

Review

A Comprehensive Bibliometric Analysis of Spatial Data Infrastructure in a Smart City Context

DMSLB Dissanayake ^{*}, Manjula Ranagalage , JMSB Jayasundara, PSK Rajapakshe, NSK Herath, Samali Ayoma Marasinghe, WMSB Wanninayake , HUK Dilanjani , ALWM Perera and Yukthi Herath

Department of Environmental Management, Faculty of Social Sciences and Humanities, Rajarata University of Sri Lanka, Mihintale 50300, Sri Lanka; manjularanagalage@ssh.rjt.ac.lk (M.R.); jmsb1610@yahoo.com (J.J.); pskr75@ssh.rjt.ac.lk (P.R.); samankherath4@ssh.rjt.ac.lk (N.H.); marasinghe@ssh.rjt.ac.lk (S.A.M.); sisirawanninayake@gmail.com (W.W.); dilanjani@ssh.rjt.ac.lk (H.D.); manoriperera95@gmail.com (A.P.); yukthi.h@gmail.com (Y.H.)

* Correspondence: dissanayakedmslb@ssh.rjt.ac.lk

Abstract: This study presents a bibliometric analysis of spatial data infrastructure (SDI) research and its application in city development. The fast urbanization and growing complexity of urban management recognize the importance of SDI in supporting sustainable urban planning and innovative city development. This study systematically reviews trends in the publications, key contributors, keywords, and thematic areas of SDI and urban settings. The study uses bibliometric tools such as VOSviewer and Biblioshiny, as well as data from 2003 to 2023. The results show that the number of publications has expanded, and the growth rate in publications has accelerated since 2013, increasing significantly due to geospatial technologies and broadening interest in the concept of smart cities. It identifies the key authors, countries, and collaborative networks that have recognized initiation in the research area. It puts forward the core contributions of Germany, Italy, and Croatia in this field. This research uses keyword co-occurrence and thematic mapping to illustrate dynamic areas of emphasis, including incorporating 3D city models with smart mapping and the application domains of Geographical Information Systems (GISs) and SDI in urban planning. This study further elaborates on other significant developing trends, such as implementing participatory sensing in environmental monitoring and securing SDI within smart city applications. It also highlights enhanced international collaborations toward strengthening the global knowledge base of the challenges in sustainable city development. Hence, this bibliometric analysis is supposed to be used for future research and policy decisions within SDI and city development. Overall, this study will support research by providing a direction for the literature on SDI and city studies and arranging bases for future studies that recommend developing urban resilience and sustainability using the effective practice of geospatial data.

Keywords: bibliometric analysis; environmental monitoring; geospatial technologies; spatial data infrastructure; urban planning



Academic Editors: Salvador García-Ayllón Veintimilla and Maria Rosa Trovato

Received: 12 December 2024

Revised: 7 February 2025

Accepted: 12 February 2025

Published: 27 February 2025

Citation: Dissanayake, D.; Ranagalage, M.; Jayasundara, J.; Rajapakshe, P.; Herath, N.; Marasinghe, S.A.; Wanninayake, W.; Dilanjani, H.; Perera, A.; Herath, Y. A Comprehensive Bibliometric Analysis of Spatial Data Infrastructure in a Smart City Context. *Land* **2025**, *14*, 492. <https://doi.org/10.3390/land14030492>

Copyright: © 2025 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Urban areas are highly complex and dynamic and thereby have a maximal socio-economic impact not only on urban communities but also on other communities (daily commuters) and peri-urban communities. Over the past few decades, urban areas have seen enormous developments in various aspects. Reshaping the built environment by transforming a rural area into an urban settlement, with a population shift from the rural to

the urban area, is a highly complex socio-economic process [1]. An urban-to-rural boundary is demarcated based on the fraction ratio of Impervious Surfaces (ISs) from the city center and whether the composition of the IS fraction is less than 10 (<10%) when compared to the zone designated as a rural area [2]. The paradigm shift from rural to urban reflects a movement in the focus of society, typified by increasing industrialization, advances in technology, and moving from agrarian-based economies to service- and information-based systems. Some researchers [3–5] have consistently emphasized the current trend of urbanization worldwide as the gradual transformation of rural into urban settings. This includes the peripheral growth of cities and their suburbs, which further diffuse into the surrounding countryside and natural landscape. Urbanization has surged in recent decades, and the global urban population surpassed the rural population in 2007 [6]. Since then, cities have become the fastest-growing locality, more so than any other area, and if they continue to gain ground, 60% of the world's population will be living in cities by 2030, and this will progress up to 66% by 2050 [7]. Rapid urbanization causes some negative impacts on cities because urban areas can develop and sprawl without a proper plan [8]. The trends that have marked cities' development over the past few decades are rapid urbanization [9,10], technological development [11,12], and a "green" tendency [13,14]. The background of these developments is that the growing number of people worldwide drives the growth of populations in urban areas, which causes improvements in quality of life [15]. The rapid increase in the building of urban areas has made urban life easy. Still, some negative externalities have directly and indirectly challenged the quality of life of urban residents [10]. Good quality of life is usually associated with smart living [16]. The smart city has emerged as a modern concept to address perceptibly complicated urban development issues. The smart city can be defined as "an urban area which uses electronic data collection sensors, positioned throughout infrastructures, buildings, vehicles, institutions and any device so-called IoT (Internet of Things), to provide in real time information on the basic systems which characterize the operation of the main cities." It is a matter of energy, transport, water supply, sewage, waste, public order, and information and communication [17]. It is anticipated that the direction of smart city initiatives will shift from infrastructure-based strategies towards citizens' lifestyles and sustainable development [18]. Since the turn of the past century, cities have come a long way; they have undergone several phases of development, right from industrialization, which has sped up urban growth and city expansion. Smart cities encompass a plethora of multiple, interlinked, smart built environments, consisting of entities that learn from inter-day activity patterns and autonomously change concerning behavior alterations [19]. The smart city is a new concept and model that utilizes next-generation information technologies such as the Internet of Things (IoT), cloud computing, big data, mobile internet, and spatial geographic information integration to implement intelligent urban planning, construction, management, and service [20]. Indeed, smart city projects involve high investment in many respects: financial, technological, human, data management, and institutional ones [21]. A smart city should entail an urban area with accessible and secure ICT infrastructure, efficient and reliable physical systems that underpin maintenance and development, a productive, innovative economy, an equitable and inclusive society, a sustainable, resilient environment, and participatory transparent governance [22].

