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REVIEW ARTICLE

A bibliometric and systematic analysis of artificial intelligence and the transition towards smart geotourism

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ABSTRACT

The rapid digital transformation of tourism has positioned artificial intelligence as a key enabler of destination intelligence, data-driven decision-making, and sustainable tourism management. Although artificial intelligence has become increasingly important in smart tourism research, its application to geotourism remains fragmented, particularly regarding geoheritage conservation, geodiversity management, and territorial planning. Employing a retrospective approach, this study delineates the developmental trajectory of artificial intelligence applications in sustainable tourism while interrogating their integration into the paradigm of smart geotourism. An integrated bibliometric analysis and systematic literature review were conducted to evaluate scientific developments and empirical applications of artificial intelligence within geotourism contexts. Such findings delineate a burgeoning field of inquiry structured through the convergence of three intersecting axes: technological advancement, analytical intelligence, and visitor-focused experiential paradigms. The review study identified four principal domains through which artificial intelligence contributes to geotourism: predictive analytics, smart destination management, geoheritage interpretation, and environmental monitoring and geoconservation. The findings further highlight significant regional differences in technological adoption and reveal a limited integration between artificial intelligence, geoheritage conservation, and sustainable territorial governance. Based on these findings, the study proposes a smart geotourism framework that connects artificial intelligence, smart tourism, geoheritage conservation, and territorial planning within a unified conceptual structure. By delivering an integrated appraisal of artificial intelligence within geotourism, this study contributes to extant scholarship by conceptualizing artificial intelligence beyond its technical dimensions—positioning it as a fundamental enabler of empirical territorial planning, destination analytics, and the sustainable preservation of geological resources. The study objectives were to propose an integrated conceptual framework that connects artificial intelligence, smart tourism, geoheritage conservation, and territorial planning to support the development of smart geotourism.

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131	9	3

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INTRODUCTION

The digital transformation of tourism is reshaping how destinations are planned, governed, and experienced. Advances in digital infrastructures, geospatial technologies, and data-driven decision-making have accelerated the transition from conventional tourism management towards smart tourism (Mehraliyev *et al.,* 2020; Zhang *et al.,* 2022). Rather than representing only the adoption of digital technologies, smart tourism constitutes a new governance paradigm based on interconnected ecosystems, intelligent networks, collaborative destination management, and data-driven decision-making (Gretzel *et al.,* 2015). Thus, smart tourism effectively couples technological innovation with sustainable destination stewardship and elevated experiential outcomes for visitors (Madzík *et al.,* 2023; Wu *et al.,* 2024). In the context of this transformation, artificial intelligence (AI) has emerged as one of the principal enabling technologies of smart destinations (Knani *et al.,* 2022; Saydam *et al.,* 2022). Recent advances in machine learning (ML), deep learning (DL), natural language processing (NLP), and predictive analytics have significantly expanded the analytical capacity of tourism organisations by facilitating demand forecasting, visitor behavior analysis, mobility modelling, and personalised service provision (Alhaddar and Kummitha, 2025; Hu *et al.,* 2022; Laesser *et al.,* 2025; Núñez *et al.,* 2024). Moreover, AI applications augment operational efficacy by leveraging recommender frameworks, conversational interfaces, and automated decision-support architectures, thereby facilitating more responsive destination management in the face of fluctuating tourism demands (Alves *et al.,* 2023; Ku and Chen, 2024). Consequently, AI is recognized not only as a technological innovation but also as a strategic instrument for destination intelligence and adaptive tourism governance within increasingly complex tourism systems (Baggio and Del Chiappa, 2014). AI is becoming increasingly relevant for addressing the sustainability challenges facing tourism destinations. The growing pressure on natural resources, biodiversity, and local communities requires planning approaches that balance tourism development with environmental conservation and social well-being (Hall, 2019; Santos *et al.,* 2021; Silva *et al.,* 2024). AI contributes to this objective through predictive modelling, environmental monitoring, optimisation of resource consumption, intelligent transport management, and spatial analysis, supporting more sustainable destination planning (García-Madurga and Grilló-Méndez, 2023; Majid *et al.,* 2023). By integrating geospatial technologies, remote sensing, and big data analytics, AI underpins territorial intelligence, harmonizing heterogeneous environmental and tourism streams into comprehensive decision-support systems (Flórez *et al.,* 2024; Parra-Sanchez and Viviescas-Jaimes, 2024). This convergence aligns with the sustainable development goals (SDGs), particularly those promoting sustainable cities, responsible consumption, climate action, and ecosystem conservation (Naciones Unidas, 2025). These advances are particularly relevant for geotourism, a specialized form of sustainable tourism centered on the conservation, interpretation, and appreciation of geoheritage and geodiversity (Gupta *et al.,* 2024; Kubalíková *et al.,* 2021). Diverging from conventional nature-based tourism paradigms, geotourism explicitly synthesizes geoconservation efforts with academic education, scientific knowledge transfer, and local economic stimulation via the valorization of geosites, geoparks, and distinctive geomorphological landscapes (Drinia *et al.,* 2023; Quesada-Valverde and Quesada-Román, 2023; Spyrou *et al.,* 2024). This territorial perspective is consistent with place-based approaches to tourism development that emphasise resilience, destination stewardship, and landscape management (Lew, 2014). In this context, geoparks function as territorial governance systems where conservation, community

participation, education, and sustainable development are integrated within a place-based management framework (Rosado-González *et al.,* 2023; Salgado-Jauregui *et al.,* 2025). This perspective on governance is intrinsically linked to sustainability transitions that frame tourism destinations as complex socio-ecological systems demanding adaptive territorial stewardship (Saarinen, 2013). Consequently, the long-term success of geotourism increasingly depends on destinations' capacity to combine geoheritage conservation with intelligent territorial planning, adaptive governance, and data-driven management. While investigation into AI applications in tourism has grown exponentially and geotourism is recognized as a cornerstone of sustainable tourism literature, the two areas continue to progress largely decoupled from each other. This separation also reflects the broader evolution of tourism research towards experience-oriented and creative destination development, where technological innovation has often progressed independently of place-based heritage management (Richards, 2021). Within the proposed framework, smart geotourism is distinguished from related concepts by its simultaneous integration of geoheritage conservation, geodiversity management, destination intelligence, and evidence-based territorial governance. Smart tourism primarily emphasises digital innovation and intelligent destination services (Koo *et al.,* 2025a); geotourism focuses on the appreciation and conservation of geological heritage (Ferdowsi and Németh, 2026); sustainable tourism seeks balanced environmental, social, and economic development (Khater *et al.,* 2025); and geological heritage tourism concentrates on visitation associated with geosites and geological assets (Salvadeo *et al.,* 2025). Smart geotourism advances these frameworks through the incorporation of intelligent spatial analytics and adaptive governance mechanisms, thereby ensuring the enduring viability and conservation of geoheritage. Existing studies primarily investigate AI applications for tourism demand forecasting, recommendation systems, destination management, and visitor behavior analysis (Ma, 2025; Wang *et al.,* 2025), whereas geotourism research mainly focuses on geoheritage conservation, environmental education, geosite assessment, and territorial development (Carrillo-Hernández *et al.,* 2024; Gupta *et al.,* 2024; Quesada-Román *et al.,* 2021). Consequently, a significant gap remains in understanding how AI mechanisms can be leveraged to advance the governance, strategic planning, preservation, and sustainable administration of geoheritage within contemporary smart tourism destinations. From the perspective of the mobilities paradigm, tourism destinations are increasingly understood as dynamic networks of people, technologies, information, and places rather than static geographical locations (Sheller and Urry, 2006). Consequently, understanding how AI interacts with geoheritage requires integrating technological innovation with territorial mobility, governance, and destination intelligence. This fragmentation also characterises the review literature. The proposed framework is underpinned by the theoretical nexus of smart tourism theory, territorial governance theory, socio-ecological systems theory, and destination intelligence paradigms. Smart tourism theory explains how digital infrastructures and AI support intelligent destination management (Koo *et al.,* 2025b); territorial governance theory emphasises coordination among public, private, and community actors (Torre, 2025); socio-ecological systems theory conceptualises geoheritage destinations as coupled human–environment systems (Esengulova *et al.,* 2026); and destination intelligence provides the analytical link through which AI-generated knowledge informs geoconservation, geodiversity management, and adaptive territorial decision-making (Ferdowsi *et al.,* 2025). Current bibliometric investigations characterize the application of artificial intelligence in tourism through technical or

managerial paradigms, whereas scholarly reviews on geotourism tend to isolate conservation, educational dimensions, and geosite assessment. To the best of our knowledge, there is a significant paucity of research that combines bibliometric analysis with a systematic literature review to investigate how AI specifically contributes to smart geotourism through geoheritage conservation, territorial planning, and destination intelligence. To explicitly position the current research gap and the distinct value proposition of this study, Table 1 offers a comparative synthesis of existing reviews addressing artificial intelligence within tourism, smart destination frameworks, and geoheritage contexts. This comparison demonstrates that previous studies have mainly focused on technological adoption, operational efficiency, destination management, or sustainability dimensions. At the same time, limited attention has been given to integrating AI with geoheritage conservation, territorial planning, and geotourism governance. Therefore, despite the growing body of research on AI in tourism, an integrated understanding of how AI can support smart geotourism remains insufficiently developed. Consequently, this study addresses this void by synthesizing bibliometric techniques and systematic review protocols, thereby elucidating the developmental trajectory, empirical scope, and conceptual architecture of AI applications in geotourism development. This knowledge gap significantly limits both the conceptual understanding of smart geotourism and the development of robust, context-specific, and practically relevant evidence-based strategies that integrate technological innovation with territorial sustainability.Accordingly, this study addresses the following research questions (RQ): (i) RQ1: How has scientific knowledge on AI in sustainable tourism evolved, and what intellectual structures, collaboration patterns, and emerging research themes support the transition towards smart geotourism? (ii) RQ2: How is AI contributing to territorial planning, destination governance, geoheritage conservation, and sustainable management within geotourism? In order to examine these questions, the present study analyzes scientific publications on AI in sustainable tourism through a dual methodological design: an integrated bibliometric analysis utilizing Scopus and Web of Science (WoS), paired with a systematic literature review dedicated to geotourism applications. Specifically, the bibliometric component maps the intellectual landscape, thematic evolution, and international collaboration networks of the overarching discipline, complemented by a systematic review that consolidates empirical findings on AI technologies, application domains, sustainability dimensions, geoconservation outcomes, and smart tourism paradigms within geotourism. This study makes three principal contributions: i) it provides an integrated synthesis linking AI, smart tourism, geoheritage conservation, and geotourism through a combined bibliometric and systematic review approach. ii) proposes a conceptual framework that explains how AI functions as an enabler of smart geotourism by connecting destination intelligence, territorial planning, geoconservation, and sustainable tourism governance. iii) identifies four strategic domains through which AI is transforming geotourism: predictive analytics, smart destination management, geoheritage interpretation, and environmental monitoring and geoconservation, while highlighting current research gaps and future directions. These findings furnish both conceptual advancements regarding the emerging domain of smart geotourism and strategic implications for destination administrators, regulatory authorities, and regional planners striving to integrate digital innovation into the long-term management of geological heritage. The study aims is to propose an integrated conceptual framework that connects AI, smart tourism, geoheritage conservation, and territorial planning to support the development of smart geotourism. The study was carried out at UPSE University, Santa Elena, Ecuador, in 2026.

