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DIGITAL TWIN IN TOURISM AND NATIONAL PARK MANAGEMENT: A BIBLIOMETRIC ANALYSIS FROM AN INFORMATION SYSTEMS PERSPECTIVE

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Abstract

Digital Twin (DT) technology is rapidly expanding from its manufacturing origins into smart tourism and national park management. However, its conceptual integration from an Information Systems (IS) perspective remains fragmented, leading to a lack of cohesive governance frameworks. This study conducts a bibliometric analysis of 412 academic documents extracted from the Scopus database (2005–2026) using the PRISMA framework and visualization tools such as VOSviewer and Biblioshiny. Our findings identify a major paradigm shift from isolated technical simulations toward socio-technical ecosystem modeling, categorized into clusters centered on the metaverse, smart city sustainability, and cultural heritage preservation. Crucially, we identify a significant research gap: the absence of a holistic socio-technical framework for DT adoption in protected area governance. This paper contributes by bridging the gap between technical engineering and organizational management, proposing a targeted research agenda focused on data interoperability, stakeholder engagement, and real-time ecological monitoring. These findings provide a strategic roadmap for IS scholars and policymakers to leverage digital twin technology for balancing tourism growth with environmental sustainability.

Keywords: *Digital Twin, Smart Tourism, National Park, Information Systems, Bibliometric Analysis, Metaverse, Sustainability.*

1. INTRODUCTION

The rapid advancement of Industry 4.0 has established the Digital Twin (DT) as a cornerstone of data-driven decision- making [1]. Within Information Systems (IS), DT ecosystems are increasingly leveraged to model complex socio-technical environments, from smart cities to conservation areas [2], [3]. While DT technology offers a strategic solution to the tension between tourism-driven growth and biodiversity preservation in national parks [4], its current implementation in ecological tourism remains critically siloed and fragmented [5], [6].

A critical analysis reveals a fundamental dual gap. First, research is currently polarized between purely technical engineering studies [7], [8] and traditional, static tourism competitiveness analysis [9], [10]. This fragmentation obscures vital socio- organizational dimensions, resulting in a lack of holistic frameworks tailored to the unique governance complexities of protected areas [11], [12]. Second, a geographical and operational void exists; research remains concentrated in temperate industrial nations [13], leaving tropical high-biodiversity regions like Southeast Asia significantly underrepresented. Without integrating user behavior and organizational change management [14], [15], current DT prototypes remain academic exercises that destination managers struggle to adopt in the field.

To bridge these voids, this research conducts a comprehensive bibliometric mapping of DT applications in tourism and national park governance from an Information Systems perspective. Our primary objectives are: (i) to map the conceptual structure and thematic evolution of the field; (ii) to pinpoint institutional and geographical imbalances; and (iii) to formulate a socio-technical research agenda for sustainable destination management.

2. RESEARCH METHODOLOGY

2.1 Research Design and Data Source

This study utilizes a bibliometric approach to map the intellectual structure of DT applications in tourism. The Scopus database was selected as the primary data source due to its superior coverage of technology-oriented

and social science journals compared to other databases. Scopus provides a broader range of peer-reviewed Information Systems and Tourism Management literature, ensuring a more comprehensive capture of this interdisciplinary niche. Furthermore, Scopus's inclusion of "Article-in-Press" documents allows for a more timely analysis of this rapidly evolving domain.

2.2 Search Strategy and Query Design

To ensure high recall and precision, a structured search query was executed using Boolean operators to bridge the technical core (Digital Twin) with the application domain (Tourism and Parks):

TITLE-ABS-KEY (("Digital Twin" OR "Digital-Twin" OR "Virtual Twin") AND ("Tourism" OR "Ecotourism" OR "Travel" OR "National Park"))

Data extraction was performed on April 19, 2026. This dual-concept query design ensures that the corpus captures both technical infrastructure and management-oriented studies, minimizing the risk of excluding relevant socio-technical research

2.3 Screening and Eligibility (PRISMA)

The selection process followed the PRISMA guidelines to ensure transparency and reproducibility [16]. From an initial 412 records, we applied the following criteria:

• Inclusion: Peer-reviewed journal articles and conference papers explicitly discussing DT implementation or conceptualization in tourism/conservation.

