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Digital Twin and AI in Marine Systems: A Bibliometric Analysis from an Information Systems Perspective

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Abstract. Marine Digital Twin (DT) and Artificial Intelligence (AI) research spans maritime engineering, environmental monitoring, and governance contexts. This study provides a Scopus-based bibliometric and scientometric mapping of 289 English-language documents published from 2020 through April 10, 2026. VOSviewer and the Bibliometrix R-package were used for keyword co-occurrence mapping and descriptive analysis. Annual output was 4, 9, 24, 37, 50, 108, and 57 documents for 2020-2026, respectively; 2026 is a partial-year observation. China (n = 78), the United Kingdom (n = 31), and the United States (n = 27) were the leading countries. University College London (n = 10), Ningbo University (n = 8), and Dr. D. Y. Patil Institute of Technology (n = 7) had the highest affiliation counts. Three clusters were identified consistently: Industrial Maritime Applications, AI and Algorithmic Methods, and Environmental Monitoring and Earth Systems. The corpus remains dominated by engineering and offshore infrastructure, while the smaller environmental cluster does not by itself demonstrate a transition toward conservation. The Information Systems contribution is framed through data governance, semantic interoperability, platform ecosystems, and decision-support systems.

Keywords: Digital Twin, Artificial Intelligence, Marine Systems, Bibliometric Analysis, Scientometric Mapping, Information Systems, Environmental Monitoring.

1. INTRODUCTION

Digital twin (DT) and artificial intelligence (AI) technologies are increasingly used in marine systems for real-time monitoring, predictive modelling, and decision support [1-6]. A DT links a physical asset or environment with a virtual representation that is updated through sensor and operational data [7-13]. In marine contexts, AI methods such as machine learning, deep learning, and predictive analytics are applied to heterogeneous data from underwater sensing, Earth observation, vessels, offshore structures, and coastal systems [14-19]. These applications also depend on broader Information and Communication Technology (ICT) components, including the Internet of Things, edge computing, data integration, and visualization [20-25].

The literature is fragmented across maritime engineering, offshore energy, autonomous systems, environmental monitoring, and governance-oriented research [26-31]. A bibliometric mapping is therefore useful for identifying publication patterns, source concentration, institutional participation, and thematic structure. Existing work in the retrieved corpus is concentrated in structural health monitoring, ship and offshore-system optimization, and predictive maintenance, whereas ecological monitoring and governance applications are less prominent [32-41]. This imbalance is treated here as a descriptive pattern in the indexed literature, not as evidence that marine DT research has already transitioned toward conservation.

This paper maps the intellectual structure of DT and AI research in marine systems through descriptive bibliometric analysis and scientometric keyword co-occurrence mapping. In this study, "marine systems" includes offshore and coastal engineering infrastructure, vessels, subsea and renewable-energy assets, marine ecological and environmental monitoring, and coastal-governance contexts represented by the Scopus search strategy. The study is a bibliometric and scientometric mapping exercise rather than a qualitative systematic literature review. Its Information Systems (IS) contribution is to interpret the observed patterns through four specific research streams: data architecture and governance, semantic interoperability, platform ecosystems, and decision-support systems. The study contributes by (1) quantifying temporal, geographic, source, and institutional patterns; (2) identifying a consistent three-cluster thematic structure; and (3) translating the observed engineering-environmental imbalance into bounded IS design and governance questions.

Therefore, this study addresses the following research questions:

1) RQ1: How has the scientific literature on digital twin and AI in marine contexts evolved temporally and geographically?
2) RQ2: What are the overarching thematic clusters, influential sources, and dominant application keywords within this literature?
3) RQ3: How can Information Systems frameworks connect engineering-oriented marine applications with environmental monitoring and ecosystem governance?

RQ1 is addressed through annual publication counts and country- and institution-level output. RQ2 is addressed through source rankings, cited-work summaries, keyword frequencies, and the keyword co-occurrence network. RQ3 is addressed interpretively by relating the patterns identified for RQ1-RQ2 to IS concepts of data governance, semantic interoperability, platform ecosystems, and decision support. Author productivity is reported at the export-entity level. Unresolved merged-name labels are retained transparently and are not interpreted as single individual authors.