Table 1: Comparative overview of previous review studies on AI in tourism/geotourism and the distinctive contribution of the present study

S.N.	Author and year	Review type	Geoheritage / geotourism	Territorial planning / geoconservation	Bibliometric and systematic integration	Research scope and main contribution
1	(Knani *et al.,* 2022)	Bibliometric	No	No	No	Maps the evolution, intellectual structure, and future research agenda of AI applications in tourism and hospitality through large-scale bibliometric analysis.
2	(Doborjeh *et al.,* 2022)	Systematic literature review	No	No	No	Reviews AI methods, algorithms, data sources, and applications in hospitality and tourism, highlighting their role in forecasting, destination management, visitor behavior analysis, and personalised services.
3	(Samara *et al.,* 2020)	Systematic literature review	No	No	No	Examines the role of AI and big data in tourism, focusing on value creation, operational efficiency, personalised experiences, and the challenges of strategic adoption.
4	(Florido-Benítez and del Alcázar Martínez, 2024)	Literature review	No	Partial	No	Analyses how AI supports smart tourist destinations through marketing, personalised services, predictive analytics, enhanced visitor experiences, and digital destination management.
5	(Nannelli *et al.,* 2023)	Bibliometric and literature review	No	Partial	Partial	Examines the evolution of AI applications in hospitality and tourism, identifying emerging research directions and future opportunities for the sector.
6	(Aliyah *et al.,* 2023)	Conceptual review / literature-based study	No	Partial	No	Explores the integration of AI and Internet of Things (IoT) in smart tourism destinations, emphasising data-driven management, connectivity, and improved tourist experiences.
7	(Kirtil and Aşkun, 2021)	Bibliometric	No	No	No	Identifies influential authors, institutions, thematic structures, and emerging trends in AI research applied to tourism.
8	(El Archi *et al.,* 2023)	Systematic literature review	No	Partial	No	Synthesises research on smart tourism destinations and sustainable development, addressing economic, social, and environmental dimensions of destination management.
9	(Jabeen *et al.,* 2022)	Conceptual and empirical framework	No	No	No	Analyses organisational factors influencing the adoption of AI and automation in hospitality and tourism, including technological, human, and institutional dimensions.
10	(Solakis *et al.,* 2024)	Literature review	No	No	No	Examines AI-enabled value co-creation in tourism by identifying technological, behavioral, organisational, and relational factors shaping AI-mediated tourist experiences.
11	(Omosanya *et al.,* 2026)	Conceptual	Yes	Yes	No	Explores digital technologies for geoheritage conservation and sustainable geotourism, proposing a framework for digital transformation based on conservation, interpretation, and management needs.
12	(Sánchez-Sánchez *et al.,* 2026)	Bibliometric analysis and content analysis	No	Partial	Partial	Analyses the evolution of AI research in sustainable rural tourism, identifying trends related to governance, sustainability, employment, ethics, and community development.
13	(Henriques *et al.,* 2025)	Conceptual	Yes	Yes	No	Discusses digital geovisualization and AI-supported geointerpretation for geoheritage management, including inventory, education, visitor engagement, and conservation applications.

METHODOLOGY

This study employed an integrated approach, combining bibliometric analysis and a systematic review to investigate the relationships among AI, sustainable tourism, and geotourism. The analytical architecture of this study implements a multi-scale framework structured across two mutually reinforcing levels: i) a macro-level bibliometric analysis examining the evolution of AI in sustainable tourism, and ii) a micro-level systematic review focused on AI applications in geoheritage and geodiversity contexts. Integrating these two levels provides the basis for conceptualising the emerging field of smart geotourism. This dual-method strategy amalgamates quantitative and qualitative frameworks to comprehensively capture the trajectory of scientific growth, thematic transformation, and empirical applications characterizing the field. Fig. 1 presents the methodological framework adopted in the study. The methodological design followed a sequential analytical logic in which a macro-level bibliometric analysis characterized the evolution, intellectual structure, thematic dynamics, and international collaboration patterns of AI research in sustainable tourism, and a micro-level preferred reporting items for systematic reviews and meta-analyses (PRISMA)-based systematic review synthesized empirical evidence on AI applications in geoheritage, geodiversity, and geotourism. Ultimately, the insights yielded across both analytical scales were brought together to furnish the theoretical underpinning that defines smart geotourism as the convergence of destination intelligence, territorial planning, geoheritage conservation, and sustainable tourism governance. The first phase of the study consisted of identifying and collecting information through structured search strategies conducted on 15 March 2026 in the Scopus and WoS databases (Escandón-Panchana *et al.*, 2024; Mongeon and Paul-Hus, 2016). All data retrieval procedures were completed on a single day to control for temporal fluctuations in database indexing, thereby preserving the consistency and comparability of the dataset. Scopus and WoS were selected because they are the two most widely used multidisciplinary databases in bibliometric research, offering high-quality indexing standards, extensive international coverage, citation metadata, and export compatibility with bibliometric software such as Bibliometrix and VOSviewer (Martín-Martín *et al.*, 2018; Belu and Marinoiu, 2025). The synergistic use of these sources curtails database-driven bias, optimizes literature representation across tourism, sustainability, geoscience, and information technology domains, and elevates the analytical rigor of cross-disciplinary analyses (Mondal, 2026). The search strategy was designed to capture publications addressing AI within tourism and sustainability contexts. Searches were conducted in the title, abstract, and keywords fields in both databases without restricting subject categories.

Scopus query: TITLE-ABS-KEY [("artificial intelligence" OR AI OR "machine learning" OR "deep learning") AND ("tourism" OR "sustainable tourism" OR "ecotourism" OR "nature-based tourism" OR "smart tourism"]

WoS query: TS=[("artificial intelligence" OR AI OR "machine learning" OR "deep learning") AND ("tourism" OR "sustainable tourism" OR "ecotourism" OR "nature-based tourism" OR "smart tourism")]

No restrictions were applied regarding publication year, country, or subject area. The scope of the analyzed publication period spans 1993 through 2026—commencing with the earliest appearance of records satisfying the search protocol in Scopus and WoS, and concluding with the latest fully compiled annual data available during the retrieval phase. The analysis therefore covers the full historical range of retrievable publications on AI in tourism and

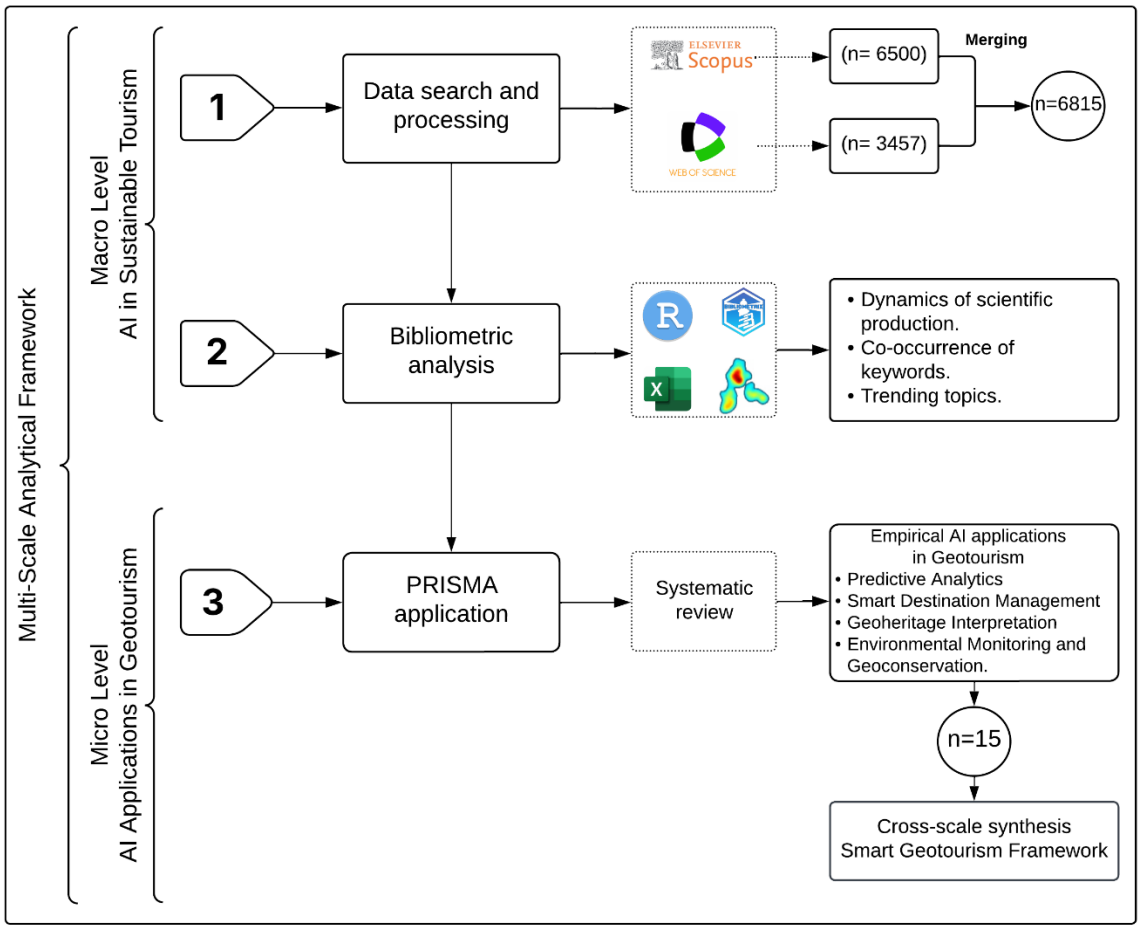

Fig. 1: Multi-scale methodological and conceptual framework integrating macro-level bibliometric analysis with a micro-level PRISMA-based systematic review to establish the foundations of the smart geotourism framework

