

Evolution of research on the use of spatial data in Industry 4.0. A bibliometrics research

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Abstract. *The digital revolution marked by the transition to Industry 4.0 has generated a profound transformation in the way organizations collect, process and use information. In this regard, a crucial component of the digitalisation process is the integration of digital technologies with spatial systems, namely through the use of geographic data and digital twin models (Digital Twins). In order to determine the primary research trends, networks of collaboration, and new directions, this study offers a bibliometric analysis of scientific papers investigating the use of spatial data and GIS systems within Industry 4.0. The results stress the importance of geographical information in bolstering digital processes and the necessity of multidisciplinary cooperation in order to create operational solutions that are both scalable and interoperable.*

Keywords: Industry 4.0, geographical information systems, digitalisation, IoT, smart cities

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Introduction

In recent years, the way organizations handle information has been redefined by Industry 4.0, in order to optimize their activities. This revolution is defined by the development of intelligent autonomous systems using the convergence of digital, spatial and physical technologies. Thus, both spatial data and geographic information systems become a central element of the digitization and development process.

By using them, the development of smart cities is allowed, it contributes to the optimization of industrial processes and the sustainable management of resources. Through the integration of the Internet of Things and GIS, a unitary perspective is presented that allows monitoring, predictive analysis and data-based decision-making on the urban environment and built space.

The widespread adoption of digital technologies has led to a profound transformation in the way organizations manage infrastructures, resources, and production processes. Digitalization is no longer just a strategic option, but a condition for competitiveness and sustainability. Process automation, big data analytics, and real-time connectivity between systems and users are helping to create a digital ecosystem capable of responding quickly to economic and social changes. This development has major implications for the way cities, industries and public services are planned and operated, where emerging technologies ensure better efficiency and data-driven governance.

In parallel with the digital transformation, more and more fields are adopting an integrated approach to spatial information, recognizing its value in understanding the geographical context of economic and technical phenomena. Spatial data infrastructures, connected sensors, and geographic analytics platforms enable data from multiple sources to be correlated and facilitate complex decision-making. This integration between the digital and space dimensions supports strategic planning processes, logistics optimization, risk assessment and sustainable solution design. Therefore, digitalisation based on geospatial information is becoming a central element in the development of smart infrastructures and the data-driven economy.

The purpose of this study is to present through a bibliometric analysis of recent research the main research directions, collaboration networks and emerging themes that define the digital transformation based on spatial information.

Literature review

The civilisation has entered a new phase of growth at this time, and the city's development has achieved significant progress against this backdrop. It is a geological information system that bridges the gap between computer science and the real-world advancement of digital city building, regardless of whether the city is being designed or managed. Thus, evaluating the historical uses of geographic information systems and suggesting the anticipated future uses of GIS in the globe are important aspects of urban and rural planning, environmental management, etc. Numerous previous investigations have led us to the conclusion that GIS has become an essential component of our environment. Notably, spatial analysis and GIS can be effective instruments for comprehending, preventing, and assisting in the planned organisation of city growth.

Systems called geographic information systems (GIS) are made to help with spatial data analysis and interpretation as well as to store, organise, and display spatial data [1] [2]. Information theory, cybernetics, computer science, system engineering, and artificial intelligence are the foundations of this cutting-edge technological field [3]. The system may provide fast and highly accurate geographic (spatial) information for regional analysis, scheme optimisation, strategic decision-making, and other purposes to geoscientific researchers, management, and production departments of a variety of sectors [4]. In the course of actual implementation, GIS may offer a scientific and methodical service to the building of a digital country and digital city when all disciplines work together.

Through its inherent capabilities of geographical data processing and analysis, geographic information system (GIS) technology, namely spatial geographic information system, can produce geospatial information and provide the impact of spatial data visualisation [5][6][7]. As computers have advanced, GIS has emerged as a popular tool that offers a new means of organising, using, and realising geographic data.

GIS technology's fundamental characteristics should be summarised in five points: cross-disciplinary, diverse data types, complex data structures, widely used applications, and mostly dependent on spatial analysis [8].

