

Emerging Technology Trends in Geocomputation Methods: A Literature Review

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Abstract. The main focus of this paper is to present a systematic literature review on the emerging technology trends in geocomputation methods. The tools supporting planning have always been influenced by scientific and technological developments in other sectors. Actually, geospatial scientific research is advancing rapidly due to the development of new Machine Learning algorithms, increased in computing power and the size of geospatial Big-data. This has led to renewed interest in this line of research and the importance to have reliable techniques for SDI's analysis and avoiding potential data biases in decision-making process. The paper analyzes the evolution of topics covered in the literature and highlights new research trends in geocomputation, including spatially explicit AI, GeoAI and Geographic Knowledge Graph. The results highlight that even though the geoAI topic is emerging, it already has a significant impact on the urban and regional planning discipline and the related scientific production. In conclusion, scientific mapping was discussed in order to assess the evolution of main research topics, identifying also the main research lab and the relevant active authors.

Keywords: geoAI · Geographic Knowledge Graph · spatially explicit AI · science mapping · Bibliometrix

1 Introduction

The integration of geocomputation and innovative modeling techniques to support the design and evaluation of decision alternatives has emerged as one of the major applications of GIS in the planning, design, and management of territories and in the recent years for smart cities [1, 2]. This has led to the development of a wide range of new or revamped tools in step with technological developments known as Space Decision Support Systems (SDSS) or Planning Support Systems (PSS) [3]. While the latter relates to the platforms used to handle long-term, strategic planning objectives, the former concept refers to the instruments used to address short-term spatial challenges [4].

Thus, the ability to synthesize the context into a short- or long-term vision turns out to be a key skill to make a choice among all the possible scenarios for spatial development of a context. Moreover, the planners' aim is to measure in details how

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space and location affect process and trying to anticipate outcomes. This skill identified in the literature as Geographical Thinking is fundamental for planning activity [5]. This perspective requires planner advanced competences in using and managing data and mining information and knowledge that often are obfuscated in the noise of data flows [6].

It is commonly accepted that a substantial amount of data has a geographic component or a geographical potential. It means that the spatial dimension of information can be easily exploited through geo-coding or geo-referencing algorithms, we are talking about percentages as high as 80% [7]. This statement is true especially when analyzing all the location-based services, sensors, and mobile devices that produce huge amounts of geospatial data. Moreover, it is recognized in the literature that social science and all scientific research can benefit from this heterogeneity of database [8].

As a result of these considerations, scientific research is moving toward the fourth paradigm: "data-driven science" [9], which heavily uses Artificial Intelligence (AI) to produce novel scientific discoveries, methods and approaches. This strand is not accepted by some authors that are concerned about the exponential growth of data and information to this revolution as the end of the theoretical approach to many disciplines in favor of data-driven theories [10]. Other authors, however, point out that the need to be able to interpret, understand, and finalize the insights gained from data. These ability that are based on disciplinary theories, must remain essential [11].

Data interpretation is always influenced by personal know-how and sometimes hunch, and working with big data is not an exception [12]. Thus, is important to be aware of potential data biases and ensure that conclusions drawn from the data are sound reasoning [13]. The tools supporting planning research have always been influenced by scientific and technological developments in other sectors [14]. Actually, geospatial scientific research is advancing rapidly due to the development of new machine learning algorithms, to the improved computing power and renewed interest in this line of research [15, 16].

New research trends result in:

- Spatially explicit AI refers to AI techniques that explicitly consider spatial relationships and patterns in the data. The spatially explicit models substantially outperform data science AI general models when applied to spatial data. Primarily, designing neural architectures for spatially explicit models can also be regarded as introducing an inductive bias [17];
- GeoAI is the integration of AI with geospatial data and technologies. It involves the use of AI techniques such as machine learning, deep learning, and computer vision to analyze and interpret geospatial data. Specifically GeoAI, is an interdisciplinary field that draws on a variety of disciplines, including geography, mathematics and computer science that enables the finalization of plan choices and maximization of positive impacts on territories without any simplification or loss of information [18].

- Geographic Knowledge Graph is a type of knowledge graph designed specifically for geospatial data. This type of Knowledge Graphs aimed at providing rich semantic representations, i.e. ontologies, of real-world entities by mainly emphasizing topological relationships between different geometric feature.

These improved GIS and Geocomputation methods help to better analyze geospatial data, to get a better insight about the fine spatio-temporal dynamics and enhance the SDIs [19].