sustainability rather than an arbitrarily selected period. It enables a longitudinal interpretation of technological evolution, capturing the transition from early exploratory AI applications in tourism during the 1990s, through the expansion of big data and digital tourism platforms after 2008, to the rapid development of ML, DL, conversational AI, and generative AI since 2017. Consequently, this observation window permits a comprehensive assessment of how artificial intelligence evolved from a minor technological interest into a central component governing destination intelligence, smart tourism frameworks, and the developing field of smart geotourism research. The retrieved records were exported in BibTeX (Scopus) and Plain Text (WoS) formats for subsequent integration and cleaning (Mitha and Omarsaib, 2025). To facilitate reproducibility, the bibliometric procedure followed four sequential steps: (i) execution of the Scopus and WoS queries on 15 March 2026; (ii) export of records in BibTeX and Plain Text formats; (iii) integration and duplicate removal using the Bibliometrix package in RStudio; and (iv) manual verification and cleaning prior to bibliometric analysis in Biblioshiny and VOSviewer. The same search strings, export formats, software versions, and cleaning criteria were applied throughout the process. No language filter was applied during the bibliometric retrieval stage in Scopus and WoS.

Consequently, to ensure comprehensive coverage, records indexed across all languages were systematically retrieved and compiled into the bibliometric database whenever they aligned with the search criteria. The language restriction was applied only during the PRISMA-based systematic review, where English-language publications were retained to ensure consistent screening, interpretation, and comparison of empirical evidence. Peer-reviewed journal articles and conference papers indexed in Scopus or WoS were selected for inclusion in the bibliometric dataset given their status as primary scholarly outputs capable of capturing cutting-edge artificial intelligence implementations prior to journal-bound release. In contrast, review articles, conference reviews, book chapters, editorials, notes, and other secondary publications were excluded from the systematic review to avoid double counting and to ensure that the synthesis was based on original empirical evidence. Owing to inconsistent indexing in Scopus and WoS and the frequent absence of rigorous peer review and complete bibliographic metadata, grey literature comprising theses, technical reports, policy briefs, and institutional outputs, was not subjected to systematic retrieval. Given the fragmented nature of the literature on AI applications in geotourism, the search strategy was developed iteratively through preliminary pilot searches. These pilot tests combined AI-related terms with geoheritage- and geotourism-specific descriptors, including geotourism, geoheritage, geodiversity, geopark, geosite, and geological tourism. The retrieved records were manually inspected to evaluate thematic relevance and indexing consistency across Scopus and WoS. This assessment showed that many potentially relevant publications were indexed under broader tourism, heritage, environmental, or geoscience categories and did not consistently use geotourism-specific keywords, resulting in fragmented retrieval and unstable search performance. Consequently, to minimize potential omissions of relevant research, a more expansive search strategy centered on AI and sustainable tourism terms was implemented to enhance retrieval sensitivity and assemble a representative corpus of scientific production. The resulting dataset was then refined through a PRISMA-based systematic review using geoheritage- and geodiversity-specific screening criteria to increase thematic specificity. This two-stage strategy combined broad bibliometric coverage with targeted geoheritage screening and was designed to maximize the identification of AI studies relevant to geotourism, geoheritage conservation, and territorial planning. As a result, 9957 publications were retrieved, including 6500 records from Scopus and 3457 from WoS. The datasets were subsequently merged and cleaned using the Bibliometrix package in RStudio version 4.1.1 (Pratama *et al.,* 2024)—duplicate removal combined automated and manual verification procedures. To resolve duplicate entries stemming from database redundancy, records were prioritized and matched using digital object identifiers (DOIs), while entries devoid of DOIs underwent subsequent cross-verification based on composite criteria including title, authors, publication year, and source title. Candidate duplicates generated by Bibliometrix were manually inspected to confirm true duplicates and avoid the erroneous deletion of records with similar titles or revised metadata. Database duplication was systematically controlled by evaluating unique identifiers across pre- and post-deduplication stages, effectively streamlining the dataset from 9957 retrieved records down to 7211 unique records. A final manual quality-control review identified residual duplicates, incomplete metadata, records without authors (298 publications), and unavailable documents (98), resulting in a final dataset of 6815 publications. The combined database was exported to Microsoft Excel 365 for data organisation and subsequently analyzed using Biblioshiny version 4.1.2 and VOSviewer version 1.6.16 for bibliometric analysis, network visualization, and identification of emerging research patterns (Gupta and Chakravarty, 2021; Arruda *et al.,* 2022;

Espinel *et al.,* 2024). Phase two of the methodology incorporated scientific mapping, utilizing a bibliometric approach designed to map the intellectual structure and thematic progression of the scholarly landscape (Chandler *et al.,* 2018). This analysis evaluated the dynamics of scientific production based on the number of publications and citations per year, as well as contributions and collaboration between countries (Moral-Muñoz *et al.,* 2020). Co-occurrence analysis was performed using author keywords, thereby identifying thematic relationships and field development patterns (Ali and Gölgeci, 2019). The terms were organised into networks, where nodes represent keywords and links reflect their degree of association. These nodes are systematically aggregated into clusters reflecting their interconnectivity levels, employing algorithms standard to bibliometric analytical tools (Velastegui-Montoya *et al.,* 2023). Additionally, emerging trends were analyzed using normalization techniques, parameter grouping, and overlay visualization (Lozano *et al.,* 2019), which enabled the identification of the temporal evolution of research topics. By examining the relationship between keywords and publication timestamps, the thematic trend analysis uncovered the emergence of more recent research trajectories (Correia and Kozak, 2022). Co-occurrence networks were generated from author keywords using full counting, association-strength normalization, and the VOSviewer clustering algorithm with default resolution settings. To evaluate thematic progression, longitudinal analyses were executed in Biblioshiny on the basis of author keywords, applying annual time-slicing parameters. Network visualization employed default attraction–repulsion parameters in VOSviewer, with node size proportional to keyword occurrence and link thickness proportional to co-occurrence strength. The third phase consisted of a systematic review using the PRISMA method, which ensures transparency, methodological rigour, and reproducibility in the selection of studies (Page *et al.,* 2022). The screening process involved reviewing titles, abstracts, and keywords and considering the specific inclusion and exclusion criteria defined in Table 2. Irrelevant documents, publications in other languages, reviews, book chapters, documents with limited access, and studies without explicit AI application were excluded, including theoretical models, geospatial analyses without AI, and conceptual approaches without applied evidence. The primary screening process was performed manually by the investigators and subsequently corroborated through an automated RStudio routine containing essential geotourism keywords, such as geoheritage, geopark, geosite, geodiversity, and natural heritage. To improve reliability and reduce subjective selection bias, two researchers independently screened articles, assessed eligibility, and extracted data. Discrepancies were discussed and resolved by consensus through joint review of the publications and predefined eligibility criteria (Sunarti *et al.,* 2024). The final dataset and extracted variables were subsequently cross-checked before synthesis. This procedure ensured consistency and accuracy in identifying relevant studies. Fig. 2 presents a schematic summary of the entire selection process, mapping the methodological flow from the preliminary identification stage through to the final incorporation of studies. Fig. 2 reports the number of records excluded at each screening stage and the specific reason for exclusion, including language, full-text availability, document type, and thematic relevance to AI applications in geoheritage, geodiversity, geoparks, geosites, and geotourism. Consequently, a total of fifteen case studies centering on AI implementations within sustainable tourism associated with geodiversity and geoheritage were selected. The reviewed corpus consisted predominantly of empirical analyses driven by observed spatial, environmental, tourism, or behavioral metrics, supplemented by one conceptual evaluation on smart tourism and volunteering (Kumar, 2025), resulting in a definitive sample comprised fifteen

Table 2: Inclusion and exclusion criteria

Inclusion	Exclusion
Publications in English	Publications written in languages other than English
Articles focusing on AI applications in geotourism	Irrelevant documents (other approaches)
Document types: Articles and conference papers	Document types: review, book chapter, and conference review
Publications with accessible full text	Publications with limited or inaccessible full text

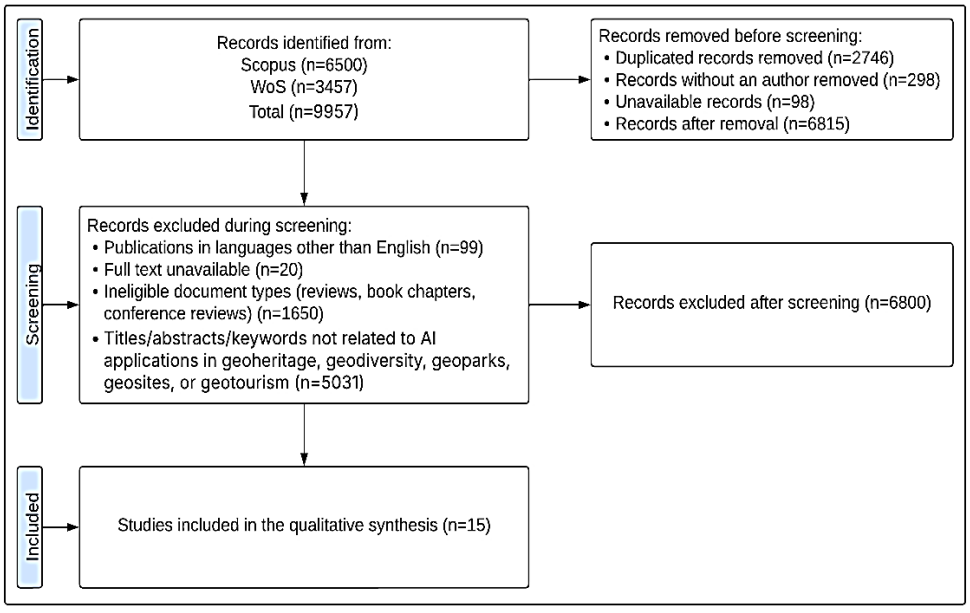

Fig. 2: PRISMA flow diagram showing the identification, screening, eligibility assessment, and inclusion process