Spatial data infrastructure (SDI) is a core element of the smart city concept, as it enables the integration, management, and distribution of geospatial data that enhance the capacity of the city to compile, analyze, and visualize complex spatial relationships for improving urban planning, resource allocation, and the sustainability of smart and resilient cities [23]. Enhanced access, as well as the analysis and visualization of geospatial

data, provides many potential benefits [24]. With rapid developments in spatial data collection and communication technologies, the role of SDI is pivoted in the way spatial data use is performed today within companies, governmental agencies, nations, regions, and even global contexts [23]. As a platform, SDI can help reduce duplication and preserve resources collected by various data in response to the common problem of different urban organizations not being aware of existing datasets [25]. Developed countries recognize the importance of this information and have already begun implementing initiatives to create SDI that facilitates the seamless sharing of such information [26]. SDI makes searching, gaining, and assessing information easier when finding necessities and infrastructure. Geographic information is critical in determining various valuable decisions regarding local, regional, and global affairs [27]. Knowing the trends and the current state of research in SDI is crucial in guiding further research on SDI and city development since it points out existing gaps, new emerging technologies, and developing challenges in integrating geospatial data within urban systems.

Studies based on the literature apply different methods of synthesizing and analyzing existing knowledge. Among them, PRISMA and bibliometric methods are the most outstanding. PRISMA is a structured approach designed to ensure transparency and reproducibility in systematic reviews by focusing on rigorous inclusion and exclusion criteria, often yielding qualitative or semi-quantitative insights. In contrast, bibliometric methods are quantitative analyses of large datasets of academic publications to uncover trends, citation patterns, and intellectual structures in a research field [28]. Further, it powers automated tools like VOSviewer and Biblioshiny with the R tool [29] for analyzing co-citation analysis, keyword clustering, and network visualization, streamlining the process and reducing manual effort [30]. Bibliometrics offers a singular advantage over PRISMA by allowing extensive bibliographic data examination and the identification of key contributors, collaborations, and thematic clusters and providing a macroscopic view of research dynamics [31]. This makes bibliometric analysis particularly valuable for understanding research landscapes and guiding future investigations, whereas PRISMA excels in synthesizing evidence for specific research questions. Both methods are complementary, but bibliometrics, with its data-driven approach, offers broader insights into the structure and evolution of knowledge, making it indispensable for fields requiring a holistic understanding of scholarly communication [28,31].

Bibliometric analysis is essential for tracing gaps in any particular research area and emerging concepts and developing future trends. Bibliometric studies provide systematic insights and collective wisdom on patterns in publications, keywords, and citation behaviors and identify the most influential studies, emerging trends, and research gaps, thereby guiding future investigations and ensuring that new research builds on a solid foundation of existing knowledge [28]. When conducting a systematic literature review, data extracting/data mining is crucial in producing science-oriented scholarly works [32–34]. Smart cities and sustainable urban planning have grown tremendously over the past decade, leading to directions for future research. One important analysis could study this discourse on SDI and local progress. At present, scholars have conducted quantitative analysis of the literature on SDI and city development-related research. Bibliometric analysis is essential to understand how research has evolved and what impact it has had in the field of SDI and city research. Most scholarly works available in the existing literature have generally studied city development, urban planning, and smart cities as concepts but have not focused on the role of SDI and its importance. This gap within the literature motivates this paper's research topic. This study aims to bridge the knowledge gap as well as the methodological gap regarding SDI in smart cities and urban development in a novel manner. Hence, our primary focus remains in this research area. Therefore, this analysis enables the discov-

ery of knowledge gaps, the evaluation of the impact of themes, and guidance on future research trends.