The aim of this paper is to propose the evidences of an extended literature review to evaluate the thematic evolutions of the previous mentioned topics in scientific literature with a specific focus on geoAI and new data sciences in planning. The principal research topics and the research labs engaged with the development of advanced research on spatial explicit AI are identified in order to support researchers and planning practitioners in mining relevant references and arguments.

2 Methods

The input data for the literature review are the results of a combination of multiple queries carried out on Scopus. Indeed, Scopus is a freely accessible online bibliographic database of scientific references that allows structured and dynamic query [20]. In the following, detailed description of query building is explained. The first query, the most general ones, ensured that the scientific mapping is carried out as comprehensively as possible and that the intellectual structure of the scientific domain is fully covered. The query is as follows:

ALL (“geoai” OR “geographic knowledge graph” OR “spatially explicit ai” OR “spatial data mining” OR “spatial ml”) AND (LIMIT-TO (LANGUAGE, “english”)) AND (LIMIT-TO (SRCTYPE, “j”) OR LIMIT-TO (SRCTYPE, “p”)) AND (LIMIT-TO (PUBSTAGE, “final”)) AND (LIMIT-TO (OA, “all”)).

The dataset was analyzed with the software Bibliometrix an open source tool for quantitative scientific research [21]. Indeed, Bibliometrix is an R statistical package that provides useful scientometrics tool for science mapping providing the conceptual, the intellectual and the social structure of the analyzed discipline [22]. Thus, the application is not limited for measuring academic publication and scientific productivity but through a robust statistical analysis it establishes a systematic, transparent and reproducible review process.

Since the aim of this research is to identify the new research trends in geocomputation domain, by examining the “trend topic graph” and dividing the analysis into different time span, it was possible to study the evolution of topics and refine the query. Therefore, the second and final query focused on the topic of “geoAI” because looking at the distribution of publication per year, a burst in the research is evident in the year 2017, which corresponds with the year this term appeared for the first time in the literature [23], (see Fig. 1).

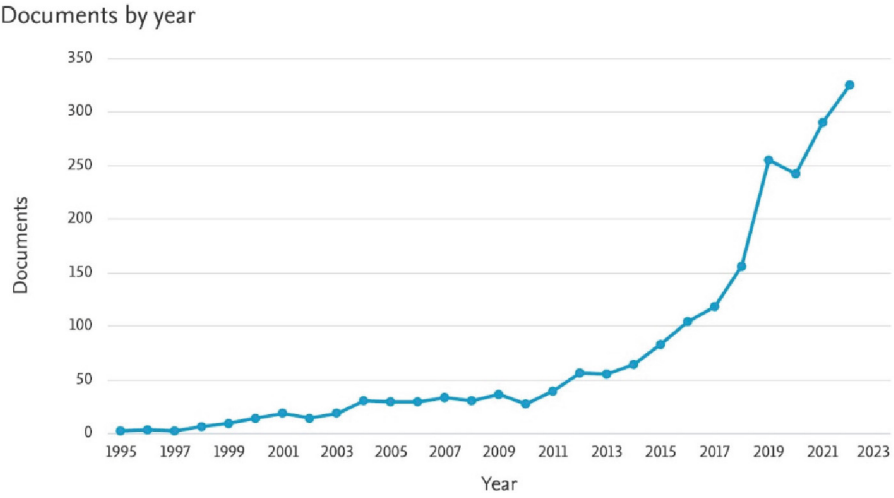

Fig. 1. The annual scientific production of the first query on Scopus.

3 Results and Discussion

This section shows the results of the two queries. The first section quickly focuses on describing the results of the first query and the need for refining the query and limiting the search to the topic "geoAI". The result of the first query leads to 2,190 articles by 5709 different authors and within a period of time between 1995 and 2023.

The figures below show the author's mostly used keywords in two different time intervals and also highlight the connections between different topics. The first image highlights the trending topics before 2017, and it is evident that the most used technique to get information from spatial data was data mining algorithm, see Fig. 2. The motor themes of these group of articles are density-based clustering, spatial relationship, information retrieval, outlier detection, and visual analytics.

The analysis of the second group of articles, i.e., those published from 2017 to 2023, highlights the tendency of some topics to merge together and shows that some topics split into multiple themes. In particular, three compact groups by both density characters and cluster centrality are shown in the figure below [24], see Fig. 3.