empirical studies. Although this number may appear limited relative to the broader bibliometric corpus, it reflects the current state of the literature on AI applications explicitly linked to geoheritage, geodiversity, geoparks, geosites, and geotourism. The review aimed to synthesise the available empirical evidence within this emerging research field, and the selected studies were considered sufficiently representative because they cover multiple geographical regions, territorial contexts, and AI techniques. From these studies, the following variables were extracted: country, type of AI technology, application in tourism, type of resources, type of data, relationship with the dimensions of sustainability, target user, impact on geoconservation, and integration with the smart tourism. Formal methodological quality appraisal was not conducted because the present study adopts an exploratory and conceptual framework, prioritizing the identification of artificial intelligence application domains in geotourism over the estimation of effect sizes. Nevertheless, a structured quality screening was conducted during the eligibility stage. Studies were retained only when they explicitly applied AI techniques, clearly described the tourism or geoheritage context, identified the data sources, and reported the analytical procedure with sufficient methodological detail. Any publications lacking these minimum criteria were systematically excluded during the full-text evaluation process. The final synthesis therefore emphasises recurring functional patterns across studies, and the conclusions should be interpreted as an evidence-informed conceptual synthesis rather than a quality-weighted quantitative assessment. Finally, the selected cases were classified into four

thematic domains: i) AI for Predictive Analytics, ii) AI for Smart Destination Management, iii) AI for Geoheritage Interpretation, and iv) AI for Environmental Monitoring and Geoconservation. These four domains represent the principal empirical manifestations of AI in geotourism identified through the systematic review. Together with the macro-level bibliometric findings, they provide the analytical basis for interpreting the emergence of smart geotourism as an integrated research field.

Time and productivity trends

Fig. 3 depicts the chronological trajectory of publications investigating AI applications within sustainable tourism over the period spanning 1993 to 2026. During this period, the dataset comprised 6815 publications from 2861 scientific sources, indicating the consolidation of a broad, interdisciplinary body of knowledge. The annual growth rate of 20.36 percent (%) demonstrates the rapid expansion of this research field, while the average of 11.93 citations per document reflects its increasing scientific relevance and international visibility. Collectively, these metrics indicate that AI has evolved from a niche topic into a core research area driving innovation, sustainability, and data-informed destination management. The temporal evolution of scientific production reveals three developmental stages (Fig. 4). The initial stage (1993–2008) was characterized by limited scientific output, reflecting the early development of AI technologies and their restricted application within tourism research. During the intermediate stage (2009–2016), publication activity increased steadily alongside the widespread adoption of big data, cloud computing, and digital tourism platforms, which substantially expanded the availability of tourism-related data for analysis (Li *et al.,* 2018; Xiang *et al.,* 2015). Finally, since 2017, there has been a pronounced acceleration in both publications and citations, coinciding with major advances in ML, DL, and intelligent decision-support systems, as well as the consolidation of the smart tourism paradigm (Yu and Chen, 2022; Zhang *et al.,* 2021). Furthermore, the Coronavirus-2019 (COVID-19) pandemic expedited tourism's digital transition by stimulating the adoption of AI tools for visitor management, service customization, operational resilience, and sustainability (Gretzel *et al.,* 2020; Sigala, 2020). From a macro-level perspective, this evolution demonstrates that AI research has progressively shifted from technology-oriented applications towards integrated approaches centered on destination intelligence, sustainable governance, and evidence-based territorial management. This broader scientific context provides the foundation upon which more specialized fields, such as AI applications in geotourism, have recently begun to emerge. Future research priorities in smart geotourism were delineated through the analysis of emerging keywords, thematic progression, and citation-intensity patterns. The increasing prominence of generative AI, conversational AI, digital transformation, sustainability, and advanced geospatial analytics indicates a transition towards intelligent territorial governance, real-time destination management, and personalised geoheritage interpretation. These trends informed the future research agenda proposed in this study, including digital twins, explainable artificial intelligence (XAI), ethical AI governance, and integrated geospatial intelligence for geoheritage management.

An analysis of the geographical distribution of scientific publications demonstrates the worldwide dissemination of AI research in sustainable tourism while revealing distinct regional disparities in academic leadership (Fig. 5). Asia dominates the field, accounting for approximately half of the top 10 most productive countries, with China (27.37%) and India (9.15%) leading. This leadership is likely associated with investments in AI research, rapid digital transformation, and the growing strategic importance of smart tourism initiatives across the region. Europe contributes nearly 40% of the

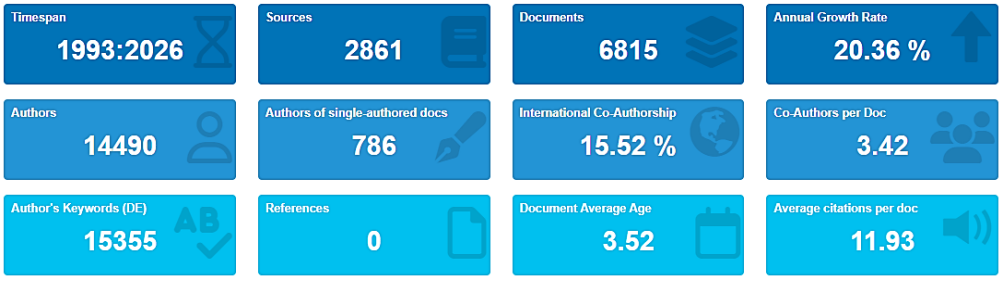

Fig. 3: Main bibliometric indicators of the dataset

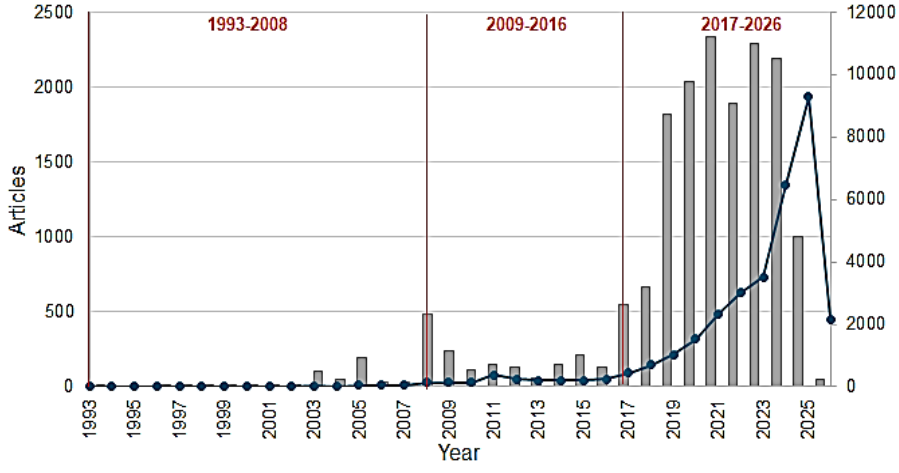

Fig. 4: Annual publication trends on AI applications in sustainable tourism

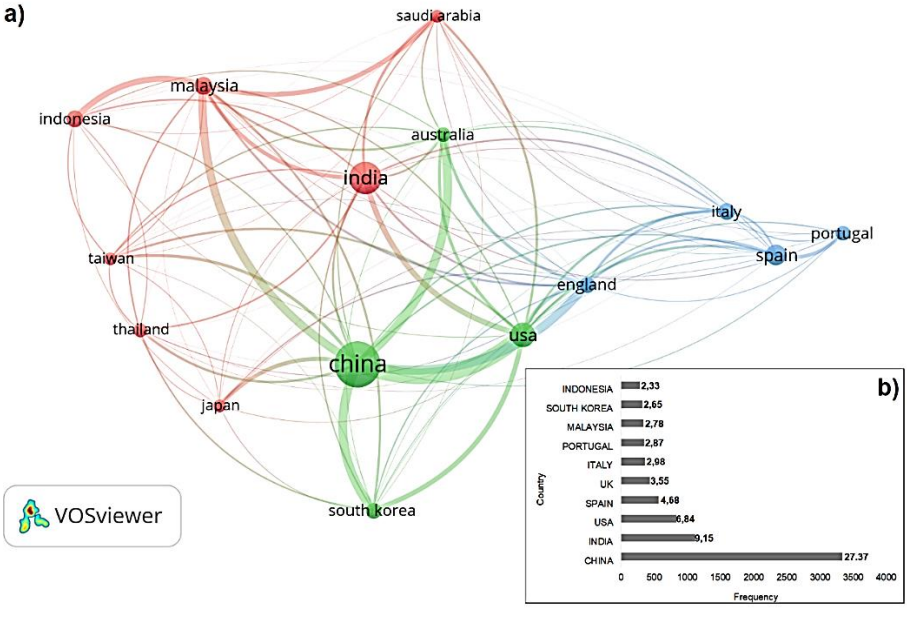

Fig. 5: International collaboration in AI research on sustainable tourism: (a) country co-authorship network generated with VOSviewer and (b) scientific output of the ten most productive countries

leading countries, with Spain (4.68%) and the United Kingdom (3.55%) drive this leadership through research intersecting technological innovation, sustainability and destination governance. The United States (6.84%) represents the principal contributor from North America, remaining among the three most productive countries worldwide. The co-authorship network further reveals a highly interconnected international research community in which China and the United States function as central knowledge hubs, establishing strong collaborative links with European countries (such as the United Kingdom, Spain, and Italy) and Asian countries (including India, South Korea, and Malaysia) (Fig. 5a). These collaboration patterns indicate that advances in AI for sustainable tourism are driven by transnational research networks that integrate technological expertise, multidisciplinary knowledge, and diverse territorial contexts. At the-analytical level, this international scientific matrix provides the epistemological foundation that drives the incremental evolution of specialized applications, encompassing geoheritage conservation, rationalized spatial planning, and smart geotourism. The collaboration networks also facilitate the diffusion of AI innovations into geotourism by enabling knowledge transfer, methodological exchange, shared datasets, and joint technological development among tourism, geoscience, and information-technology researchers. Countries occupying central positions in the collaboration network act as innovation hubs that accelerate the dissemination of analytical tools, geospatial methods, and smart destination practices into geopark management, geoheritage interpretation, and territorial planning. These temporal and geographical patterns demonstrate the rapid consolidation of AI research in sustainable tourism; however, they do not explain how the field is intellectually organised. To address this objective, the following section investigates the conceptual framework and thematic trajectory of the extant literature utilizing bibliometric science mapping methodologies.