Methodology

In order to carry out this research, a bibliometric analysis was carried out, in order to determine the most recent publications on the use of spatial systems or data in the context of Industry 4.0. For data manipulation, both Excel and VOS Viewer, version 1.6.20, were used.

The research was carried out in August 2025, and the chosen database was Web of Science, being one that provides access to scientific papers indexed in prestigious conferences and journals, highlighting the quality of the results presented.

The words chosen for this research wanted to index the intersection between Industry 4.0 and its lexical field as well as that of spatial data. In order to take into account the key elements of Industry 4.0, the RO operator in search was used. The same operator was used for the sphere of words related to the concept of spatial data. The connection between them was made through the DNA operator.

Thus, the following keywords related to the sphere of Industry 4.0 were chosen: "Industry 4.0" OR "digital twin*" OR "smart factory" OR "smart manufacturing" OR "industrial internet of things" OR "IIoT" OR "smart city"

OR "digitalisation" OR "digital transformation", and for the sphere of spatial data: "geospatial" OR "spatial data" OR "GIS" OR "geographic information system*" OR "spatial analysis" OR "spatial analytics" OR "spatial digital twin" OR "geoinformation".

Conditions of inclusion:

1. All searches that included the aforementioned keywords. Here a sample of 1.264 studies resulted.
2. All research published in the last 5 years 2021 – 2025. Here a sample of 877 papers was obtained.
3. All Article, Proceeding Paper and Review Article research. A number of 861 studies reached this criterium.
4. All research written in the international language English. The final sample of 844 papers was established.

Exclusion criteria:

1. Other databases
2. Articles published before 2021 as technology in this field and the discoveries made progress rapidly

Following the use of these filters, a final sample of 844 searches was obtained, which was downloaded both in excel format and in Tab delimited file format, which is supported by the VOS Viewer computer tool.

Results and further discussions

Most articles on this topic were written in 2024, namely 219, in 2025, which has not yet been completed, 196 being published (Figure 1). In 2023, there is a slight decline, but the average number of scientific papers published is 168.8. Thus, the general trend is strongly increasing, with a compound annual growth rate between 2021 and 2025 of 13.3 % per year being estimated.

$$\text{CAGR} = \frac{196^{1/4}}{119} - 1 \cong 13.3\% (1)$$



Figure 1: Overview on published scientific research 2021-2025

Source: Author's own research.

It was carried out an analysis of Co-authorship Author, having maximum numbers of author for a paper is 25, a minimum number of documents of an author is 3 and a minimum number of citations 1. Out of the 3136 authors, 73 meet the thresholds. This type of analysis indicates who collaborates with whom, illustrating collaboration patterns. The largest set of connected items consists of 5 items: Portugal Paulo, Peixoto Joao Paulo Just, Vasques Francisco, Bittencourt Joao Carlos N. and Costa Daniel G.

For each of the 73 authors, the total strength of the co-authorship links with other authors is calculated and the top 10 ones with the greatest total link strength are presented in Figure 2.

Using filtering in excel, the most cited articles in all databases were identified. Table 1 shows those with more than 90 citations, 11 such works being identified. They are presented together with the authors who wrote them, the title of the paper, the journals in which they were indexed, as well as the type of document.