2. METHODS

To structure a transparent and reproducible selection process, this study followed the Identification, Screening, Eligibility, and Inclusion phases of PRISMA 2020 [42], summarized in Figure 1. PRISMA is used here as a reporting structure for bibliometric corpus construction; the study does not claim to be a qualitative systematic review or meta-analysis.

2.1. Identification and Screening

The dataset was exported from Scopus. The search was executed on April 10, 2026, at approximately 14:00 WIB using TITLE-ABS-KEY (("digital twin*" OR "virtual twin*") AND (marine OR ocean* OR coastal) AND ("artificial intelligence" OR AI OR "machine learning")), with the publication window set from 2020 through the search date in 2026. The 2026 records therefore represent a partial-year observation. Scopus was selected because it provided multidisciplinary metadata for both marine engineering and environmental venues and was the database for which the authors had complete export access. The search identified exactly 342 records. Alternative-query sensitivity results are not reported because exact retrieval and overlap counts were not retained; the findings should therefore be interpreted as specific to the stated query. Before screening, 28 records were removed: 12 duplicate records and 16 non-English records. The remaining 314 records were screened and assessed for eligibility. No records were lost during retrieval.

2.2. Eligibility and Inclusion

Records were included when they (i) addressed a digital twin or virtual twin implementation, framework, or review; (ii) situated the DT/AI application in a marine, ocean, offshore, coastal, or substantively related aquatic context; (iii) provided sufficient bibliographic metadata for analysis; and (iv) were published in English between January 2020 and April 10, 2026. Records were excluded when the marine context was incidental, the use of "twin" was non-technical, or the metadata was incomplete. Eligibility assessment excluded 25 records: 15 terrestrial or non-marine digital-twin records and 10 records with incomplete metadata.

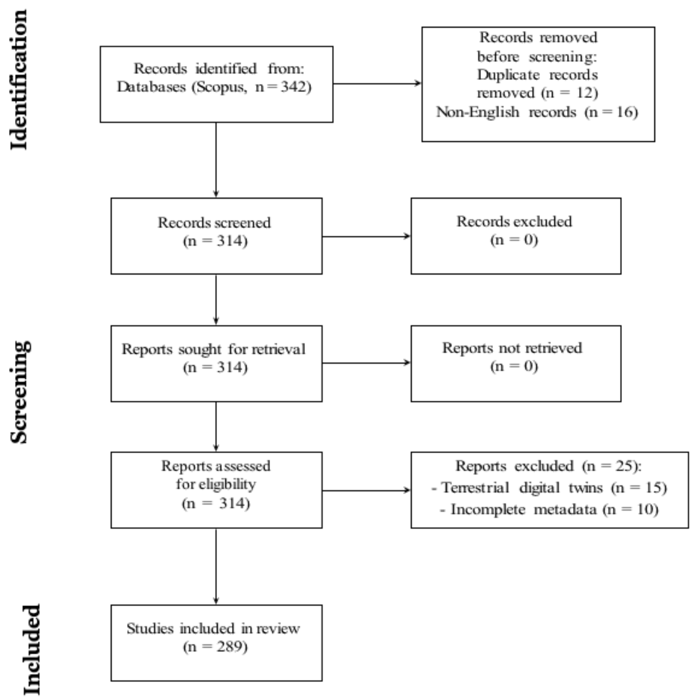

Figure 1. PRISMA for corpus identification, screening, eligibility, and inclusion [42].

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The final corpus contained 289 documents in BibTeX format: 175 journal articles, 101 conference proceedings, and 13 book chapters or books. These document-type counts sum to the final corpus. The annual distribution also sums to 289 when the partial 2026 records are included. A cleaned record list should accompany the resubmission as supplementary material so that the corpus can be independently checked. Narrative citations used for conceptual or methodological background are not, by themselves, evidence of corpus membership; inclusion is determined only by the stated selection criteria. Figure 1 illustrates this process as a PRISMA 2020 flow diagram, summarizing the identification, screening, eligibility, and inclusion steps described above.