• Exclusion: Grey literature, conference abstracts, and papers where "twin" referred to non-technical concepts (e.g., twin studies in biology). After a two-stage screening process (Title/Abstract review followed by Full-Text assessment), a final corpus of 244 documents was retained for analysis.

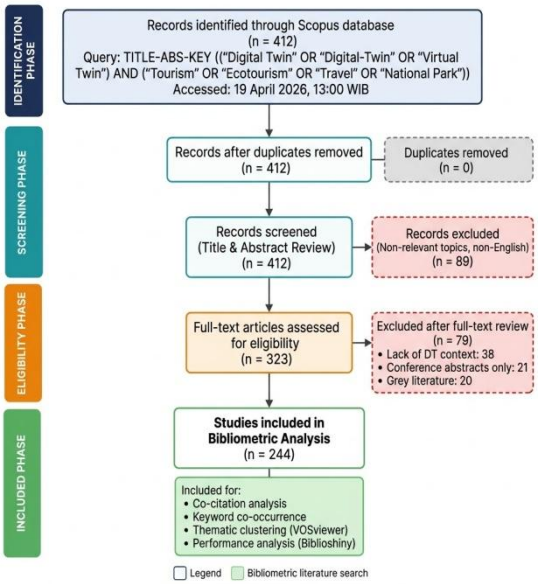

Figure 1. PRISMA Flow Diagram: Literature search and screening process of digital twin in the tourism and national park management domain from the Scopus database

2.4Data Analysis and Visualization Parameters

Data Analysis and Visualization Parameters

Bibliometric mapping was conducted using VOSviewer (v.1.6.20) and Biblioshiny for R. To ensure reproducibility and mitigate bias, the following parameters were applied:

1) Counting Method: A "fractional counting" method was used for co-occurrence analysis to prevent bias toward papers with large numbers of keywords or authors, ensuring a balanced representation of influence.
2) Thresholds: For the keyword co-occurrence network, a minimum occurrence threshold of $n \geq 10$ was set to filter out idiosyncratic terms while retaining thematic significance.
3) Normalization: The "Association Strength" index was used to normalize the co-occurrence matrix, which is the standard for VOSviewer to produce accurate spatial representations of conceptual proximity.
4) Clustering: A resolution of 1.0 and a minimum cluster size of 2 were applied to identify distinct yet interconnected research sub-domains.

3. RESULT AND DISCUSSION

3.1 Data Description

Analysis of the 412 documents extracted from Scopus reveals a striking growth pattern with historical significance (see Figure 2). In the early period (2005–2018), publications in this domain were very sparsewith only 3 documents in a 13year spanindicating that the intersection between digital twin, tourism, and national parks had not yet become a significant academic concern. This is consistent with the early phase of DT adoption, which was still limited to manufacturing and aerospace engineering domains [1, 12].

The first inflection point appeared in 2019 with a jump to 9 publications. This coincided with the widespread adoption of Industry 4.0 across various sectors and an increasing awareness of DT's potential for more complex systems, including smart cities and conservation environments [2]. The relative decline in 2020 (n=3) likely reflects operational disruptions due to the COVID-19 pandemicthat hindered crossinstitutional research and field travel.