Table 1: Most cites articles in all databases 2021-2025

Authors	Article Title	Source Title	Document Type	Times Cited, All Databases
He, J.X.; Lv, ZH; Yuan, DP; He, B; Chen, W.J.; Ye, XF; Li, DH; Yang, G	A spatiotemporal intelligent framework and experimental platform for urban digital twins	VIRTUAL REALITY & INTELLIGENT HARDWARE	Article	497
García-Aranda, C; Martínez-Cuevas, S; Torres, Y; Sanz, MP	A Digital Twin of a University Campus from an Urban Sustainability Approach: Case Study in Madrid (Spain)	URBAN SCIENCE	Article	263
Herlé, S; Blankenbach, J	Hypermedia-driven RESTful API for digital twins of the built environment	AUTOMATION IN CONSTRUCTION	Article	223
Agostinelli, S; Cumo, F; Nezhad, MM; Orsini, G; Pyres, G	Renewable Energy System Controlled by Open-Source Tools and Digital Twin Model: Zero Energy Port Area in Italy	ENERGIES	Article	150
Yamashita, T; Sekimoto, Y; Koshihara, M; Nakagawa, T; O-Tani, H; Horiuchi, T	A digital twin prototype to visualize heterogeneous seismic damage simulation results on web-GIS	JOURNAL OF ASIAN ARCHITECTURE AND BUILDING ENGINEERING	Article	146
Liu, XF; Zhao, J; Sun, GZ; Zhou, GS; Han, XD	Supply chain management for modular construction using building information modeling	PCI JOURNAL	Article	101
Zhu, J.X.; Wu, P	Towards Effective BIM/GIS Data Integration for Smart City by Integrating Computer Graphics Technique	REMOTE SENSING	Article	100
Reitberger, R; Kooniyara, VP; Parhizgar, L; Roetzer, T; Lang, WR	Tree growth simulation in Geographic Information Systems: Coupling CityTree and ArcGIS for solar radiation analysis	SUSTAINABLE CITIES AND SOCIETY	Article	98

Kim, YS; Yu, SC; Jwa, YS; Ahn, J.W.	Examining the Development of a Geographic Information System Georeferencing Algorithm for Building Informaiton Modeling	SENSORS AND MATERIALS	Article	97
Xia, H.H.; Liu, ZS; Efremochkina, M; Liu, XT; Lin, CX	Study on city digital twin technologies for sustainable smart city design: A review and bibliometric analysis of geographic information system and building information modeling integration	SUSTAINABLE CITIES AND SOCIETY	Review	93
Elshaboury, N; AlMetwaly, WM; Hesham, A; Abbas, A	Integrated BIM-GIS framework for holistic building stock assessment using 5D geo-modeling and digital twin concepts	JOURNAL OF BUILDING ENGINEERING	Article	91

Source: Authors' own research.

Further there were analyzed from the point of view of the methodology used and the results obtained, within a qualitative research.

In [9] it was developed a spatiotemporal intelligent framework that integrates GIS, artificial intelligence, and digital twin technologies to monitor urban environments in real time. Their findings show that coupling spatial data with intelligent analytics enables continuous observation, detection, and prediction within a city's digital model. This study demonstrates the technical feasibility of real-time urban digital twins and provides a foundation for later works linking spatial systems and digitalization.

Other authors [10] applied the digital twin concept to a university campus, focusing on sustainability and urban management. Their work emphasizes how a GIS-based digital twin can function as a living lab, allowing simulation and analysis of environmental and social factors in campus operations. Compared with Hu et al. (2021), who prioritized data integration and sensing, García-Aranda et al. focus more on *application outcomes*—they use digital twins not only to visualize space but to evaluate and improve sustainability indicators. Both studies connect through their shared reliance on spatial data infrastructures to create functional, data-driven digital environments.

In another scientific study it was approached the topic from a software architecture perspective, proposing a hypermedia-driven RESTful API for digital twins in the built environment [11]. Their main contribution lies in demonstrating interoperability between BIM, GIS, and IoT systems through standardized communication. While in [9] and [10] the focus is on what digital twins can *do*, in [11] it is addressed *how* such systems can technically communicate and exchange data. Their findings support the idea that open and interoperable frameworks are essential for scalable spatial digitalization.

In [12] it was introduced a digital twin model to control renewable energy systems in a zero-energy port district in Italy. Their work expands the digital twin concept into energy management and sustainability. Unlike Hu et al. (2021), whose system was primarily informational, Agostinelli et al. show a direct operational use of digital twins—controlling and optimizing infrastructure performance. This creates a practical link between spatial digital models and environmental efficiency goals, connecting in spirit with [10] but in a different domain.

A prototype to visualize seismic damage simulations using web-based GIS and digital twin concepts was developed [13]. Their results underline how digital twins can integrate heterogeneous engineering data for urban resilience planning. The study connects conceptually to [9] through the shared aim of dynamic urban representation but diverges in application, focusing on hazard analysis instead of daily monitoring or sustainability.