The present study aims to explore the prevailing gaps and afford a new influence on SDI and city research. This study identifies the initial expansion phases in SDI and city development research. The study recommends bibliometric analysis to achieve this aim and offer valued comprehension. Scholars can gain a wide-ranging comprehension of the knowledgeable structure and influence of SDI and city research by analyzing publication records, collaboration networks, citation patterns, and other bibliographic measures. The study aims to discover trends and shifts in focus over time by this bibliometric analysis. When one is permitted to look at the trends, it allows the detection of emerging topics, growing or decelerating interest in any particular area, and the diffusion of concepts from one discipline to another. The capability to observe the path of a research field is significant in comprehending its future directions, what scholars can look forward to, and how their work may align with these upcoming developments. The proposed bibliometric analysis methodology will be described first, followed by an overview of the global research output on selected study areas covering publication trends, the collaboration patterns of authors and countries, and widespread keywords and themes [35]. Further, it can help identify the life cycle of the research themes from emerging to peaking and then declining, thus providing a roadmap of where to place reserves in research.

The “author and country analysis” is another primary tool for bibliometric analysis to understand the inputs of individual researchers and specific regions or countries in any given field. The author analysis permits research on the most active and influential scholars and, therefore, the nature of the collaboration network, identifying major experts driving innovation and knowledge creation. This is invaluable in grasping a research field’s intellectual structure and identifying possible researchers, collaborators, or crucial people whose work is leading the discourse. In the meantime, co-citation analysis also gives a different aspect to this research. Science mapping is supposed to uncover the intellectual structure of a scientific field. Science mapping focuses on terms such as intellectual structure, scientific evolution, research front, invisible college, and domain analysis [36].

In bibliometric analysis, keywords and thematic analysis comprise core topics and develop SDI research field themes. Such research may permit the recognition of the most frequent terms and concepts at the heart of mapping the intellectual structure of the area under study and understanding the central topics driving the research. Keywords also allow for the potential to recognize emerging trends and shifts in focus within the data, whether in terms of how new topics grow in prominence or how established ones may change over time. This method enables the possibility of showing the patterns and trends by calculating the strength of associations between terms that represent relevant publications and patterns. These associations outline the conceptual structure of a specific scientific field [37]. This is supplemented by thematic analysis and grouping related keywords into broader themes, showing how research topics are intertwined and how they feed into bigger research agendas. Keyword analysis and thematic mapping techniques identify dominant topics and themes in the field, giving a more finely grained understanding of key research trends in the research area [35]. Knowledge of these themes can help strategic planning in research funding and policy-making by underscoring areas of current interest and potential future development.

2. Materials and Methods

In this study, bibliometric analysis was employed as a tool to provide an overview of the entire present scenario of scientific creation, assess the quality of prior studies, and gain extensive knowledge concerning particular subjects. Bibliometric analyses inform

researchers about the history of a domain, highlight the present situation of the domain, and propose new research trends [38]. This bibliometric analysis study targeted publications dealing with spatial data infrastructure systems and city research, and the review only contains empirical and review publications. Studies produced in languages other than English were excluded from the data-gathering process in the Scopus database. Scopus is currently the largest existing multidisciplinary database [39]. Most bibliometric analyses involve an average of five stages: research design, data collection, analysis, visualization, and interpretation [40]. In this study, we focus on the following three main stages, which align with this research, as depicted in Figure 1.

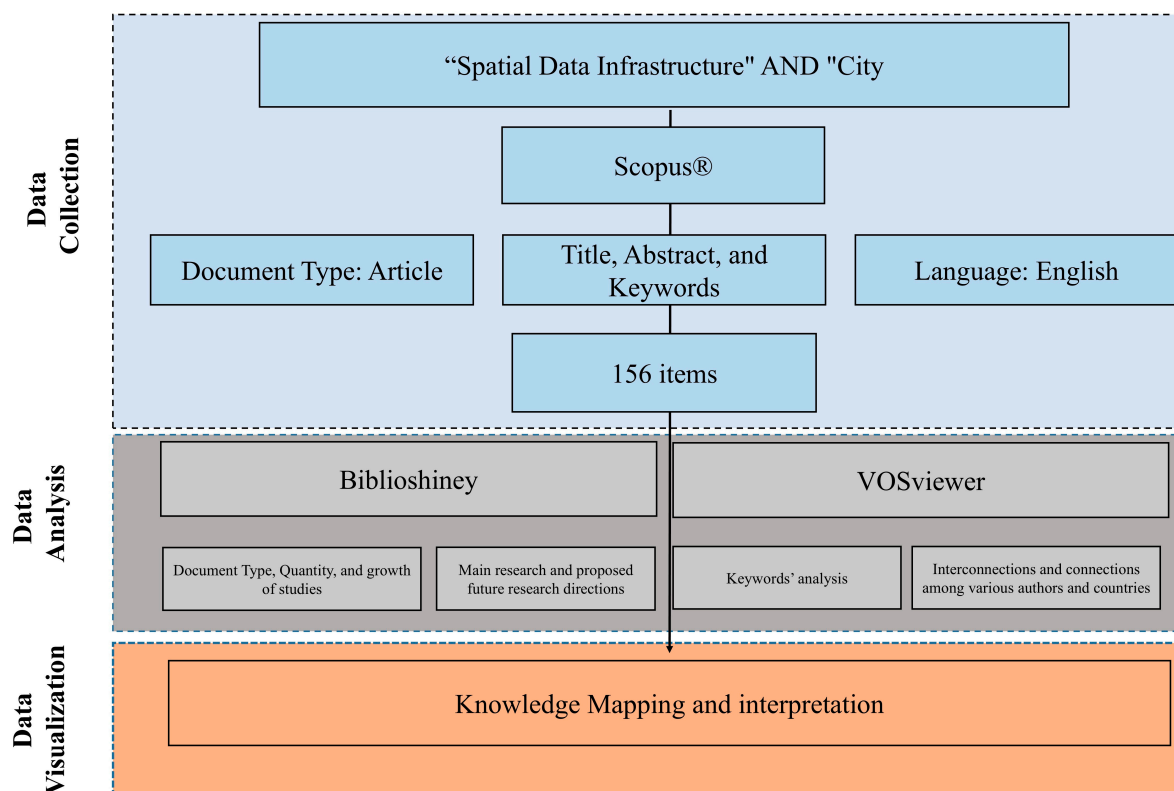


Figure 1. Schematic illustration of conceptual research flow.