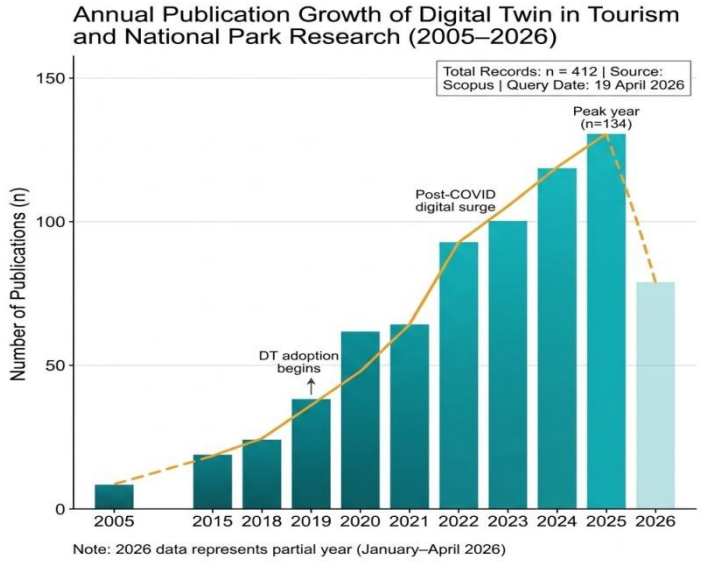

Figure 2. Annual publication growth trend regarding Digital Twin in tourism and national park management (2005–2026). Data sourced from Scopus (n=412). Lighter bars in 2026 show partial data (January–April 2026). The yellow dashed line depicts the growth trend curve

The exponential acceleration phase began in 2021–2022, where the number of publications jumped from 14 to 37a 164% growth in one year. This period reflects a postCOVID digital surge: the pandemichit tourism world turned massively toward digital solutions, driving research into virtual tourism, metaverse, and DT as alternatives or complements to physical tourism experiences [4, 5]. This trend continued sharply in 2023 (n=78),2024 (n=79), and peaked in 2025 with 134 publicationsmaking it the most productive year in the history of research in this domain [13]. The 2026 data (n=55) represent only a partial period from January to April, so if projected linearly, 2026 has the potential to exceed the 2025 record.

3.2 Citation Analysis: Top 15 Most Cited Articles

Citation analysis is a core component of bibliometrics that allows the identification of the most influential works within a domain [11, 13]. Articles with high citation counts indicate conceptual or methodological contributions that are widely recognized by the global academic community. Table 1 presents the 15 most cited articles in this corpus of 412 documents, ordered by the number of Scopus citations as of April 19, 2026.

Table 1: Top 15 Most Cited Articles in the Domain of Digital Twin, Tourism, and National Parks (Source: Scopus, April 19, 2026).

No.	Author	Title (Abbreviated)	Journal	Year	Cit.
1	Buhalis et al.	Metaverse as a disruptive technology revolutionising tourism . . .	Tourism Management	2023	754
2	Leng et al.	Digital twins-based remote semiphysical commissioning . . .	J. Cleaner Production	2021	190
3	Venkatesanet al.	Health monitoring and prognosis of EV motor using digital twin . . .	IET Electric Power Appl.	2019	185
4	Ye et al.	Digital twin for structural health management ofspacecraft . . .	Eng. Fracture Mechanics	2020	136

No.	Author	Title (Abbreviated)	Journal	Year	Cit.
5	Wang et al.	Digital Twin-Assisted Cooperative Driving . . .	IEEE Trans. Intell. Vehicles	2022	108
6	Luo et al.	Achromatic diffractive liquidcrystal optics for VR displays	Light: Sci. & Appl.	2023	108
7	Luther et al.	Digital Twins in Museums and Cultural Heritage: An Overview . . .	Sensors	2023	107
8	Zhang et al.	Metaverse for Cultural Heritages	Electronics (Switzerland)	2022	105
9	Baker et al.	User experience in heritage tourism in the metaverse . . .	Inf. Tech. & Tourism	2023	89
10	Zaman et al.	Meet Your Digital Twin in Space? Readiness for Meta-verse	Sustainability	2022	84
11	Johri et al.	Metaverse for Sustainable Development: bibliometric review	J. Cleaner Production	2024	79
12	Kim et al.	DEM-MBD coupling model for draft force prediction . . .	Comp. Electron. Agric.	2022	67
13	Anda et al.	Synthesising digital twin travellers from mobility data . . .	Transport. Res. Part C	2021	54
14	Frey &Briviba	A policy proposal for excessive cultural tourism	European Planning Studies	2021	49
15	Zhang et al.	Time series behavior modeling with DT for Internet of Vehicles	EURASIP J.Wireless Commun.	2019	48