As shown in Figure 1, the Identification stage retrieved 342 records from Scopus, after which 28 records were removed before screening (12 duplicate records and 16 non-English records), leaving 314 records for screening. All 314 reports were sought and successfully retrieved, and none were excluded at the screening stage. These 314 reports were then assessed for eligibility against the criteria in Section 2.2, and 25 were excluded (15 terrestrial or non-marine digital-twin records and 10 records with incomplete metadata). The process therefore produced a final corpus of 289 documents included in the review, consistent with the corpus size used throughout Sections 2.3 and 3.

2.3. Analysis Procedures

The validated metadata were analysed with VOSviewer (version 1.6.20) and the Bibliometrix R-package (version 4.1.4). VOSviewer was used for keyword co-occurrence mapping with a minimum occurrence threshold of 3, fractional counting, and the embedded Louvain clustering procedure with the default resolution parameter. Bibliometrix supported annual production, source, author-entity, country, institution, and citation summaries. Institutional names were normalized to parent organizations and manually spot-checked against affiliation strings. Author-name variants were reviewed using the same normalization workflow. Where the export retained a merged label containing more than one name, that label is reported explicitly as an author entity and is not interpreted as one individual author. The final results cover temporal production, sources and cited works, author entities, countries, institutions, and keyword clusters.

3. RESULTS AND DISCUSSION

3.1. Publication Trend

The annual distribution is 4 documents in 2020, 9 in 2021, 24 in 2022, 37 in 2023, 50 in 2024, 108 in 2025, and 57 in the partial 2026 period through April 10. These values sum to the final corpus of 289 documents. The full-year series shows marked acceleration from 2022 to 2025. The 2026 value is not interpreted as a decline because it represents only the first part of the year.

Table 1. Annual scientific production and share of the 289-document corpus.

Year	Documents	Share of corpus	Observation
2020	4	1.4%	Full year
2021	9	3.1%	Full year
2022	24	8.3%	Full year
2023	37	12.8%	Full year
2024	50	17.3%	Full year
2025	108	37.4%	Full year
2026	57	19.7%	Partial year to April 10
Total	289	100.0%	

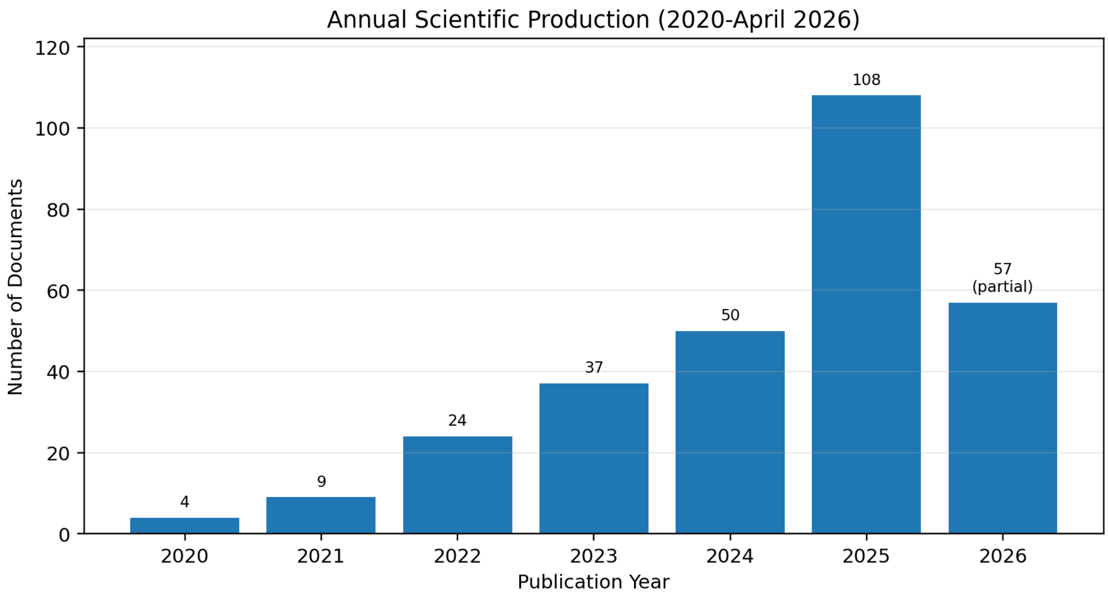

Figure 2. Annual scientific production from 2020 through April 10, 2026. The 2026 bar is a partial-year observation.