2.1. Research Questions

The spatial dynamics of SDI and city research are solely mapped out from a world-wide perception. This sets the basic knowledge framework within SDI and city research, examining developmental trends in these fields and revealing the current SDI and city research landscape. This offers an objective view not only of the existing research in the area but also affords a scientific base for the future directions of studies on SDI and urban studies. More importantly, it has substantial reference value for information science studies in other areas. This study addresses the following questions:

1. What is the development of publications associated with SDI and its application in urban settings?
2. Who are the most cited authors in the SDI study field?
3. What is the total number of articles by country, and how is international collaboration linked to this?
4. What are the related author keywords associated with SDI and city research?

2.2. Data Sources

Data were collected from the Scopus database (<https://www.scopus.com>) under the keyword string (“City Planning” OR “Urban Development” OR “Smart Cities” OR “Urban Management”) AND (“Spatial Data Infrastructure” OR “SDI” OR “Geospatial Infrastructure” OR “Geospatial Data Management”) AND (“GIS” OR “Geographic Information Systems” OR “Geospatial Analysis” OR “Spatial Analysis”) on 28 June 2024. Two steps were employed in the process, as follows:

First, inclusion and exclusion criteria were applied to select a reliable dataset. In this process, non-English-language articles and non-journal publications were removed to obtain a better review. Finally, we analyzed 156 English-language journal publications and scholarly works, carefully choosing the timespan between 2003 and 2023.

Second, we generated a comma-separated value (CSV) file by selecting appropriate meta-information and chose 156 scholarly works as usable documents for analysis.

2.3. Research Methods

Data records were analyzed using bibliometric tools, focusing on various aspects. We addressed publication trend analysis, countries, authors, and author keywords to gain an in-depth understanding of the collected data. Bibliometrics has become an essential technique for assessing research [41]. The statistical results of the large sample of the academic literature were visualized using bibliometric tools, including the Bibliometrix R package (www.Bibliometrix.org—Version 4.3.2) and VOSviewer (www.vosviewer.com—Version 1.6.20). The extracted data were efficiently organized in a bibliometric way and analyzed using the Bibliometrix software, thus supporting the thorough synthesis of the findings [35]. The Bibliometrix R package provides a set of tools for quantitative research [29].

This study used VOSviewer and Bibliometrix software for various reasons. VOSviewer is one visualization tool that focuses only on bibliometric maps. It has a functionality that is very appropriate for showing large bibliometric maps clearly and easily for interpretation [30]. According to Moral-Munoz (2020) [42], Bibliometrix is a robust tool for scientific mapping and data visualization. The use of Bibliometrix, an R package for bibliometric analysis, and VOSviewer, for network visualization, was based on the structured workflow of our literature review process. First, bibliographic data from Scopus were collected and subsequently analyzed with Bibliometrix to identify publication trends, country collaboration, keyword co-occurrence, and thematic evolution. This gave a comprehensive quantitative outlook of the research landscape. The steps involved mapping bibliometric networks of co-authorship structures, citation linkages, keyword clusters, and collaboration networks between countries by VOSviewer, which helped identify key research themes, influential authors, and collaboration networks among countries. This ensured a statistically solid and graphically represented methodology.

2.4. Data Visualization and Interpretation

Data visualization was accomplished using trend charts, top authors, country maps, and thematic maps [43]. Facts were envisaged via tables and figures, with trend graphs produced for top authors. Next, the tables and statistics were evaluated to draw relevant findings.

3. Results

This study is structured as follows to solve the research questions: First, the publication trends of SDI-related research and its applications in urban contexts are analyzed to understand influential works and their evolution. Next, it involves the analysis of authors and countries to explore the interrelationships among authors, countries, and affiliations,

showing how SDI research in urban contexts has historically developed. Then, the study focuses on high-frequency author keywords and their evolution over time to highlight significant research trends and the impact of various contributors. Next, thematic evolution analysis visualizes the knowledge structure, research hotspots, limits, and emerging trends in SDI and urban studies to identify critical themes and future research directions. Finally, the highly cited articles and major contributions in the study area are qualitatively analyzed, and the structural gaps to be explored in the future are highlighted.