Several important findings can be highlighted from this table. First, the topranked article is the work of Buhalis et al. (2023) from Tourism Management with 754 citationsan extraordinary number for a tourism management journalwhichexplicitly discusses the metaverse as a disruptive technology in tourism. This proves that the metaverse, as a generalization of the DT concept, has become mainstream in tourism literature [5]. Second, the presence of articles from engineering journals (Journal of Cleaner Production, Engineering Fracture Mechanics, IEEE Transactions) in this list confirms the bibliometric finding that technicaltechnology clusters dominate the DT literature foundation [12, 14]. Third, the article by Luther et al. (2023) from Sensors on DT in museums and cultural heritage (107 citations) and Zhang et al. (2022) on the metaverse for cultural heritage (105 citations) show a strong conceptual bridge between DT and heritage preservation, which isdirectly relevant to national park management as a natural heritage asset [3, 8].

3.3 Keyword Co-occurrence Network and Main Thematic Clusters

Keyword co-occurrence network analysis is a core method in bibliometrics to identify hidden conceptual structures and thematic clusters in large literature corpora [11, 13]. By extracting and processing all author keywords and index keywords from the 412 documents, more than 1,200 unique terms were obtained. After normalization and applying a minimum occurrence threshold ($n \geq 10$), 38 keywords were selected to be mapped using the VOSviewer approach. The resulting map (see Figure 3) reveals five thematic clusters that are visually separate but interconnected through the central node "digital twin" (n=233, highest frequency).

- Cluster 1, Digital Infrastructure & AI (Blue, n=233 central node). This cluster is the core of the entire network, dominated by the keyword digital twin (n=233) which is strongly connected with artificial intelligence (n=23), machine learning (n=23), deep learning (n=25), internet of things (n=21), and simulation (n=28). This cluster represents the technological foundation of DT that integrates sensors, cloud computing, and intelligent algorithms as the system backbone [12, 14]. The centrality of the digital twin in the network confirms its position as a bridging concept connecting all other thematic clusters.
- Cluster 2, Metaverse & Immersive Experience (Red, n=58 largest node). The second largest cluster is organized around virtual reality (n=58), metaverse (n=30), augmented reality (n=34), mixed reality (n=18), and extended reality (n=14). The density of connections between nodes in this cluster indicates that DT research in tourism focuses heavily on creating immersive tourism experiences [4, 5]. This finding is relevant for national parks: DT-based AR/VR technology can provide virtual experiences of conservation areas that cannot be physically accessed by tourists, while simultaneously reducing visit pressure on sensitive ecosystems.
- Cluster 3, Smart Tourism & Urban Sustainability (Green). The green cluster groups the keywords tourism (n=30), smart city (n=24), sustainable development (n=26), urban planning (n=19), and sustainability (n=14). The conceptual proximity between smart city and tourism in this cluster reflects the trend of integrating smart urban infrastructure with the digital tourism ecosystem—an approach that is increasingly relevant for naturebased tourism destinations [2, 15].

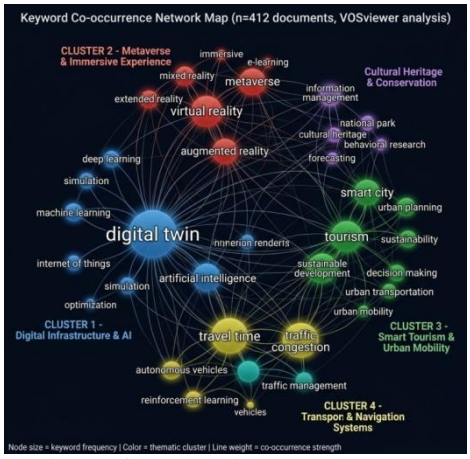

Figure 3. Keyword co-occurrence network map from 412 documents (Scopus, 2005–2026). Node size represents occurrence frequency; color represents thematic clusters; line thickness represents co-occurrence strength between keywords. Visualizations generated using the VOSviewer approach.

