reliable cellular networks, and affordable IoT devices. The commercial intensity of rural tourism remains low, and its operators are numerous and small, which creates difficulties for large-scale data collection and technology implementation. Most of the research funding and industry partnerships focus on urban hubs, as these areas offer better opportunities to measure and demonstrate the economic impact and scalability of innovative tourism solutions. Future research should aim to develop and test affordable IoT and Big Data solutions that address the specific requirements of rural and peripheral tourism destinations. Policymakers, in collaboration with technology providers, should establish cross-sector partnerships to support public-private collaborations and provide infrastructure grants specifically targeted to rural tourism development. Research studies comparing digital transformation barriers and enablers in urban and rural areas will establish a balanced body of knowledge that encompasses all regions, providing a comprehensive understanding of imaginative tourism. The research community can achieve digital tourism innovation accessibility for all areas through these approaches, which will drive sustainability and resilience throughout the tourism sector.

5.7. Future Research Directions

Smart tourism is based on an ecosystem with interconnected stakeholders. All sources of information are influenced by online and offline activity generated by tourism consumers, intermediaries, public organizations, and technology applications. The interactivity of all stakeholders, including providers, sellers, and consumers of tourist goods, is dynamically facilitated via the Internet. Smart tourism is based on advanced technology and is a subset of broader development, encompassing the online presence and interactivity of a wide range of observable entities available on the internet. Online tourism systems, or e-tourism, encompass the online search, sale, and purchase of travel and tourism products and services and are now well-established, mature technology domains with both enablers and inhibitors. The evolution of technology has resulted in the development of generic technologies that can now enable the online and electronic sharing, publishing, searching, and brokering of a wide range of objects, as well as the easily executable negotiation of service provision or acquisition for a fee or other business model [131-133].

Online tourist information has replaced the old telephone-based information services established in the early 21st century, including both the current platform and a SET-based tourism booking system. Various other technological

developments based on demographics implemented during 2004–2005 have resulted in an intelligent system that enables the execution of the right e-tourism business at the right time using the appropriate communication device or infrastructure. The success and exploitation opportunities these technologies offer may have a profoundly disruptive impact on tourism supply chains. Tourism organizations cannot exploit them on a mass scale. Further developments have since been implemented and tested using end-to-end tourism industry pilots. Still, as of the end of 2009, the operative version of Ambient Intelligence tourism makes full use of disruptive yet generally available widespread technologies. These are reported within a broader conceptual framework, encompassing the significant economic and social changes of the last decade, as well as the real and pilot experiments conducted across a widely diverse tourism ecosystem convened for these purposes [134-136].

Privacy-Enhancing Technologies and Ethical Frameworks: As Big Data and the Internet of Things (IoT) continue to permeate tourism, developing robust privacy-enhancing technologies and ethical frameworks is crucial for addressing growing concerns about data security and user consent. Future research should focus on creating data anonymization techniques and secure data-sharing protocols that protect tourist privacy while enabling meaningful data analysis. Establishing ethical guidelines specific to tourism could help balance the benefits of personalization with privacy concerns, fostering trust between tourists and service providers [137-139].

Scalable, Low-Cost IoT Solutions for Sustainable Tourism: The high implementation costs of IoT systems remain a barrier, particularly in rural and developing regions where sustainable tourism efforts are most needed. Future research could explore scalable, cost-effective IoT infrastructure that adapts to the unique needs of low-resource environments, making innovative tourism technology more accessible. This could include modular IoT systems or partnerships between technology providers and local governments, allowing even resource-limited destinations to benefit from enhanced sustainability through digital innovation [140-142].

AI-Enhanced Predictive Analytics for Dynamic Tourism Management: Integrating AI with Big Data and IoT holds promise for advancing predictive analytics, enabling the real-time management of tourist flows and personalized services that support sustainable tourism practices. Future research could investigate AI-driven models that dynamically adjust services based on tourist preferences, environmental factors, and crowd levels. Such advancements would optimize visitor satisfaction and alleviate pressure on high-traffic sites by redistributing demand more effectively, aligning with sustainable tourism goals [143-145].

Exploring the Role of Explainable AI (XAI): Future research should investigate how explainable AI techniques—such as SHAP (SHapley Additive exPlanations) and LIME (Local Interpretable Model-Agnostic Explanations)—can be practically applied in tourism information systems to enhance transparency, user trust, and accountability in data-driven service delivery. SHAP and LIME enable the interpretation of complex AI and machine learning model outputs by identifying which input factors most significantly influenced a specific recommendation or prediction. In tourism contexts, these methods could clarify why a recommender system suggested a particular itinerary, how demand forecasting models make predictions, or which features are most important for customer sentiment analysis. Applying such techniques can reinforce confidence among tourists, help service providers justify and refine AI-driven strategies, and ensure compliance with emerging ethical and regulatory standards. As AI systems become more integrated into tourism management and personalization, future research should prioritize the development and testing of XAI approaches that are user-friendly, contextually relevant, and capable of supporting responsible and trustworthy tourism operations [146-148]. These directions aim to address the limitations identified in this review, including infrastructure challenges and ethical concerns, thereby fostering a responsible and inclusive application of these technologies.