3.1. Trend of Publications on SDI and Cities from 2003–2023

Figure 2 presents an annual direction assessment for the number of publications (NoP) between 2005 and 2023. The NoP is divided into three stages; each development stage is provided to trace the trend. Only a few publications were found from 2005 to 2010, reflecting the lack of concern and interest in these concepts. The period from 2011 to 2016 provided results of approximately 15 publications for one year and fewer publications for other years. The maximum number of publications, i.e., 19, was reported for 2019. This denotes that researchers' concern on this topic was more significant this year than the others. From 2020, the aforementioned equal stage of development was observed, present in every year up to 2023, showing a considerable growth in publications. This growth may have arisen from discovering new scientific interests that have become popular with the broader public. This sharp increase in the NoP and the number of their citations is evidence that the “Spatial Data Infrastructure system of a City” can be called a hot topic in the research arena at present. There will be a continuous tendency for this line of investigation; on average, publications present 8.72% of growth yearly. Overall, 4229 references amounted to 12.79 citations in one document, on average.

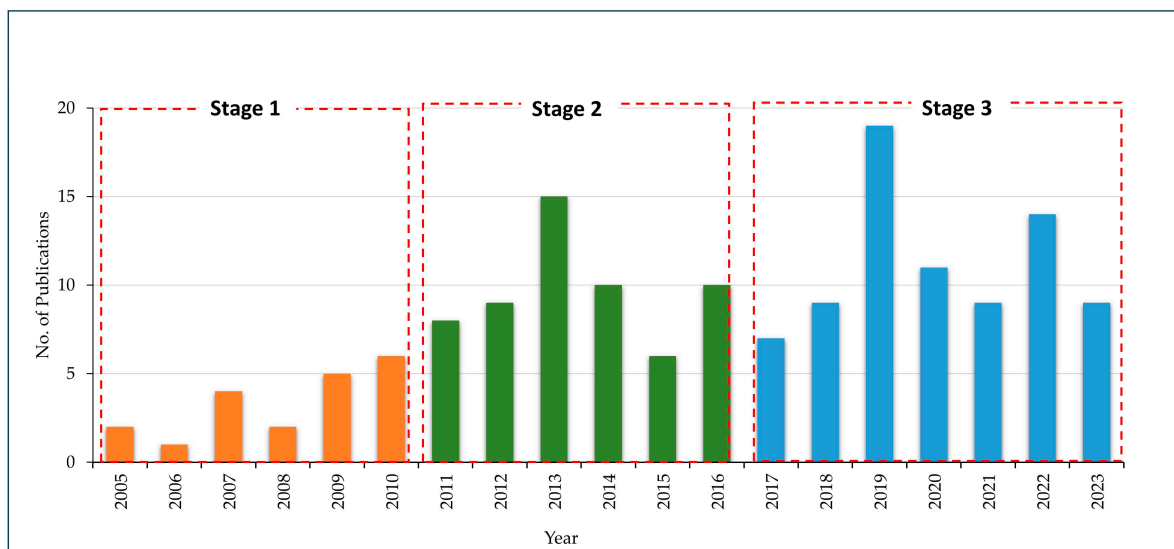


Figure 2. Publication trend in research on “SDI and Cities”.

3.2. Authors

Four hundred and sixteen authors contributed to SDI- and city-related publications from 2003 to 2023. The five top-cited authors were Gorger, Gerhard (documents—three; citations—848); Plumer, Lutz (documents—three; citations—848); Kolbe, Thomas H, (documents—three; citations—404); Zipf, Alexander (documents—three; citations—50); and Dawidowicz, Agnieszka (documents—three; citations—13). This uncovers the relationships between authors using co-citation analysis and bibliometric coupling. Under author co-citation analysis, 6808 authors had a minimum of 19 citations for co-citation with other

authors. The four clusters in the co-citation network are observable in Figure 3. The most critical cluster is the red one. In addition to having the highest number of authors, $n = 06$, it has some highly cited authors, such as Gorger G, who ranked first, and Plumer Lutz, who ranked first.