New techniques for geospatial domain such as random forest, support vector machine and artificial neural network gaining momentum while spatial data mining is set as a basic topic. The methods described above all refer to AI and data science and specifically to machine learning models [16]. Moreover, analyzing this cluster in detail showed that the trend themes that occur most frequently are precisely geoAI, Knowledge graph and geospatial data with a term frequency of 31, 10 and 9 respectively.

Then, once we assessed the evolution of the topics, we focused on identifying the main research laboratories and the most influential authors on the discipline by restricting our focus to the topic of geoAI. Thus, the second database consists of 686 resources spanning from 2017 to 2023 with an annual growth rate of 25.88% and an average citation per document of 8.68. These data highlight that even though the topic is emerging

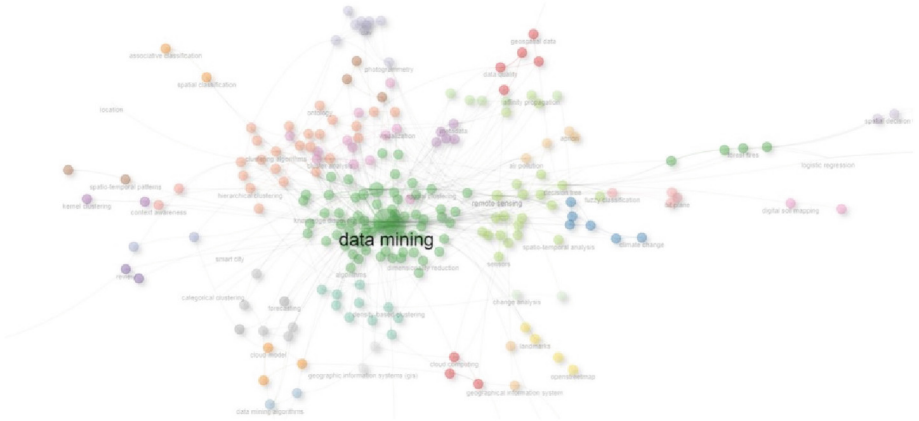

Fig. 2. Author's keywords Co-occurrence network before year 2017, the size of node is the topic relevance and the colors represent the clusters to which each word belongs.

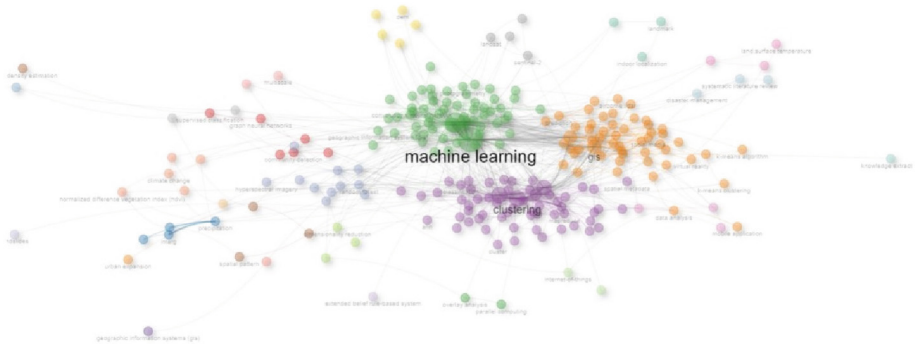

Fig. 3. Author's keywords Co-occurrence network after year 2017, the size of node is the topic relevance and the colors represent the clusters to which each word belongs.

it has a significant impact on the discipline and the related scientific production. The most relevant authors are represented below through Bibliometrix's fractional authorship indicator, which allows the individual author's contribution to published papers to be assessed, see Fig. 4.

As depicted by the graph, Wenwen li who is Professor of Geographic Information Science at the Arizona State University and director of the Cyberinfrastructure and Computational Intelligence Lab (CICI), with a score of 7 is the author with the greatest impact on the field. She is followed by Assistant Professor Filip Biljecki from the National University of Singapore and Professor Song Gao from the University of Wisconsin, Madison, where he leads the Geospatial Data Science Lab (GeoDS@UW). Moreover, the co-authorship network, shown in Fig. 5, which represents the collaborations between various research labs, confirm the importance of those institutions in the emerging field of geoAI .