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3.2. Leading Sources and Cited Works

The source distribution is concentrated in maritime engineering and offshore-mechanics venues. Ocean Engineering contributed 22 documents, followed by the Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering (18), Oceans Conference Record (IEEE) (9), and the Journal of Marine Science and Engineering (9). Environmental and conservation-first venues were less visible among the highest-frequency sources. Author productivity was recalculated and reconciled with the retained author-entity output. The highest-frequency export entity was "Taghavi M; Perera LP" (4 documents), followed by "Taghavifar H" (1), "Purss MBJ" (1), and "Ringsberg JW; Paik J-K" (1). Because two labels still contain merged names, the manuscript reports them as author entities rather than as individual-author rankings.

Table 2. Most relevant publication sources.

Source / Venue	Count
Ocean Engineering	22
Proc. Int. Conf. Offshore Mech. 18 (OMAE)	18
Oceans Conference Record (IEEE)	9
J. of Marine Science and Engineering	9
Ships and Offshore Structures	6
CEUR Workshop Proceedings	4
Ocean Modelling	3
Int. Geoscience & Remote Sensing Symp.	3

Table 3. Ten highly cited relevant journal articles in the analysed metadata.

Title	Lead Authors	Year	Citations
State of the art in structural health monitoring of offshore…	Pezeshki H. et al.	2023	128
Artificial Intelligence in Underwater Digital Twins…	Lv Z. et al.	2022	89
Behavior-Based Formation Control Digital Twin for Multi-…	Wen J. et al.	2023	71

Title	Lead Authors	Year	Citations
An Outlook on the Future Marine Traffic Management System…	Martelli M. et al.	2021	63
Marine energy digitalization digital twin's approaches	Majidi Nezhad M. et al.	2024	58
Dynamic Positioning using Deep Reinforcement Learning	Øvereng S.S. et al.	2021	39
Toward digital twin of the ocean: from digitalization to…	Chen G. et al.	2023	39
An Operational Image-Based Digital Twin for Large-Scale…	Benzon H.-H. et al.	2022	36
Uncertainties in modelling the low-frequency wave-induced…	Parunov J. et al.	2022	36
Digital Engineering and Its Ten Application Outlooks…	Tao F. et al.	2023	34

3.3. Author Productivity

Table 4 and Figure 3 report the author entities exactly as represented in the normalized export. This presentation resolves the earlier inconsistency between the narrative and the figure while retaining the merged-name labels transparently. The counts are descriptive export-entity counts and are not used to infer individual author performance.

Table 4. Most productive author entities after name normalization.

Author entity	Documents
Taghavi M; Perera LP	4
Taghavifar H	1
Purss MBJ	1
Ringsberg JW; Paik J-K	1

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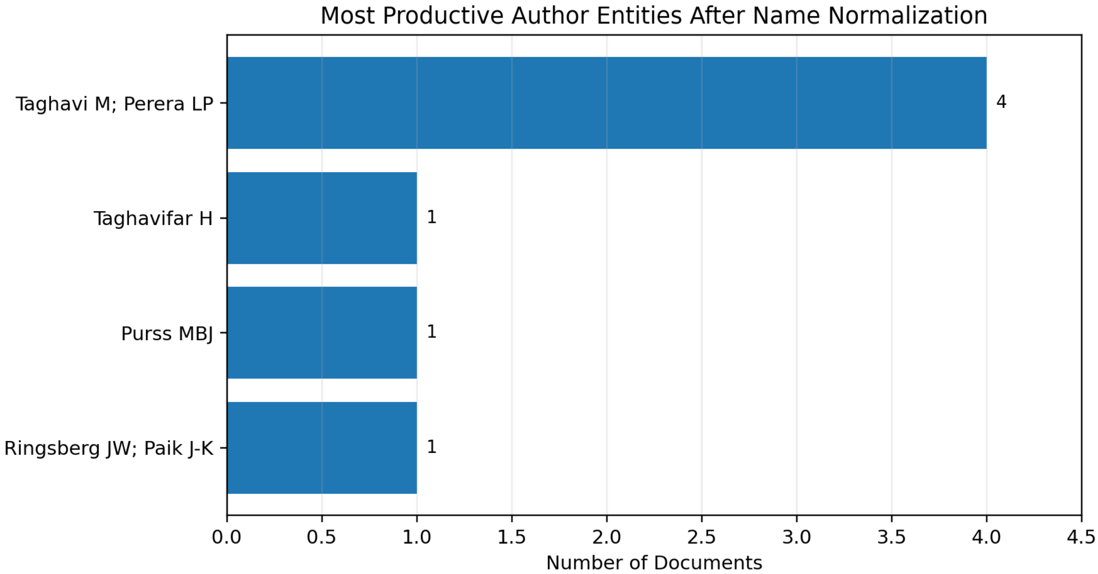