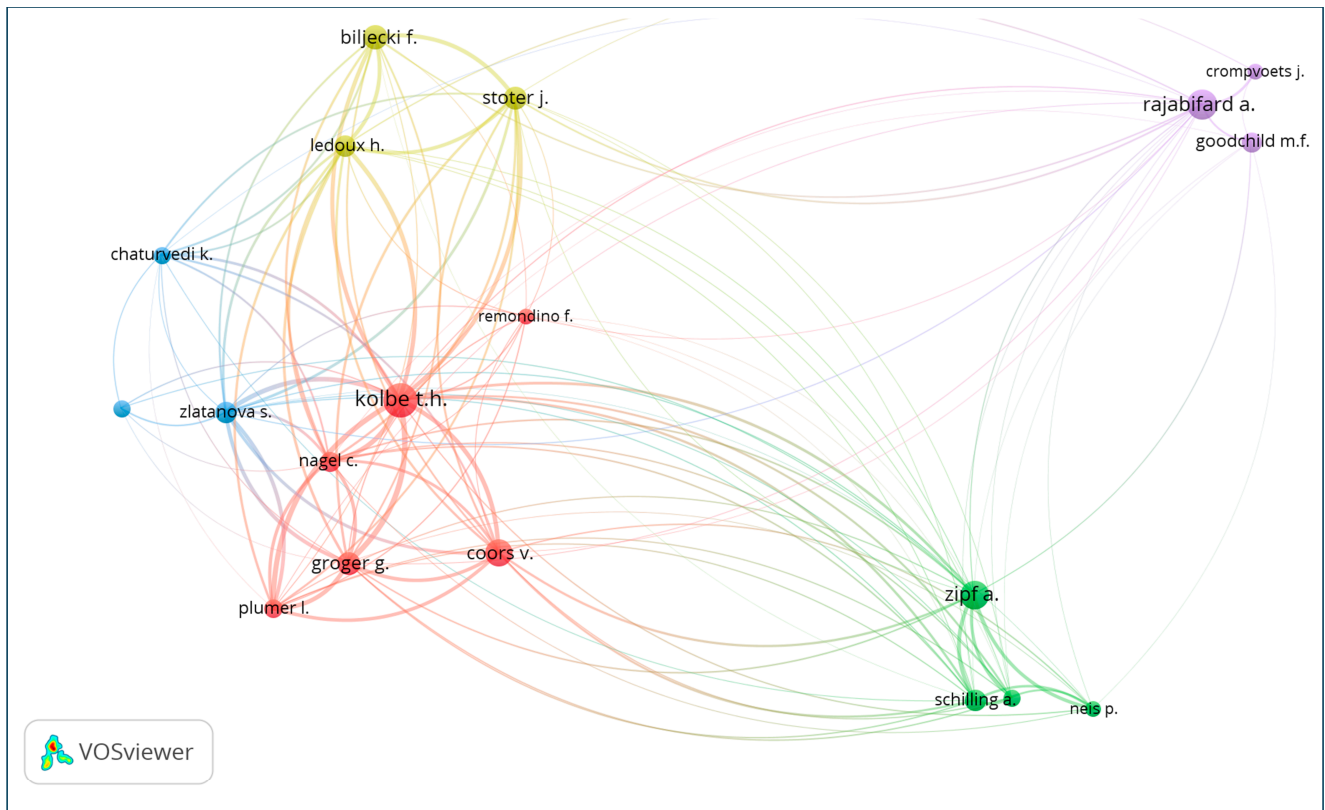


Figure 3. This network map displays clusters of authors (clusters of co-citations).

This cluster is central and connects to all other authors, implying that it enjoys high collaboration and complements research themes. The blue cluster acts more or less like an extension of the red cluster. The authors of this cluster are not entirely isolated from the central authors; therefore, their work relatively builds upon or complements the research conducted by the core cluster. The green cluster is the second-largest cluster, ranked second, and led by Luthe T. This cluster centers on urban analysis and spatial data. These stronger ties between the authors might indicate their interest in urban spatial data infrastructure and its uses, which likely results in closer contributions to GIS and urban planning methods. The yellow cluster is the smallest among the clusters and is also more detached and separate from the other researchers. It is more oriented toward data integration and 3D modeling.

By setting the minimum threshold for an author to seven for the study of author bibliographic coupling, seven authors met this threshold and were grouped into four clusters, as shown in Figure 4. The red cluster at the center of the map includes some of the most-cited authors. This centrality cluster indicates its core role in the field, contributing much to SDI research and urban studies. The bibliographic coupling analysis also represents the central figures and key clusters within SDI and urban research.

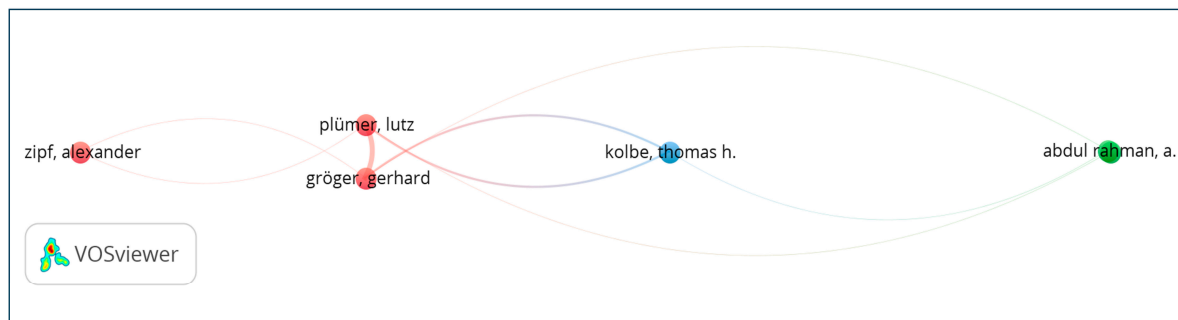


Figure 4. Network map presenting clusters of authors in spatial data infrastructure (SDI) and city research (2003–2023) (clusters of bibliographic coupling).

3.3. Countries

Based on the origin of the authors, forty-eight countries contributed to the publication of SDI and city research within the investigated period of 2003–2023. The country-level citation network was calculated by selecting countries with at least five publications reported in the investigated period (Table 1). In the process, 12 countries were selected and clustered into three sections, as shown in Figure 5.

Table 1. Most productive countries in SDI and city research (2003–2023).

S/N	Country	No. of Publications	No. of Citations
1	Germany	21	1184
2	Malaysia	12	16
3	India	11	31
4	Italy	10	158
5	Croatia	8	21
6	The Netherlands	8	54
7	China	7	90
8	Spain	6	15
9	Hong Kong	5	126
10	Brazil	5	7
11	Iran	5	34
12	Poland	5	13

Note: only countries with at least five published documents are included.

The red cluster represents five countries, led by Italy and Croatia. The visualization shows a global spread of collaborations or citations, representing countries from Asia (China, Hong Kong, Malaysia), Europe (Germany, Spain, Croatia, Italy), North America (United States), and South America (Brazil). The thickness of the connecting lines reflects the strength of these relationships, emphasizing the robust global academic network among these countries.