Paper [14] examined supply chain management for modular construction using BIM, GIS, blockchain, and IoT integration. Their findings show that combining spatial data with digital technologies can increase traceability and efficiency in prefabricated construction logistics. This paper connects indirectly to [11] because both emphasize interoperability and data flow, though [14] apply these principles to an industrial context rather than digital urban twins.

Other authors [15] concentrated on integrating BIM and GIS data through computer graphics techniques to improve smart city modeling. They conclude that graphical and semantic consistency between the two systems is vital for reliable smart city simulations. Their outcomes resonate strongly with [11] in that both point to the *data integration challenge* as central to digitalization, yet [15] keep the focus on smart city visualization rather than framework design.

In [16] it was used GIS-based digital twins to simulate tree growth and analyze solar radiation in cities. Their findings demonstrate that digital twins can be extended to model ecological and environmental systems, not only buildings or infrastructures. This expands the digital twin concept into the sustainability and ecosystem service domain, connecting back to [10] and [12] through a shared sustainability perspective.

A scientific research was developed to improve georeferencing algorithms for integrating BIM into GIS environments [17]. Their results contribute to increasing the positional accuracy and compatibility between construction and spatial databases. The study forms a clear technical bridge between [11], who addressed interoperability through APIs, and [15], who emphasized 3D model alignment for smart city use.

A comprehensive review and bibliometric analysis of city digital twin technologies focusing on GIS and BIM integration for sustainable urban design was made [18]. The authors' findings synthesize the progress of earlier works, confirming that spatial digitalization is moving toward sustainability-oriented smart city design. The review explicitly connects the technical advances of studies such as [11] and [15] with application-focused approaches like [10].

An integrated BIM–GIS framework for building stock assessment using 5D geo-modeling and digital twin concepts was proposed [19]. Their findings highlight that combining spatial data, building information, and lifecycle dimensions enables holistic management of urban building assets. This work closes the loop started by earlier BIM–GIS interoperability studies [11], [17] by demonstrating a mature, operational use of integrated data for decision-making.

Taken together, these articles form a coherent research continuum rather than isolated studies. Early contributions such as [9] and [11] built the conceptual and technical foundations of spatially enabled digital twins. Later works like [10], [12], and [16] applied these concepts to sustainability and domain-specific challenges. More recent research, including [18] and [19], demonstrates the consolidation of these ideas into integrated, data-rich frameworks for smart and sustainable urban management.

Conclusion

According to the study, one of the main areas of growth for the current digital revolution is the integration of digital technologies with spatial systems. Spatial data, GIS platforms, and digital twin models (also known as "Digital Twins") are no longer stand-alone technologies in the context of Industry 4.0; rather, they are essential components of intelligent built environment management and decision-making. The examined research shows a distinct progression from integrated designs and experimental solutions to useful applications that have a direct bearing on energy efficiency, sustainability, and urban resilience.

The results also show that the field is in a consolidation phase, where challenges related to interoperability, standardization and data quality are being addressed simultaneously with the expansion of practical applications. A convergence is observed between technically oriented works, proposing GIS–IoT integration frameworks, and application oriented ones, exploring the use of spatial data in infrastructure management, urban planning and sustainability assessment. Overall, research on spatial information-based digitalization confirms the high potential of these technologies to support the transition to smart cities, optimized industrial processes and sustainable resource management, but also the need for continued interdisciplinary collaboration to transform this potential into scalable operational solutions.

The identification of new trends and research gaps that characterise the field's current state was made possible by the thorough bibliometric analysis. Despite a notable rise in publications in recent years, the distribution of these papers reveals a strong thematic concentration on urban applications, with sectors like smart agriculture, spatial logistics, and green infrastructures still receiving little attention. The development of prominent scientific centres in Asia and Europe is highlighted by collaboration networks between authors and institutions, but there is also a need for stronger ties between academics and business. A shift from conceptual methods to integrated solutions based on real-time location data and artificial intelligence was shown by the bibliometric examination of correlations between keywords and publishing sources. These results imply that the automation of spatial activities and the worldwide standardisation of digital infrastructures will characterise the next phase of development.

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