Figure 3. Most productive author entities identified in the dataset after name normalization.

3.4. Institutional and Geographic Distribution

Country and institutional outputs were calculated from normalized affiliation metadata. China accounted for 78 documents (27.0%), the United Kingdom for 31 (10.7%), and the United States for 27 (9.3%); together, these countries contributed 136 documents (47.1% of the corpus). At the institutional level, University College London had the highest count (10), followed by Ningbo University (8) and Dr. D. Y. Patil Institute of Technology (7). Tables 5 and 6 report the exact values used in the text, and Figure 4 visualizes the institutional ranking.

Table 5. Leading countries by document count.

Country	Documents	Share of corpus
China	78	27.0%
United Kingdom	31	10.7%
United States	27	9.3%
Top-three total	136	47.1%

Table 6. Top institutional affiliations.

Institution	Affiliation-linked records
University College London	10
Ningbo University	8

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Institution	Affiliation-linked records
Dr. D. Y. Patil Institute of Technology	7
University of Strathclyde	6
Texas A&M University	6
Old Dominion University	5
Nanjing Normal University	5
Department of Information Technology	5
University of Macau	5
Yantai Research Institute	4

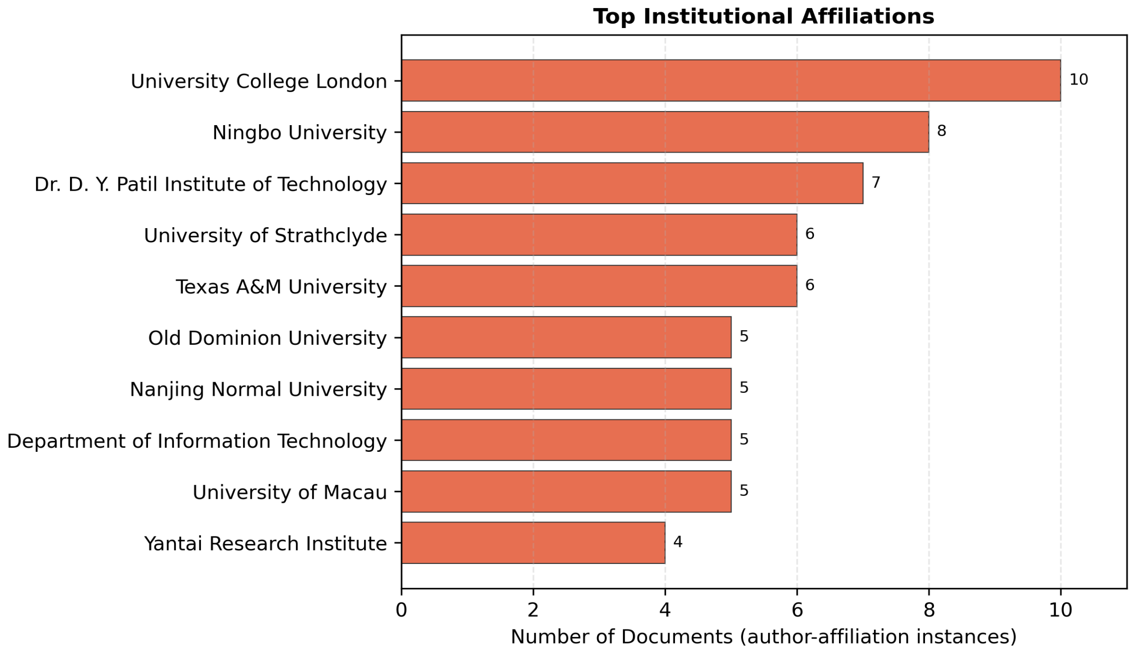

Figure 4: Institutional affiliation-linked record counts used in Table 6.