Figure 6 illustrates a collaboration map presenting the level of partnerships between countries in the SDI and city research domain. Within this context, notable collaboration is exhibited only twice in Croatia, Belgium, and Slovakia. Notable collaboration refers to significant connections between authors, institutions, or countries based on their co-authorship or shared research topics based on the SDI and city research context. Figure 6 depicts no existing collaborative networks among the countries analyzed. Figure 6 indicates the unique geographic distribution of global scientific production, with dark-blue regions,

such as Germany, Spain, Croatia, and Italy in Europe and China, Hong Kong, and Malaysia in Asia, representing the highest amount of research being produced. In contrast, less research activity is represented by light-blue regions, and gray represents few or no recorded scientific papers in SDI and city research. This presents an international dimension, as this collaboration is permitted across countries or regions, enhancing information exchange and partnerships.

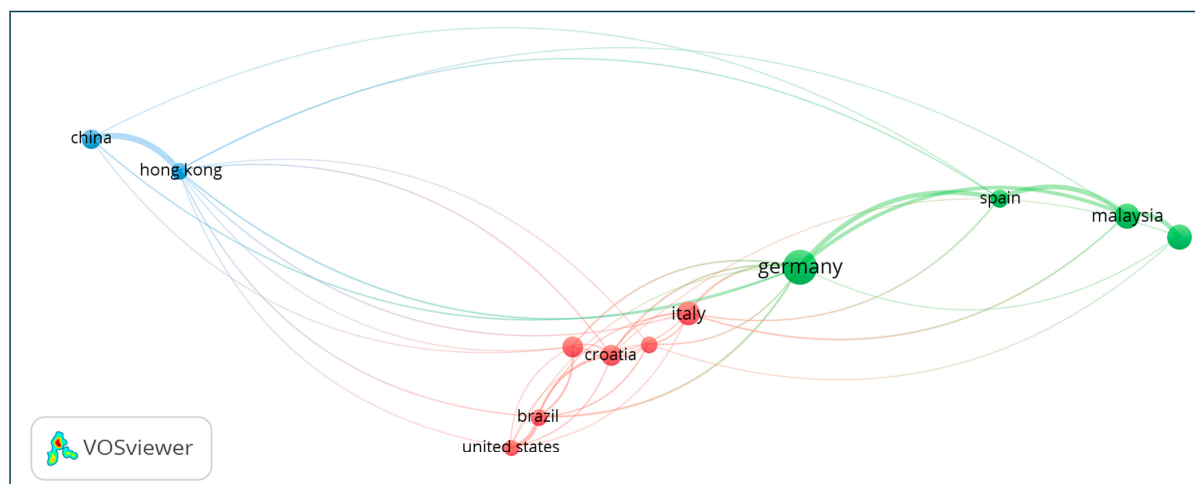


Figure 5. Network map showing clusters of countries in spatial data infrastructure (SDI) and city research (2003–2023): clusters of citations.

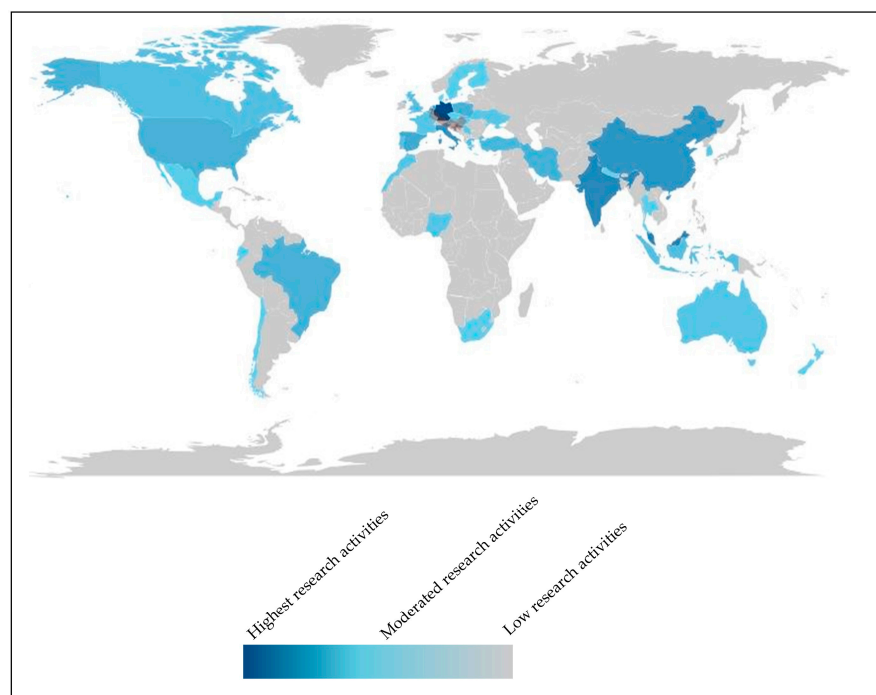


Figure 6. A country collaboration map for the SDI and city research across the world.

3.4. Keyword Analysis

Keyword analysis facilitates the identification of fundamental themes, enhances search tactics, and filters pertinent studies. Researchers may guarantee the inclusion of all relevant material through keyword analysis, enhancing the review process's comprehensiveness. It also facilitates uniformity and reproducibility, enabling others to follow the same process.