Thematic structure and evolutionary dynamics of the study

The macro-level bibliometric analysis reveals that AI research in sustainable tourism has evolved through the progressive integration of three complementary knowledge domains that constitute the scientific foundations of smart tourism. Instead of operating as isolated domains, these thematic areas highlight the synchronized development of technological advancements, analytical capabilities, and visitor-oriented applications, creating the necessary epistemological conditions for the adoption of AI within specialized niches such as geotourism (Fig. 6). The thematic clusters were identified using the VOSviewer modularity-based clustering algorithm and subsequently validated through qualitative consistency assessment. Validation considered the semantic coherence of keywords within each cluster, the strength of co-occurrence links, and the stability of the three-cluster structure under the selected normalization and counting settings. The pronounced demarcation separating technological infrastructure, analytical intelligence, and visitor-centered applications, reinforced by the dense network of internal keyword connections, validates the premise that these clusters reliably capture the primary intellectual domains of AI research in tourism sector. Cluster 1 (red) represents the strategic and technological infrastructure supporting the digital transformation of tourism. This cluster connects concepts such as digital transformation, sustainable tourism, smart tourism, big data, blockchain, IoT, and immersive technologies such as virtual reality (VR) and augmented reality (AR), indicating that research has progressively shifted from isolated technological innovations towards integrated destination ecosystems. Moreover, this thematic grouping highlights the ways in which advanced technological infrastructures increasingly reinforce territorial governance, long-

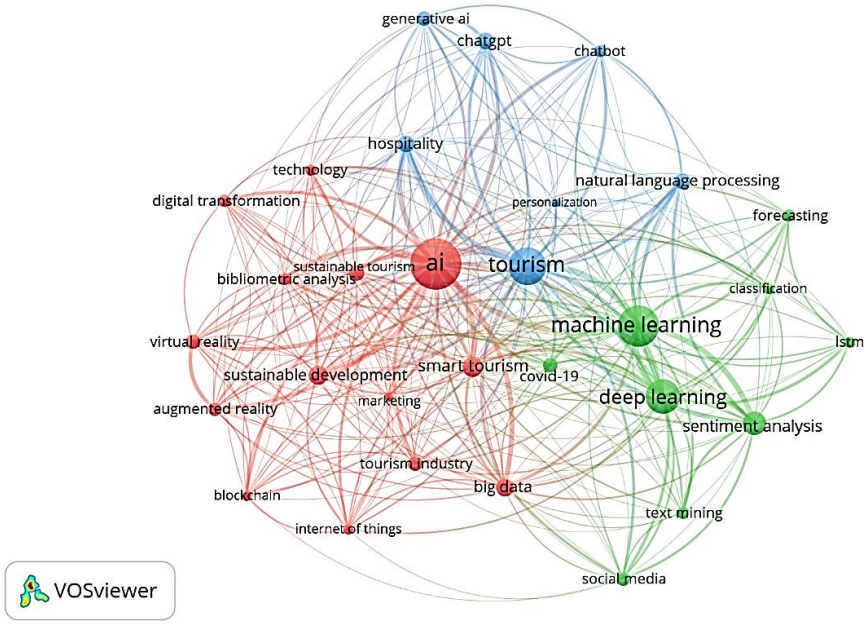

Fig. 6: Keyword co-occurrence network generated with VOSviewer showing the three main thematic clusters of AI research in sustainable tourism

term sustainability, and overall destination competitiveness. These developments provide the technological foundation upon which geoheritage destinations may later implement intelligent planning and management strategies. Cluster 2 (green) represents the analytical intelligence underpinning smart tourism. ML, DL, sentiment analysis, text mining, forecasting, and classification occupy central positions within the network, reflecting the growing importance of predictive analytics for understanding tourism dynamics. The presence of COVID-19 in this cluster illustrates how external disruptions accelerated the adoption of AI-based analytical approaches that support adaptive destination management and resilience. Thus, this grouping marks the critical progression from data proliferation to knowledge creation and empirical, evidence-based policy formulation. Cluster 3 (blue) reflects the evolution of AI towards human-centered tourism experiences. NLP, conversational agents, ChatGPT, generative AI, personalization, and hospitality demonstrate how recent research focuses on improving tourist interaction rather than merely automating operational processes. This evolution suggests that AI is serving as an interface between visitors and destinations, facilitating interpretation, communication, and personalised experiences that are particularly relevant to heritage-based tourism. The three clusters illustrate a broader scientific transition from technological development towards intelligent destination governance. The interaction between digital infrastructures, analytical capabilities, and visitor-oriented provisions reveals that smart tourism transcends its origins as a technological artifact, emerging instead as a holistic paradigm for territorial management. This macro-level evidence provides the conceptual rationale for examining how these AI capabilities are currently being adopted within the more specialized context of geotourism.

From a temporal perspective, the field's evolution shows a clear transition towards greater complexity and specialisation (Fig. 7). To minimize synonym variation and optimize conceptual consistency, keyword standardization procedures

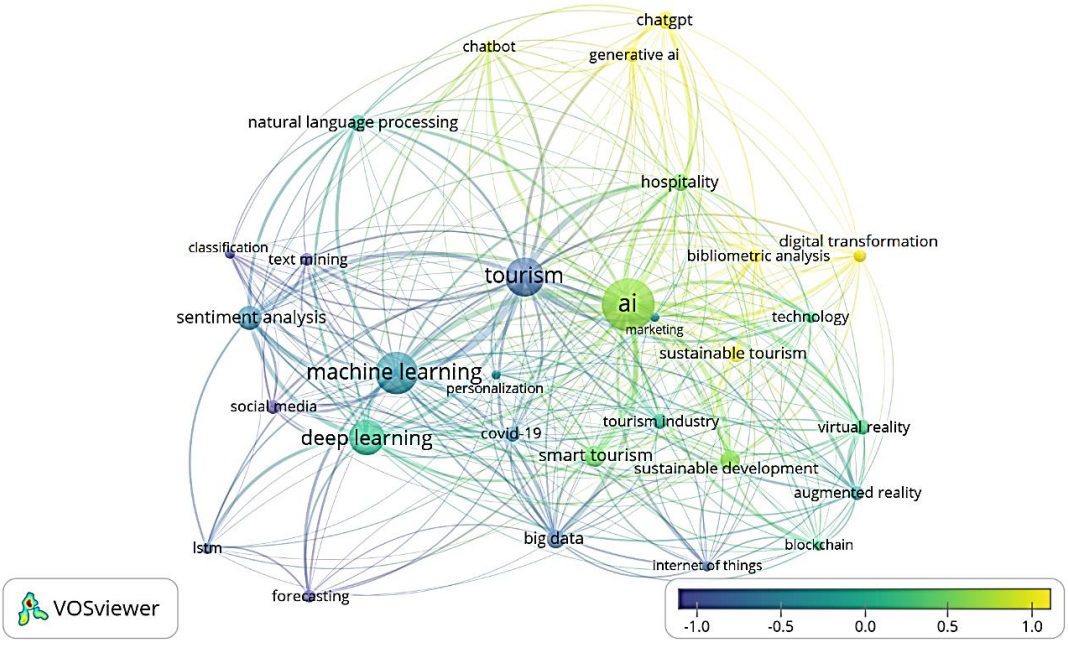

Fig. 7: Overlay visualization of author keywords showing the temporal evolution of AI research in sustainable tourism between 2022 and 2024

were executed prior to the construction of the network. Equivalent terms and spelling variants were merged using a thesaurus file in VOSviewer, including artificial intelligence/AI, machine learning/ML, deep learning/DL, and smart tourism/smart tourism destination. Singular–plural variants, hyphenation differences, and capitalisation inconsistencies were also standardized. The normalization procedure preserved the conceptual distinction between AI, ML, DL, and smart tourism while reducing redundant nodes and improving the interpretability of thematic relationships and temporal trends. The earliest phase (from -1.0 to -0.5) is characterized by data-oriented AI applications, in which research focused on exploiting digital information generated by tourism activities through techniques such as text mining, classification, forecasting, and social media analytics. The intermediate phase (0.0) reflects methodological consolidation, with ML and DL becoming central analytical approaches that generate predictive knowledge rather than descriptive information. The latest developmental phase (normalized from 0.5 to 1.0) highlights a pronounced evolution towards intelligent destination ecosystems, with digital transformation, sustainable tourism, generative AI, ChatGPT, and advanced conversational systems establishing themselves as primary research focal points. Rather than introducing isolated technologies, these topics indicate the convergence of AI, sustainability, and governance within smart tourism. This temporal evolution suggests that smart tourism is no longer defined solely by technological innovation but increasingly by the capacity to integrate AI into destination governance, sustainability, and visitor experience. Consequently, specialized tourism niches necessitating territorial intelligence, exemplified by geotourism—manifest as natural extensions of this overarching scientific progression, establishing the epistemological foundation for the micro-analytical investigation pursued hereafter. The temporal persistence analysis (Fig. 8) complements the previous findings by