3.5. Keyword Analysis and Thematic Structure

Author keywords were dominated by technological terms: "digital twin" (91 occurrences), "machine learning" (46), "artificial intelligence" (32), "deep learning" (17), and "artificial neural network" (4). Application-oriented terms formed three consistently named clusters: Industrial Maritime Applications; AI and Algorithmic Methods; and Environmental Monitoring and Earth Systems.

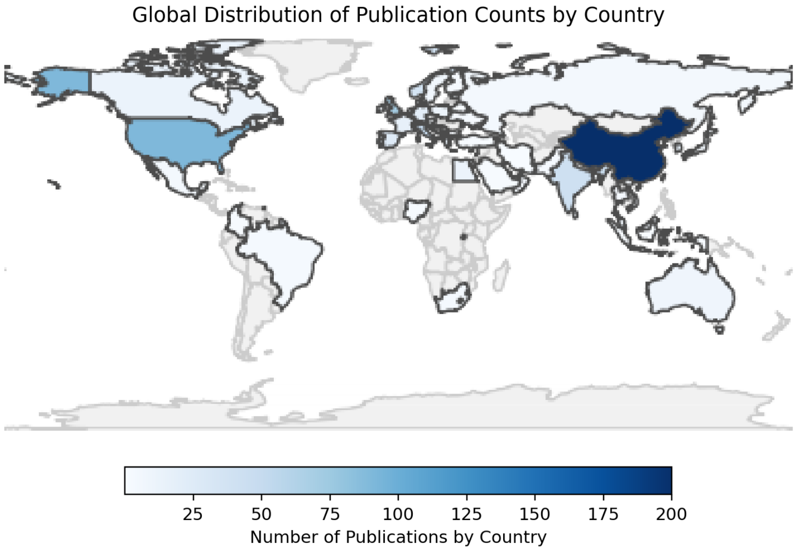

Figure 5. Global distribution of publication counts by country based on affiliation metadata.

The Industrial Maritime Applications cluster includes predictive maintenance, structural health monitoring, renewable energy, and offshore wind. It is the largest cluster in the VOSviewer export and reflects the concentration of the corpus in asset management, vessels, platforms, and offshore-energy infrastructure. The AI and Algorithmic Methods cluster contains machine learning, deep learning, artificial intelligence, neural networks, and LSTM. The Environmental Monitoring and Earth Systems cluster contains remote sensing, climate change, Earth observation, and coastal monitoring. The latter cluster is smaller and more loosely connected. This pattern supports describing environmental applications as an adjacent and comparatively less developed stream, but it does not establish a time-based transition toward conservation

Table 7. Keyword co-occurrence clusters, top keywords, item counts, and interpretation.

Cluster Label	Top Keywords	Items (n)	Interpretation
Industrial Maritime Applications	predictive maintenance; structural health monitoring; renewable energy; offshore wind	18	Anchors the corpus around offshore asset management (turbines, vessels, platforms); the largest and most cohesive cluster.

Cluster Label	Top Keywords	Items (n)	Interpretation
AI and Algorithmic Methods	machine learning; deep learning; artificial intelligence; neural networks; LSTM	15	Cross-cutting methodological cluster supplying predictive and time-series techniques used across the other two clusters.
Environmental Monitoring and Earth Systems	remote sensing; climate change; earth observation; coastal monitoring	14	Smaller, more loosely connected cluster representing environmental monitoring and Earth-system applications; it is not treated as evidence of a completed conservation transition.

The network was constructed in VOSviewer with a minimum keyword occurrence threshold of 3, yielding 47 qualifying terms from the 289-document corpus. Fractional counting was used for edge weights, and clusters were identified with the Louvain algorithm at the default resolution parameter. Node size represents total link strength. The sparse links between Environmental Monitoring and Earth Systems and the two technology-oriented clusters indicate limited integration in the current corpus; longitudinal or document-level content analysis would be required to determine whether that relationship is changing over time.