5.8. Broader Impact

The use of IoT and Big Data for sustainable tourism has long-term implications beyond short-term operational efficiency, substantially contributing to the United Nations' Sustainable Development Goals (SDGs). Technology particularly promotes objectives related to responsible consumption and production (SDG 12), industry, innovation, and infrastructure (SDG 9), as well as sustainable economic growth (SDG 8). By facilitating data-driven decision-making, IoT and Big Data enable tourism businesses to become more efficient in management, streamline visitor flows, and mitigate environmental impacts, thereby directly contributing to the development of sustainable tourism destinations [149-151].

Within the scope of environmental sustainability, IoT and Big Data enable tourism destinations to monitor and control natural resources with precision. Real-time data from IoT sensors can potentially track parameters such as water and energy usage, waste production, and carbon emissions. With such information available, destinations can pre-empt the environmental impact of tourism activity, responding to usage levels and ecological pressures in real time. This information-based strategy supports resource conservation and provides a valuable feedback mechanism to help destinations reduce their environmental impact while preserving natural ecosystems and biodiversity [152-154].

They also reinforce tourism's economic resilience. By optimizing resource management, anticipating peak demand, and personalizing tourists' experiences, IoT and Big Data enhance the quality of tourist products, contributing to increased customer satisfaction and longer tourist stays. Such tools may ensure a level playing field for smaller and

developing destinations, allowing them to manage visitor flows effectively and preserve the integrity of their natural and cultural resources, even as they expand their operations. Such an approach encourages sustainable economic development by linking visitor numbers to the local infrastructure's ability to cope, thereby avoiding over-strained resources and delivering a satisfactory experience to both tourists and residents [155-157].

Also important is the empowerment and involvement of the community because of these technologies. With IoT and Big Data sending real-time data and insights to local stakeholders, communities are empowered to participate in the control of tourism activities and the conservation of their culture. Data transparency empowers community-led tourism initiatives, enabling locals to promote sustainable tourism, set visitor limits, or market green attractions. This empowerment fosters a participatory approach to sustainable tourism, where development is achieved without compromising local values, resources, or quality of life [158-161].

As the tourism sector continues to develop, Big Data and IoT can help create a more responsive, sustainable, and resilient form of tourism that is sensitive to the demands of increasingly environmentally conscious visitors. The intelligence they provide enhances day-to-day decision-making and enables destinations to plan long-term issues, such as climate change and shifts in tourism demand [162-164]. Ultimately, this evidence-based approach can lead to a tourism industry that fosters economic prosperity, preserves the environment, and respects the cultures and individuals that give each destination its unique character [165-167].

6. Conclusion

This systematic review presents an extensive synthesis of the Internet of Things (IoT) and Big Data applications in sustainable tourism. It provides a close analysis of their potential to optimize resource management, customer experience, and environmental and community objectives. By bridging the gap between theoretical research and practical application, this paper serves as a valuable guide for technology suppliers, policymakers, and tour operators seeking to implement IoT and Big Data responsibly. Among the most significant contributions of this review is the interpretation of abstract theoretical findings into practical prescriptions for tourism operators. The findings specify exact ways through which tourism operators can utilize data-driven technologies to streamline operations, promote sustainability, and encourage customer loyalty. The review, for example, prescribes how to operate IoT for real-time environmental monitoring and data-supported crowd management—tools that can alleviate resource pressure and enhance visitor experience. Conversely, policymakers can utilize ethical and privacy-driven findings to craft regulations that balance innovation with the safeguarding of personal data, thereby promoting responsible tourism behavior at the policy level. Technology vendors can perhaps learn from this to create scalable, low-cost IoT solutions that address the needs of diverse tourism settings, from urban to rural and ecologically vulnerable environments. The use of artificial intelligence within tourist information systems will introduce significant operational changes, complemented by its potential when combined with the Internet of Things (IoT) and Big Data analysis. The convergence of technologies will create intelligent ecosystems that can analyze and interpret real-time data, enabling tourism operators to make anticipatory choices about individual tourist behavior, decisions, and environmental conditions. These ecosystems will provide personalized travel recommendations while optimizing itineraries and amplifying customer engagement at every stage of travel. The cutting-edge AI-powered ecosystems will provide strategic decision-making support for more innovative resource planning, operations management, and sustainability, developing adaptive, resilient tourism destinations that address visitors' needs while safeguarding communities and the environment.

7. Declarations

7.1. Author Contributions

Conceptualization, L.T., I.K., A.T., and C.H.; methodology, L.T., I.K., A.T., and C.H.; software, L.T., I.K., A.T., and C.H.; formal analysis, L.T. and I.K.; investigation, A.T. and C.H.; resources, L.T., I.K., and A.T.; data curation, I.K., A.T., and C.H.; writing—original draft preparation, L.T., I.K., A.T., and C.H.; writing—review and editing, L.T., I.K., A.T., and C.H.; visualization, L.T., I.K., A.T., and C.H.; project administration, L.T., I.K., A.T., and C.H.; funding acquisition, L.T., I.K., A.T., and C.H. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

Data sharing is not applicable to this article.

7.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

7.4. Institutional Review Board Statement

Not applicable.

7.5. Informed Consent Statement

Not applicable.

7.6. Declaration of Competing Interest

The authors declare that there are no conflicts of interest concerning the publication of this manuscript. Furthermore, all ethical considerations, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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