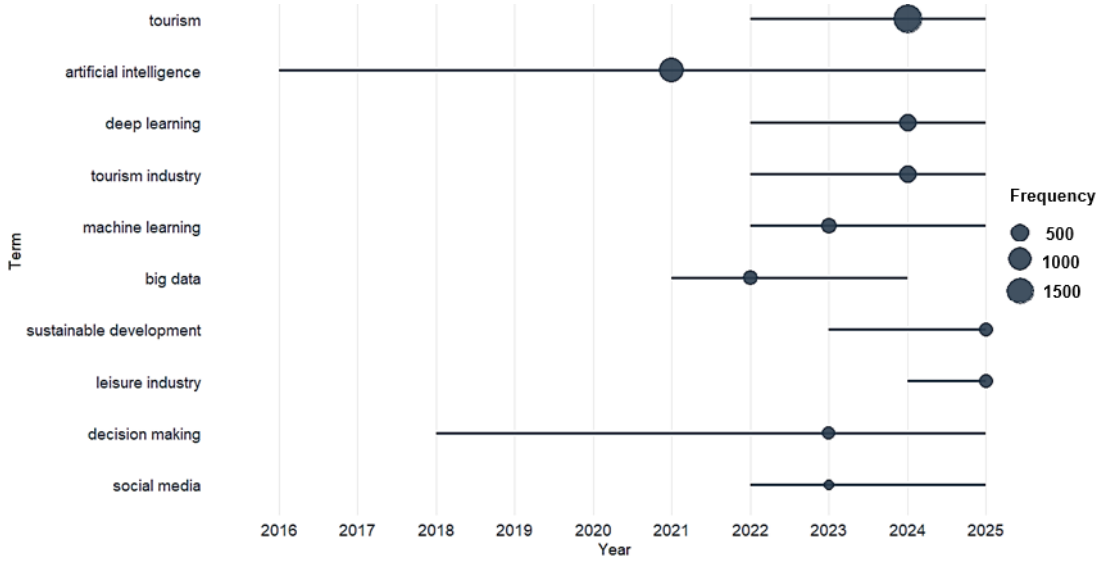

Fig. 8: Temporal evolution and persistence of the principal research topics in AI applied to sustainable tourism

distinguishing between foundational concepts and emerging specialisations. Tourism and AI remain the structural pillars of the field. In contrast, ML, DL, sustainable development, and the tourism industry represent rapidly expanding research domains that have achieved notable structural consolidation in recent years. This pattern indicates that the scientific evolution of AI in tourism is characterized not only by the emergence of new technologies but also by their progressive integration into sustainability-oriented destination management. Furthermore, this trajectory highlights a progression from foundational terms to nuanced, localized concepts, thereby supporting the premise that the maturation of smart tourism and geotourism relies on the systematic convergence of advanced technological tools with strategic and sustainable methodologies. These macro-level trends demonstrate that the scientific community has progressively developed the technological and conceptual foundations required to transfer AI applications to specialized sustainability contexts. The following systematic review explores how these broader scientometric developments translate into geotourism practices through empirical implementations in geotourism through empirical applications in geoheritage interpretation, destination management, predictive modeling, and environmental surveillance.

Empirical AI applications in geotourism: functional typologies from the systematic review

Operating in tandem with the macro-level bibliometric analysis, this systematic review furnishes empirical validation of the deployment of AI in geotourism. Whereas the bibliometric evaluation highlights sustainable tourism as a broader scientometric framework, the chosen case analyses reveal how underlying technological proficiencies convert into applied mechanisms reinforcing geoheritage conservation, destination planning, visitor dynamics, and environmental management (Table 3). The reviewed studies illustrate the emerging transition from smart tourism towards smart geotourism through the integration of AI with destination governance,

Table 3: Empirical evidence on AI applications in geotourism synthesized into four functional domains supporting smart geotourism: (i) predictive analytics, (ii) smart destination management, (iii) geoheritage interpretation, and (iv) environmental monitoring and geoconservation.

S.N.	Author	Country	AI Technology	Application in tourism	Resource type	Application purpose	Data types	Target user
Predictive analytics								
1	(Das *et al.*, 2025)	India	ML / Topic Modelling (BERTopic, NLP, BERT embeddings)	Strategic planning	Natural heritage / Geoheritage	Identification and mapping of key sustainable tourism themes	Textual	Policymakers / Academics
2	(Distefano *et al.*, 2025)	Italy	ML/Space Clustering	Tourism planning / Territorial analysis / Destination management	Cultural heritage	Identification of the likelihood of tourist attraction in museums	Spatial and attraction variables	Tourism planners and cultural managers
Smart destination management								
3	(Li *et al.*, 2022)	China	ML/Big Data/Intelligent systems	Destination Management	Cultural heritage	AI model promoting sustainable and smart heritage tourism	Tourism, behavioral and management data	Destination Managers / Tourism Planners
4	(Kumar, 2025)	India	Smart technologies	Tourism Management / Social Tourism	Community / Cultural	Smart tourism in the transformation of tourism volunteering	Theoretical and descriptive information	Local Communities / Volunteer Tourists / Managers
Geoheritage interpretation								
5	(Bozkurt and Şeker, 2023)	China	ML / DL / ANN	Tourism Planning / Sustainability Assessment	World Heritage Sites	ANN's role in sustainable tourism assessment	Socioeconomic, environmental, and tourism-related factors	Conservation organizations / Tourism planners
6	(Luo *et al.*, 2021)	China	ML / NLP / Text mining	Tourist Behavior Analysis	Geopark / Geoheritage	Analysis of tourist perceptions in geoparks	Tourist reviews and digital platforms	Geopark managers/Tourism marketers
7	(Karadayı *et al.*, 2026)	Türkiye	Metaverse / VR / AR	Heritage Interpretation / Digital Accessibility	Geosite / Geoheritage / Geodiversity	Use of metaverse technologies for the valuation of isolated geosites	Multimedia, virtual environments, and 3D models	Tourists, educators, and managers
8	(Zhao *et al.*, 2025)	China	ML / Data mining	Tourist Experience Analysis / Perceptual Assessment	Natural heritage / Geoheritage	Quantification of the aesthetic value of karst landscapes	Multimedia, reviews, and digital platforms	Destination managers / Tourism planners
9	(Cheng *et al.*, 2025)	-	LLMs / NLP / Text Mining	Tourist Perception Analysis / Sustainability Assessment	Natural heritage / World Heritage	Analysis of sustainability characteristics in natural heritage destinations	Tourist reviews and big data	Destination managers / Policymakers
10	(Benantar *et al.*, 2025)	Spain	HBIM	Digital Conservation / Heritage Interpretation / Cultural Dissemination	Cultural heritage	Sustainable conservation of built heritage	Point clouds, geospatial data, and 3D models	Heritage managers / Researchers / Planners

Environmental monitoring and geoconservation								
11	(Bravo-Jaico *et al.*, 2026)	Brazil	ML / DL / MLP / ANN	Tourism governance / Environmental management	Geodiversity / Natural heritage	Analysis and prediction of the relationship between biodiversity and tourism in sustainable governance contexts	Ecological, tourism, and territorial indicators	Policymakers / Environmental Managers
12	(Pham *et al.*, 2024)	China	DL / CNN / Computer Vision	Environmental monitoring / Destination management	Geopark / Geoheritage / Geodiversity	Monitoring landscape changes in a geopark for its sustainable management	Satellite imagery, geospatial data, and time series	Geopark Managers / Environmental Authorities
13	(Nugraha *et al.*, 2025)	Indonesia	ML / DL / ANN	Tourism planning / Development assessment / Territorial management	Geopark / Geoheritage / Geodiversity	Quantification of the geopark's contribution to the development of local communities	Socioeconomic, territorial, and VDI indicators	Policymakers / Geopark Managers
14	(Shahabi *et al.*, 2026)	China	ML	Tourism planning / Destination management / Territorial management	Geoheritage / Geopark / Geotourism	Analysis of geotourism resilience considering spatio-temporal dynamics	Geographic, time series, and tourism indicators	Policymakers / Destination Managers
15	(Naimi *et al.*, 2024)	Morocco	ML	Geotourism planning / Territorial assessment / Resource management	Geosite / Geoheritage / Geodiversity	Identification and classification of geosites with potential for geotourism development	Geomorphological, Geographic information system (GIS), and environmental criteria	Land Planners / Tourism Managers

Note: Fourteen of the fifteen studies synthesized in Table 3 are empirical studies based on observed or measured data, whereas one study is conceptual (Kumar, 2025). BERT: Bidirectional Encoder Representations from Transformers, ANN: Artificial Neural Network, LLMs: Large Language Models, HBIM: Heritage Building Information Modelling, MLP: Multilayer Perceptron, CNN: Convolutional Neural Network, VDI: Village Development Index and GIS.

geoconservation, and place-based sustainability. Rather than representing isolated technological developments, the reviewed studies reveal a coherent functional evolution of AI applications. Across diverse geographic contexts, AI supports decision-making throughout the geotourism management cycle, from predictive analytics and territorial planning to heritage interpretation and environmental monitoring. This diverse functionality highlights that AI has increasingly shifted beyond its role as a decision-support utility, emerging instead as a foundational catalyst for intelligent territorial governance. The empirical evidence also highlights the increasing integration of heterogeneous data sources, including textual information, social media content, geospatial databases, satellite imagery, environmental indicators, three-dimensional models, and multimedia resources. Through the integration of these complementary datasets enables AI systems are capable of generating multi-dimensional territorial intelligence that collectively reinforces tourism planning, resource management, visitor interaction, and geoheritage conservation. Another consistent finding concerns the diversity of stakeholders involved in AI implementation. Destination managers, policymakers, geopark authorities, environmental agencies, researchers, educators, local communities, and tourists all appear as active users of AI-based systems. This multidimensional participation suggests that smart geotourism

should be understood as the adoption of digital technologies and a governance model in which multiple actors interact through data-driven decision-making processes. Grounded in these insights, the synthesized corpus was structured into four key functional domains, delineating the core pathways by which AI drives smart geotourism.