3.6. Findings Relative to the Research Questions

1) RQ1: Temporal and Geographic Evolution

Publication output grew from 4 documents in 2020 to 108 in 2025, with 57 documents recorded in the partial 2026 period (Table 1, Figure 2), showing marked acceleration from 2022 onward. Output is geographically concentrated in China (78 documents, 27.0%), the United Kingdom (31, 10.7%), and the United States (27, 9.3%), which together account for 47.1% of the corpus (Table 5), while University College London, Ningbo University, and Dr. D. Y. Patil Institute of Technology are the most prolific affiliated institutions (Table 6, Figure 4).

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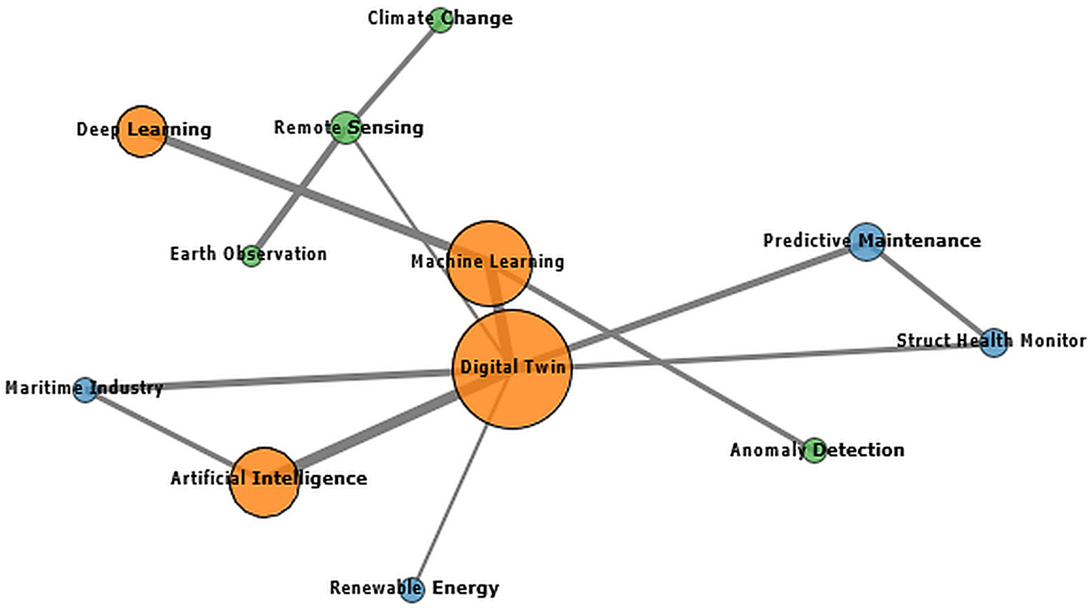

Figure 6. Keyword co-occurrence network and the three-cluster thematic structure.

2) RQ2: Thematic Clusters, Sources, and Keywords

Ocean Engineering and the Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering are the leading venues (Table 2), and the most frequent author keywords are digital twin, machine learning, and artificial intelligence. The keyword co-occurrence network identifies three consistent clusters - Industrial Maritime Applications, AI and Algorithmic Methods, and Environmental Monitoring and Earth Systems (Table 7, Figures 5-6).

3) RQ3: Connecting Engineering and Environmental Applications through Information Systems

The results show that engineering-oriented applications - predictive maintenance, structural health monitoring, and offshore energy - dominate the corpus, while environmental monitoring forms a smaller, more loosely connected cluster (Table 7, Figure 6). This descriptive imbalance is addressed interpretively in Section 4 through four bounded IS research streams: data governance, semantic interoperability, platform ecosystems, and decision-support systems.

3.7. Discussion

The source, country, institution, and keyword results consistently show that the corpus is anchored in maritime engineering and offshore infrastructure. Ocean Engineering and OMAE are the two most frequent sources, while the largest keyword cluster is organized around predictive maintenance, structural health monitoring, renewable energy, and offshore wind. This dominance is consistent with the availability of high-frequency sensor data, clear asset-performance objectives, and strong industry demand for maintenance and operational optimization. The smaller environmental cluster suggests that related methods are also used in remote sensing, Earth observation, and coastal monitoring, but the bibliometric evidence does not demonstrate a completed transition from engineering optimization to conservation governance.