- Cluster 4, Transport & Navigation Systems (Yellow). The fourth cluster, dominated by travel time (n=48), traffic congestion (n=30), autonomous vehicles (n=22), and traffic management (n=15), reflects DT applications in smart transport systems. Although appearing somewhat distant from conservation issues, this cluster is important in the context of tourism destination accessibility and vehicle traffic management in national park areas that have limited road capacity.
- Cluster 5, Cultural Heritage & Conservation (Purple). The smallest but most strategically relevant cluster for this study contains the keywords cultural heritage (n=11), national park, information management (n=18), and behavioral research (n=14). Its position close to Cluster 3(Sustainable Tourism) but slightly separated from Cluster 1 (DT Infrastructure) indicates that DT applications in the context of heritage and national park preservation are still in the early stages of development and have not been fully integrated with a strong technological baseconfirming the research gap identified in this study [3, 11].

3.4 Timeline View of Major Research Hotspots

To complement the thematic cluster analysis, a timebased overlay visualizationknown as a timeline viewwas also performed, mapping the same keywords based on the average publication year of findings [13]. In this representation, node colors shift from blue-purple (older/earlykeywords) to yellowgreen (intermediate) to redorange (hottest/newest keywords).Figure 4 presents the results of this overlay based on the actual data extraction from 412 Scopus documents.

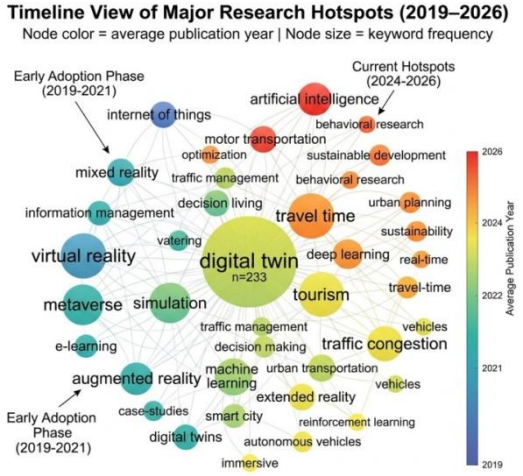

Figure 4. Timeline overlay view of the keyword co-occurrence network. Node color represents average publication year per keyword (blue = 2019, red = 2026). Node size represents total frequency. Visualizations generated based on 412 Scopus documents (April 19, 2026)

The timeline overlay visualization maps the evolution of research hotspots from mere technical exploration toward more mature systemic applications. Initially, literature was dominated by the development of digital infrastructure through the utilization of internet of things (average 2023.4) and the integration of immersive

technologies such as mixed reality (2022.9), augmented reality (2023.6), and virtual reality (2023.7). This early period reflects researchers' efforts to integrate DT with the XR ecosystem, although its application was still limited to specific technical environments [1, 12]. Over time, research focus has undergone significant diversification toward broader domains, such as metaverse (2023.9), simulation (2024.1), and the concepts of smart city (2024.2) and tourism (2024.4). This shift indicates that DT research has transcended its original functional boundaries and is beginning to be adopted as a solution for tourism sustainability and smart environmental governance [2, 4]. Overall, the digital twin node (n=233, average 2024.4) remains the central point bridging this entire evolutionary trajectory, solidifying its role as the primary knowledge infrastructure in mediating the transition from basic technology toward complex sociotechnical implementation.

3.5 TrendTopics:EvolutionaryPathof Keywords

To explore the evolutionary trajectory of terminology in this corpus, this study applies a Trend Topics analysis that provides an explicit temporal dimension to the development of each major keyword (see Figure 5).

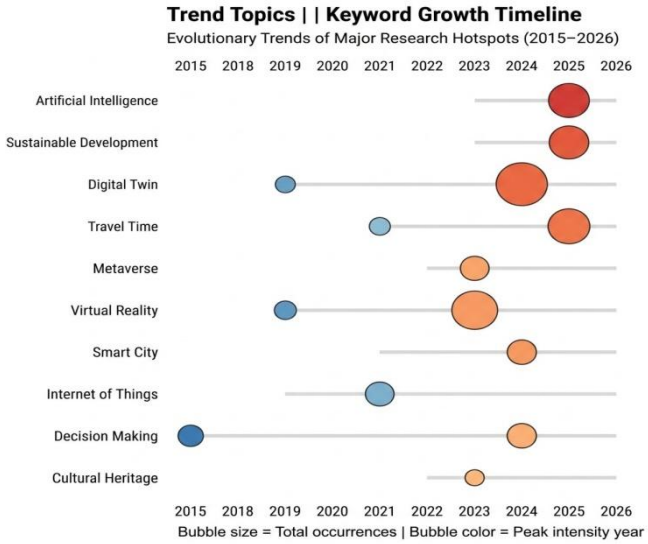

Figure 5. The evolution of trend topics and keyword growth (2015–2026). Circle size represents total occurrences, while the horizontal axis position shows the peak intensity year. Horizontal lines indicate the duration of keyword presence in the literature.