These four functional domains illustrate the progressive operationaliZation of AI within geotourism. Predictive analytics supports anticipatory planning and decision-making; smart destination management strengthens governance and territorial coordination; geoheritage interpretation enhances visitor engagement through intelligent digital experiences; and environmental monitoring reinforces geoconservation through continuous assessment of landscape dynamics. These distinct domains illustrate that the emergence of smart geotourism is predicated on embedding complementary AI functionalities into sustainable destination management paradigms. The reviewed studies also reveal clear technological patterns. Predictive analytics is mainly supported by ML algorithms such as random forests, support vector machines, and neural networks. In contrast, image recognition and automated geosite detection are more closely associated with DL and computer vision, particularly CNNs. Geospatial modelling is significantly enhanced by coupling ML with GIS and spatial statistics, whereas environmental monitoring commonly leverages DL techniques applied to temporal sequences of remote sensing time series. NLP, LLMs, recommender systems, and immersive AI platforms increasingly support geoheritage interpretation and visitor interaction. ML and geospatial AI improve geoheritage assessment by integrating geomorphological, geological, topographic, environmental, and tourism variables within predictive spatial models (Sousa *et al.,* 2024). Through these approaches, automated geosite identification is achieved alongside the hierarchical categorization of geoheritage resources relative to their scientific and touristic utility, as well as multi-faceted vulnerability evaluations accounting for erosion, anthropogenic land-use modification, climate vulnerability, accessibility constraints, and visitor intensity. The evidence further highlights opportunities for integrating remote sensing, unmanned aerial vehicles (UAVs), light detection and ranging (LiDAR), GIS, and AI into smart geotourism management systems. Satellite imagery provides continuous regional monitoring (Bhattacharjee *et al.,* 2026), UAVs enable high-resolution local observation (Williams *et al.,* 2025), LiDAR supports detailed terrain modelling (Sahahiri *et al.,* 2026), GIS integrates spatial information (Sahahiri, 2025), and AI supports automated classification, change detection, risk assessment, and scenario simulation (Tang, 2025). Thus, the deployment of integrated geospatial intelligence platforms serves to bolster environmental surveillance, visitor management, carrying-capacity evaluation, early hazard detection, and adaptive conservation planning. Moreover, AI contributes to real-time environmental tracking in vulnerable tourist destinations by integrating diverse observational inputs—such as sensor arrays, mobile tracking data, UAV observations, remote sensing temporal series, and comprehensive environmental monitoring systems. ML models can identify crowding hotspots, detect early signs of erosion or vegetation degradation, and support dynamic carrying-capacity assessment (Xiong *et al.,* 2026). In hazard-prone areas, AI-based change detection and forecasting can assist in monitoring landslides, rockfalls, flooding, and geomorphological instability (Bera *et al.,* 2025). Effective, large-scale implementation requires the establishment of interoperable geospatial infrastructures combining GIS, remote sensing repositories, environmental sensor networks, tourism databases, and cultural heritage inventories. Open geospatial standards, interoperable metadata protocols, common spatial reference systems, and standardized geoheritage taxonomies constitute

fundamental prerequisites for effective data sharing across institutional and destination boundaries (da Silva Mano *et al.,* 2024). Cloud-based spatial infrastructures can facilitate multi-source integration and collaborative territorial management (Zhidebayeva *et al.,* 2025). Emerging opportunities also include integration with Digital Twins, AR, VR, and immersive geospatial visualization platforms. Digital Twins can simulate visitor flows and conservation scenarios in real time (Durden, 2025), while AR and VR can enhance geoheritage interpretation, accessibility, and virtual access to fragile geosites (Vandelli *et al.,* 2024). When synthesized with AI-enabled personalization and advanced geospatial visualization, these systems serve to augment visitor education and risk mitigation awareness, thereby bolstering both destination management and conservation planning initiatives. Their adoption, however, remains uneven across regions due to differences in technological maturity, governance capacity, environmental priorities, and territorial conditions.

Regional comparative assessment of sustainability and tourism intelligence in geotourism

Fig. 9 provides a comparative assessment of the fifteen empirical case studies according to three complementary dimensions that underpin the smart geotourism framework proposed in this study: geoconservation, smart tourism integration, and sustainability. As depicted in Fig. 6, different geographical settings combine these structural dimensions to advance AI-driven geotourism, exposing a multiplicity of pathways towards smart geotourism. Asia represents the largest body of empirical evidence and exhibits the greatest variability across the three dimensions. Several studies demonstrate high levels of smart tourism integration, supported by advanced AI techniques such as ML, DL, computer vision, and large-scale spatial analytics. At the same time, the empirical cases highlight considerable divergence concerning the degree to which geoconservation priorities and broader sustainability outcomes parallel technological advancements. This diversity suggests that Asian research is characterized by rapid technological experimentation while simultaneously exploring different governance models for integrating AI into geoheritage management. European studies present a comparatively more balanced profile. Despite the limited corpus of empirical cases identified, these instances consistently align advanced technologies with the core objectives of heritage conservation and sustainability objectives. European research tends to position AI as a decision-support tool within integrated territorial governance, reinforcing the relationship between destination intelligence, heritage interpretation, and sustainable planning. North American evidence is characterized by strong smart tourism integration combined with moderate levels of geoconservation and sustainability. Empirical findings reveal that the investigated instances predominantly utilize AI to advance destination intelligence and administrative efficiency, thereby suggesting a management-driven approach where technological adoption outpaces broader environmental integration. In contrast, Latin American and African case studies demonstrate a more balanced interaction among the three analytical dimensions. Although the technological sophistication of AI applications is generally lower than in Asia, these studies consistently link AI to local territorial planning, environmental conservation, and community-oriented sustainability. Consequently, these observations implies that smart geotourism is forged not solely through technological evolution, but fundamentally through the deepened integration of territorial governance and conservation mandates. Overall, the regional comparison demonstrates that smart geotourism does not follow a single developmental trajectory. Instead, destinations combine AI, sustainability, and geoconservation across different territorial contexts, with varying governance capacities and levels of technological maturity. Consequently,

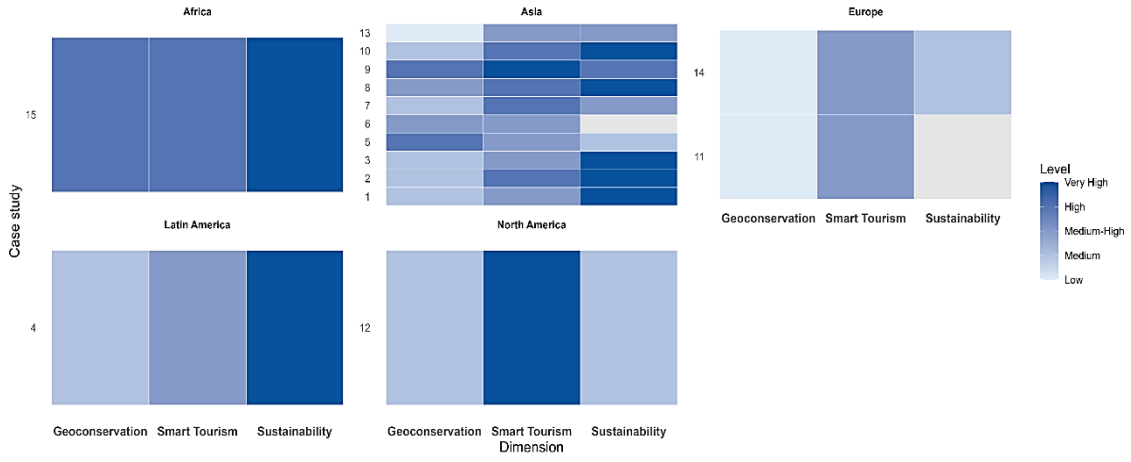

Fig. 9: Regional implementation patterns of the smart geotourism framework based on geoconservation, smart tourism integration, and sustainability

these findings validate that the evolution of smart geotourism is governed less by the standalone adoption of advanced AI capabilities than by their functional efficacy in underpinning integrated destination intelligence, evidence-based territorial planning, and long-term geoheritage conservation. The integration of bibliometric analysis and systematic review provides a multi-scale interpretation of the evolution of AI in tourism. The results indicate a transition from isolated digital applications towards a scientific system in which analytical intelligence, territorial governance, and sustainability increasingly converge. This evolution provides the conceptual basis for understanding smart geotourism as a specialized extension of the smart tourism paradigm. In this perspective, smart geotourism emerges within this framework as a complex socio-technical system driven by the ongoing, reciprocal feedback loops connecting technological innovation, environmental stewardship, tourist behavior, and regional progression (Zheng *et al.,* 2025). AI-based monitoring and analytics inform management decisions, while visitor responses generate new behavioral and spatial information that supports adaptive territorial management (Gacu *et al.,* 2025). Bibliometric evidence shows that the rapid growth of scientific production reflects a structural transformation of the field rather than merely an increase in publications. The temporal evolution of publications (Fig. 4), the consolidation of international collaboration networks (Fig. 5), and the progressive thematic maturation demonstrate that AI has become a central component of destination intelligence. This trajectory corresponds with the transition from digitization to data-driven smart tourism ecosystems highlighted by recent studies (Gajdošík and Marciš, 2025; Mondol *et al.,* 2026). Furthermore, the findings of this analysis reveal that these developments constitute the empirical and theoretical bedrock for novel geoheritage-oriented applications. Co-occurrence analysis reveals three complementary domains (Fig. 6), digital infrastructures, analytical intelligence, and visitor-centered services, which together illustrate the progressive integration of AI within smart tourism systems. This pattern supports previous research on AI-based destination planning (Ku and Chen, 2024; Wang *et al.,* 2025) and suggests that smart tourism is increasingly incorporating territorial conservation and geoheritage management objectives (Ferdowsi, 2025). The substantial contributions spanning tourism studies, computer science, geosciences,

geography, environmental sciences, remote sensing, GIS, and sustainability studies clearly validate the inherently multidisciplinary paradigm of the field. The temporal evolution of keywords indicates a transition from data-processing-oriented research towards themes such as digital transformation (Fig. 7), generative AI, and sustainability, suggesting that AI is being embedded within broader territorial governance frameworks. Thus, smart tourism is evolving beyond a technology-centric efficiency paradigm, reorienting instead toward destination intelligence, adaptive planning, and sustainability, a trajectory consistent with contemporary frameworks of resilient tourism and smart governance (Gómez Rodríguez, 2025; Song and Chen, 2025). Comparison with previous reviews highlights an important gap between AI-oriented tourism research and geotourism research. AI reviews mainly focus on visitor analytics, recommendation systems, and smart destination management (Bingöl and Yang, 2025; Panigrahy and Verma, 2025), whereas geotourism reviews emphasise geoheritage assessment, conservation, education, and territorial development (Reynard and Brilha, 2025). The reviewed empirical studies indicate that these research traditions remain only partially connected. Moreover, while increasingly sophisticated AI applications tend to concentrate on destination intelligence and visitor management, concrete evidence demonstrating their direct impact on measurable geoheritage conservation outcomes remains limited (Bingöl and Yang, 2025; Tuo *et al.,* 2025). In contrast, several Latin American and African studies demonstrate stronger integration between territorial planning and conservation despite using less advanced AI techniques (Córdoba Azcárate, 2025), suggesting that governance capacity may be as important as technological maturity. This study fundamentally contributes by coupling macro-level bibliometric evidence with micro-level data within the domains of geoheritage and geotourism. This combined approach facilitates the extraction of four recurring functional categories: predictive analytics, smart destination management, geoheritage interpretation, and environmental monitoring, which collectively underpin the proposed smart geotourism framework (Table 3). Although the empirical sample is limited to fifteen studies, the diversity of territorial contexts, governance arrangements, heritage types, and AI techniques strengthens the robustness of these recurring patterns. Synthesizing the reviewed findings, AI underpins evidence-based territorial planning by interconnecting four core processes: data acquisition, spatial intelligence, decision support, and adaptive management (Hao *et al.,* 2024). By integrating geospatial, environmental, tourism, and behavioral data, AI can generate predictive models, suitability assessments, risk maps, carrying-capacity indicators, and alternative planning scenarios that support conservation prioritization, visitor management, and monitoring of landscape change (Kim *et al.,* 2026). Reported conservation outcomes involve more efficient tracking of landscape alterations, the precise identification of at-risk geosites, the systematic prioritization of remedial measures, and the reinforcement of adaptive management frameworks within geoparks and protected geological regions. Predictive models can also identify emerging threats associated with erosion, climate change, uncontrolled tourism, and land-use transformation (Goyal *et al.,* 2025), while AI-based decision-support systems can help balance tourism development with conservation objectives (Vujko *et al.,* 2025). Sustainability considerations across the reviewed studies encompass environmental, social, economic, cultural, and governance dimensions, including landscape conservation, community participation, tourism development, heritage interpretation, and institutional coordination. The available data imply that the successful implementation of smart geotourism relies on complex, multi-level governance structures comprising UNESCO Global Geoparks, environmental authorities, tourism bureaus, planning agencies, research bodies, and