From an IS perspective, the engineering-environmental gap can be formulated through four specific research streams. First, data-governance frameworks can allocate ownership, stewardship, quality assurance, and access rights across engineering and ecological data. Second, semantic interoperability can connect vessel telemetry, offshore-asset data, Earth-observation products, and ecological indicators. Third, platform-ecosystem theory can explain how operator-specific DT platforms may support regulators, researchers, and conservation organizations while protecting commercially sensitive data. Fourth, decision-support-system design can translate model outputs into dashboards, alerts, and scenario tools for operational and policy decisions. These are bounded IS implications derived from the observed thematic structure rather than claims that the underlying technologies have already been validated for ecosystem governance.

Marine conservation applications remain a plausible extension of the methods observed in the corpus. Predictive coastal and marine models may be integrated with DT architectures for coastal erosion, habitat stress, and environmental-risk monitoring [43, 44]. However, transferring methods from turbine or vessel monitoring to ecological systems requires different indicators, validation procedures, data-governance arrangements, and stakeholder decision processes. The present bibliometric analysis identifies this opportunity but does not evaluate the effectiveness of specific conservation implementations.

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Based on the identified gaps, future research may pursue the following evidence-proportionate directions:

1) Dynamic Ecological Digital Twins: Integrate biological sampling, autonomous underwater vehicles, and satellite observations into governed digital representations of marine ecosystems [34].
2) AI-Enabled Early Warning Systems: Evaluate deep-learning models, including ConvLSTM architectures, for coastal hazards and environmental risk while reporting validation data and uncertainty [45].
3) ESG-Linked Sustainability Monitoring: Define traceable indicators, audit trails, and data-quality controls before using marine DT outputs for corporate or regulatory sustainability reporting.
4) Governance and Decision Support: Design accessible dashboards and scenario tools that connect technical model outputs with marine spatial planning and multi-stakeholder decisions.
5) Social Acceptance of Autonomous Systems: Examine trust, regulatory acceptance, accountability, and human oversight in the deployment of autonomous marine systems.

Several factors threaten the precision of the descriptive results. First, institutional and author-name normalization may retain minor ambiguities, especially where the export merges more than one author label. Second, the keyword network is based on author-supplied terms and therefore represents an interpretive map rather than a document-level taxonomy. Third, the 2026 observation is partial and is not compared directly with complete publication years. Fourth, citation and affiliation counts are sensitive to metadata completeness and Scopus indexing practices. These issues affect the precision of individual counts but do not change the manuscript's bounded descriptive interpretation.

4. CONCLUSION

This study mapped 289 Scopus-indexed documents published from 2020 through April 10, 2026. The annual counts now reconcile with the corpus total: 4, 9, 24, 37, 50, 108, and 57 documents for 2020-2026, respectively, with 2026 treated as a partial year. China, the United Kingdom, and the United States were the leading countries, while University

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College London, Ningbo University, and Dr. D. Y. Patil Institute of Technology had the highest institutional affiliation counts. The thematic structure is reported consistently as Industrial Maritime Applications, AI and Algorithmic Methods, and Environmental Monitoring and Earth Systems. The results show a corpus dominated by engineering and offshore-infrastructure applications, with a smaller environmental-monitoring stream. The IS contribution is therefore framed specifically around data governance, semantic interoperability, platform ecosystems, and decision-support design. These mechanisms provide a research basis for connecting mature engineering DT capabilities with environmental governance, but the current bibliometric evidence does not by itself establish a transition toward conservation. This study is limited to Scopus-indexed, English-language records retrieved with one stated TITLE-ABS-KEY query. Relevant regional, non-English, non-indexed, grey-literature, and functionally equivalent cyber-physical-system studies may therefore be omitted. Exact retrieval and overlap counts from the exploratory alternative queries were not retained, so no sensitivity estimate is claimed. The analysis is bibliometric and scientometric rather than a qualitative content review; consequently, it does not measure implementation effectiveness or calculate a conservation-focused document share without a separate coding protocol. The cleaned 289-record list should be supplied with the resubmission as supplementary material for independent checking.

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