This approach enables the identification of a concept's duration within the literature and the peak research intensity that marksshiftsin intellectual focus within the digital twin and tourism domains systematically.This analysis reveals a pattern of research maturity that has transformed significantly over time. Concepts such as decision making, although having historical roots since 2015, only reached their peak intensity in 2024 along with the integration of more complex DT analytics in destination decisionmaking processes. This transition is further emphasized by the emergence of artificial intelligence and sustainable development as highly potent emerging hotspots dominating the final period (2025–2026). This phenomenon indicates a shift in research paradigm from mere passive technical modeling toward the development of intelligent systems explicitly oriented toward ecological sustainability goals. Amidst this evolutionary trajectory, the dominance of the digital twin node, which has been consistent since 2019, solidifies its position as the fundamental knowledge infrastructure that umbrellas and integrates various emerging technological trends [12, 13].

3.6 ThematicSynthesis:IntegratingInformation Systems in Conservation

A synthesis of the existing literature shows that the link between tourism, national park management, and community participation can be strengthened through an integrative Information Systems framework. Bibliometric analysis reveals that indicators such as visitation intent and destination perception are now being linked with DT simulation capabilities to understand the impact of promotional policies on tourist behavior more dynamically [20]. Furthermore, DT has the potential to become an effective datadriven communication platform between the government, local communities, and industry players, which in turn supports sustainable ecotourism governance in national park areas [9].

Practical implementation of this synergy is seen in the use of GIS and DT for facility monitoring and realtime visitation capacity management, allowing managers to simulate various environmental impact scenarios before policies are implemented [6, 8, 10, 16]. The integration of spatial data not only enhances the tourism experience but also ensures the preservation of geotourism assets through more measurable infrastructure planning [21]. As a policy implication, the transition toward datadriven destination management requires the

formation of DMOs driven by strict interoperability standards and transparent unified information platforms. Moving forward, the research agenda should focus on strengthening ecological carrying capacity evaluations and integrating DT with formal environmental management systems such as ISO 14001 to guarantee the long-term sustainability of national park ecosystems [9, 10, 16].

3.7 Discussion of Nuance and Potential Controversy

A critical nuance in the literature is the varying definition of DT. While some sources define DT as a "real-time digital representation" for analytics (CPS, IoT), others treat it as a broader platform for the metaverse economy [5]. For national park managers, this distinction is vital: a DT for experience (VR tourism) serves a different purpose than a DT for operations (real-time biodiversity monitoring). Maintaining consistency in these definitions is essential for future destination management frameworks

3.8 Research Limitations

This study is limited by its reliance on Scopus, which may exclude engineering-specific work indexed in IEEE Xplore or Web of Science [16]. Additionally, the temporal snapshot (ending April 2026) does not capture the full exponential growth of the domain for the current year. Future research should prioritize multi-database extraction and include local-language publications to mitigate geographical and linguistic biases [13].

4. CONCLUSION

This study demonstrates that while Digital Twin technology is technically mature, its application in national park governance remains conceptually fragmented and geographically biased toward industrial nations. To overcome the identified "governance gap," we propose a roadmap centered on three specific pillars: (1) establishing cross-sectoral data interoperability standards based on unified ontologies [11]; (2) integrating human-behavior simulations with ecological sensors to model stakeholder impacts [14], [15]; and (3) aligning DT frameworks with formal environmental standards such as ISO 14001 [17]. Future research must transition from lab-based prototypes to empirical field trials in high-biodiversity regions like Indonesia to validate these socio-technical frameworks in real-world settings.

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