host communities (Xanthakis *et al.,* 2024). AI-enabled decision-support systems can facilitate collaboration among these stakeholders through shared geospatial planning platforms. At the same time, responsible AI adoption requires data governance, interoperability standards, ethical guidelines, and community participation mechanisms. Regional disparities in AI adoption are associated with differences in institutional capacity, investment, digital infrastructure, geospatial data availability, technical expertise, and education (Fig. 9). Consistent with antecedent literature highlighting the mediating influence of institutional frameworks on smart technology adoption and territorial innovation, these patterns reinforce the significance of local governance contexts (Frenzel *et al.,* 2022; Reverte and Luque, 2021). Asian cases generally reflect stronger technological ecosystems, whereas several Latin American and African studies demonstrate that effective smart geotourism can emerge through stronger integration between conservation objectives, governance arrangements, and community participation. Thus, successful execution seems governed less by standalone technologies than by the strategic synthesis of AI applications with clear institutional governance and conservation-driven planning (Güngör *et al.,* 2026). Persistent barriers include data ownership restrictions, limited interoperability, fragmented institutional responsibilities, insufficient financing, and weak technological governance frameworks. Recent technological developments indicate that smart geotourism is entering a new phase. Generative AI and LLMs are increasingly used for multilingual geoheritage interpretation, conversational visitor assistance, educational content generation, and personalised storytelling (Mah, 2025), while Digital Twins offer opportunities for real-time simulation of visitor flows and conservation scenarios (Florido-Benítez, 2024). Simultaneously, these technological strides present profound governance complexities associated with transparency, interpretability, data privacy, algorithmic equity, accountability, and civic engagement (Ma *et al.,* 2026). The limited attention to responsible AI governance in the reviewed studies highlights a significant research gap. Overall, the findings support the interpretation of AI not merely as a tourism technology but as a strategic enabler of territorial intelligence. Consequently, smart geotourism emerges as an integrative paradigm uniting AI, territorial governance, geoconservation, and sustainability under the umbrella of a unified destination management system. Future studies should prioritize operational indicators, longitudinal validation, comparative destination studies, ethical governance frameworks, and interdisciplinary integration among AI, geoscience, tourism management, spatial planning, environmental governance, and sustainability science.

Limitations of the study

This study presents some limitations that should be considered for the correct interpretation of the results: i) the bibliometric search was conducted in Scopus and WoS without language restrictions; however, the systematic review was restricted to English-language publications. Thus, relevant literature published across diverse linguistic contexts, regional outlets, or grey literature repositories could be inadvertently overlooked, potentially imparting geographical and intellectual skewness to the aggregation of empirical data. ii) the systematic review identified fifteen empirical case studies explicitly applying AI within geoheritage and geotourism contexts. This limited number reflects the emerging nature of smart geotourism and the current scarcity of empirically documented applications. Nevertheless, the selected studies were intentionally retained because they represent diverse geographical regions, territorial settings, and AI application domains. Additionally, given that a formal methodological quality appraisal tool was omitted from the study selection process, the present synthesis captures the existing empirical literature without quantitative adjustment for individual

study rigor. (iii) the regional comparative assessment relied on qualitative interpretation of the relationships among geoconservation, sustainability, and smart tourism integration. Although the comparative framework enabled systematic interpretation across heterogeneous studies, differences in methodologies, AI techniques, geographical contexts, and evaluation criteria limited the possibility of quantitative meta-analysis. The proposed smart geotourism framework remains conceptual and has not yet been empirically validated through expert assessment, pilot implementation, or comparative case-study testing. Thus, rather than functioning as a verified operational model, its pragmatic value lies in serving as a structured planning and governance reference drawn from the synthesis of current empirical findings. Future research should validate and operationalise the framework through Delphi studies, longitudinal assessments, comparative case studies, and the development of standardized performance indicators.

Political implications

The findings have important implications for tourism governance and territorial planning. Public policies should integrate AI into broader strategies linking destination intelligence, geoheritage conservation, and sustainable territorial development. As evidenced by the regional comparison, standalone technological advancements fall short of achieving smart geotourism; rather, effective implementation is contingent upon institutional readiness, interdisciplinary synergy, equitable geospatial data stewardship, and comprehensive planning systems capable of unifying tourism, environmental tracking, and cultural heritage management. To improve the operational value of the smart geotourism framework, the following stakeholder-specific recommendations are proposed:

- For policymakers, priorities include establishing national and regional smart geotourism strategies, promoting open geospatial data infrastructures, strengthening local AI capabilities, and adopting ethical and transparent governance frameworks.
- Geopark managers and conservation authorities should prioritize AI-supported visitor monitoring, carrying-capacity assessment, digital interpretation, environmental monitoring, and interoperable geospatial databases that support adaptive geoheritage management.
- Tourism planners should incorporate predictive analytics, mobility modelling, and geospatial decision-support tools into destination planning and conservation-sensitive zoning.

Policy priorities should be adapted to regional conditions. Developing regions require investment in digital infrastructure, access to geospatial data, technical training, and institutional strengthening for AI-enabled territorial governance. Consequently, in advanced technological contexts, policy frameworks should increasingly incorporate geoconservation objectives into smart tourism strategies, ensuring that digital and technical innovations serve directly to safeguard geological heritage over the long term. Overall, the proposed smart geotourism framework provides a practical governance reference for coordinating AI, destination management, sustainability, and territorial planning, supporting a transition from technology-driven tourism towards evidence-based territorial management aligned with the SDGs.

CONCLUSION

This study demonstrates that research on AI in sustainable tourism has evolved from isolated technological applications towards a broader scientific paradigm centered on destination intelligence, sustainability, and evidence-based governance. The bibliometric analysis confirms the field's progressive maturation. Simultaneously, the findings of the systematic review reveal that AI applications in geotourism

cluster primarily into four distinct functional domains: predictive analytics, smart destination management, geoheritage interpretation, and environmental monitoring and geoconservation. In addition, the synthesis reveals that AI integration across geotourism sectors is unevenly distributed geographically. Such adoption is fundamentally contingent upon a triad of factors: technological maturity, institutional capacity, and the embeddedness of sustainability and geoconservation into tourism planning. By integrating macro-level bibliometric evidence and micro-level empirical studies, the present study advances a smart geotourism framework designed to unify destination intelligence, spatial planning, geoheritage conservation, and sustainable tourism stewardship. This framework should be interpreted as a conceptual synthesis derived from the reviewed literature rather than as an empirically validated operational model. Accordingly, the study contributes to the emerging smart geotourism literature by offering an integrated analytical perspective that connects AI, territorial governance, and geoheritage management. Looking ahead, future inquiries must move beyond the current empirical boundaries to address operational implementation, ethical and trustworthy AI governance, and the interdisciplinary appraisal of smart geotourism frameworks. Further research should prioritize empirical validation of the framework through comparative case studies, longitudinal assessments, and the development of standardized indicators for destination intelligence, geoheritage conservation, governance capacity, and sustainability outcomes. Cutting-edge technological paradigms, encompassing as generative AI, digital twins, sophisticated geospatial analytics, XAI, and Earth observation systems, establish valuable avenues for operational validation in practical geotourism contexts. These directions should be interpreted as priorities for future research rather than as conclusions demonstrated by the present review.

AUTHOR CONTRIBUTIONS

T. Aguirre-Suárez contributed to the conceptualisation, formal analysis, data curation, investigation, methodology, writing - original draft, writing - review and editing, project administration, software and validation. M. Pérez-Chiquito contributed to the conceptualisation, formal analysis, data curation, methodology, writing - original draft and writing - review and editing. H. Cochea-Tomalá contributed to the formal analysis, investigation, methodology, writing - original draft, writing - review and editing and project administration. P. Escandón-Panchana contributed to the conceptualisation, data curation, investigation, methodology, writing - original draft, writing - review and editing, project administration and software.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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NEGATIVE AI STATEMENT

The author(s) declare that no AI tools or services were not used or not highly applied during the preparation of this work.

ABBREVIATIONS

%	Percent
AI	Artificial intelligence
ANN	Artificial neural network
AR	Augmented reality
BERT	Bidirectional encoder representations from transformers
CNN	Convolutional neural network
COVID-19	*Corronavirus-2019*
DL	Deep learning
DOIs	Digital object identifiers
e.g.	Exempli gratia (for example)
GIS	Geographic information system
HBIM	Heritage building information modelling
IoT	Internet of Things
LiDAR	Light detection and ranging
LLMs	Large language models
ML	Machine learning
MLP	Multilayer perceptron
NLP	Natural language processing
PRISMA	Preferred reporting items for systematic reviews and meta-analyses
RQ	Research questions
SDGs	Sustainable development goals
UAVs	Unmanned aerial vehicles
VDI	Village development index
VR	Virtual reality
WoS	Web of Science
XAI	Explainable artificial intelligence

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