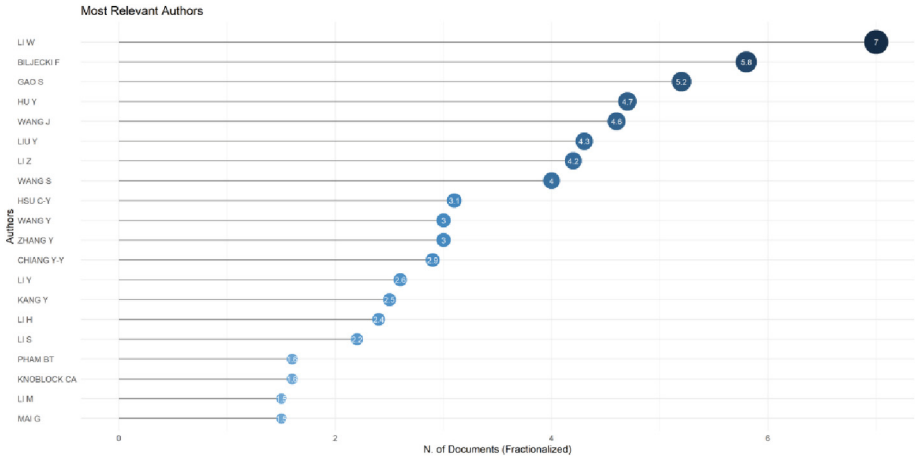

Fig. 4. The 20 most relevant authors per n. of authored documents in the field of geoAI.

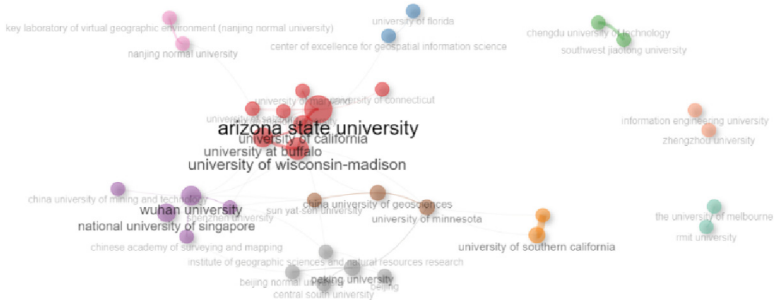

Fig. 5. The co-authorship network representing collaborations among various institutions, the size of node indicates the centrality of the research lab.

4 Conclusions

The literature review proposed in this paper is useful in assessing the rapid advancement of geospatial scientific research in the last years. Indeed, the mapping of the discipline, although still in a preliminary form, has identified emerging trend topic for geocomputational methods. In particular three key topics represent the most promising research area where advances in the short term will be available:

- Spatially explicit AI,
- geoAI
- Geographic Knowledge Graph.

This work benefitted from the robust support in science mapping of the Bibliometrix software. It represents an outstanding tool for analyzing the scientific literature in a specific field of research and inferring the evolution of trends over time, the most researched topics, identifying the most relevant authors and the relationships between different

research laboratories. More generally, it was possible to highlight the "big picture" of a discipline and identify themes that are intertwined among various disciplines [21].

Indeed, we know that planning has always been a bridging discipline that seeks to make synthesis from the scientific advancement of other fields [25] through an integrated approach that links thematic knowledge [26–34], lessons learned [35–41], normative references and collaborative approaches [42–51]. Especially planning tools have always been influenced by technological developments and in the last decade by the rapid advances in Computer Science [52, 53].

The present work focused on understanding the contribution that innovative geo-computational methods already delivered to improve planning discipline and what we expect in the short term. The approach of this work primarily analyzed the evolution of author's keywords on 2,190 scientific articles by 5709 different authors. It emerged that from a broader analysis of the literature, issues related to clustering and data mining have been influencing the discipline for the longest time. Since the identification of a burst in the literature production around 2017, the query was refined to the geoAI theme because it was considered as the motor trend in the last years.

In conclusion, these improved Geocomputation methods, that refer to AI and specifically ML techniques, seems to be used by planner to better analyze geospatial big-data, to get a better insight about the fine spatio-temporal dynamics and enhance the SDIs [54, 55]. Furthermore, accurate measurement and synthesis of context dynamics, made possible by geoAI techniques, could play a crucial role in supporting sustainable development of the urban and territorial context especially regarding environmental issue [56, 57], for defining better climate change actions and policies [58], and to include in planning practice the emerging topics [32, 33, 59–65] for better cities of the future.

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