Keyword co-occurrence network analysis can identify research hotspots over time. This study used 1194 keywords in the literature on SDI and cities from 2003 to 2023.

By setting the keyword co-occurrence analysis criterion to a minimum frequency of five, 53 keywords satisfied this threshold. The 53 keywords were grouped into three clusters, indicating three different SDI and city domains. Figure 7a, concerning the keywords that belong to the red cluster, “Spatial data and urban,” has 21. The list of them is spatial data infrastructure, spatial data, geographic information system, GIS, information management, SDI, decision making, local government, land use, sustainable development, inspire, urban area, urban growth, urban development, European Union, crowdsourcing, open data, volunteered geographic information, and Croatia. In the same way, the most significant cluster is the spatial data infrastructure and city cluster because it has the largest size and contains the keyword most important to this concept, that is, “spatial data infrastructure,” which anchors the network center, while the green cluster represents the computer graphics system and contains a total of 19 keywords. Meanwhile, the blue cluster presents “data integration and new technology” with ten keywords.

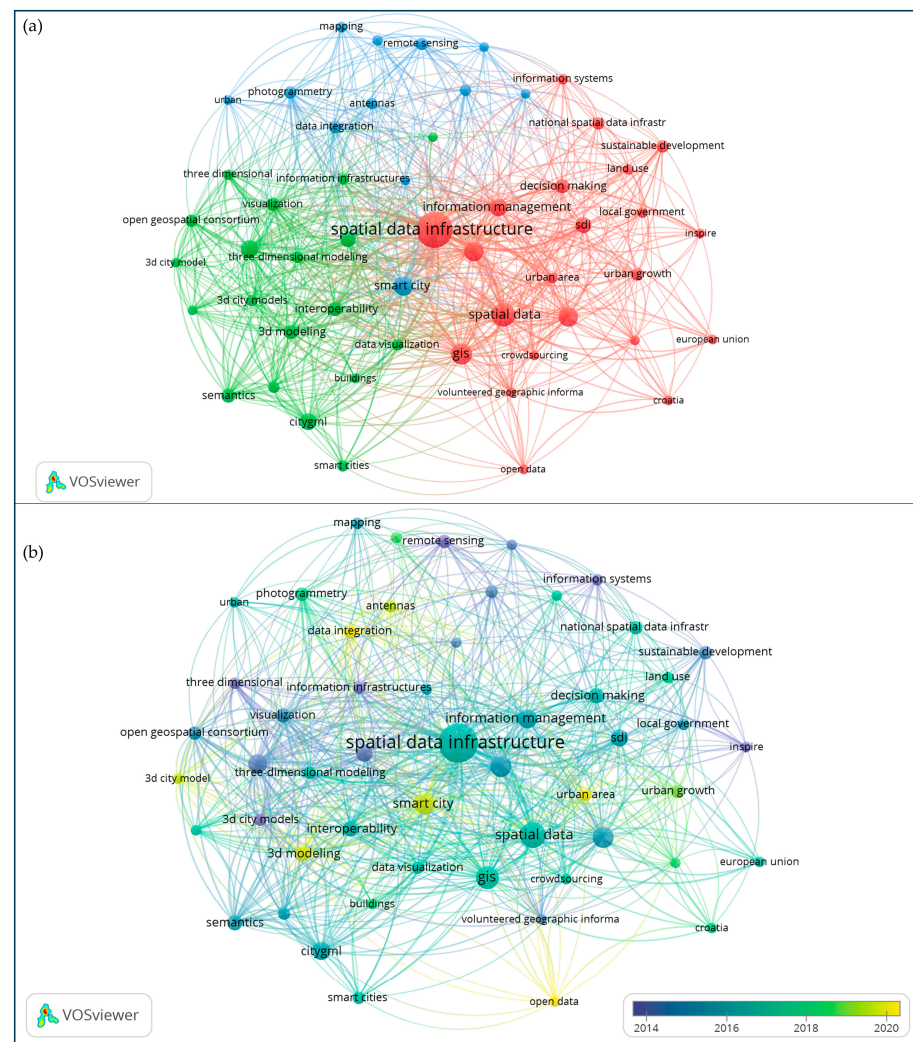


Figure 7. Keyword co-occurrence network map: (a) keyword clusters; (b) occurrence timeline.

The color gradient (from blue to yellow) shows a trend in research themes from 2014 to 2020. A standard period of keyword occurrence can be discovered for patterns of SDI and city research (Figure 7b). The earlier studies (darker blue) focused on areas like “information infrastructures”, “interoperability”, and “data integration” between 2014 and

2016. These themes changed, and research moved toward urban applications such as “smart cities”, “open data”, and “crowdsourcing”. This resulted in an increased focus on practical implementations or community involvement. Further, “spatial data infrastructure”, “smart city”, and “GIS”, among others, were the key elements resulting from the network of this study, which seemed to mark their centrality in both fields.

Tree mapping helps visualize the most important key areas based on their size and frequency. As shown in Figure 8, the most prominent term is “Spatial Data Infrastructure (12%)”, which denotes a significant focus or interest in spatial data infrastructure and city. The ones that show a substantial concentration in this area are “Spatial Data (6%)”, Urban Planning (4%)”, “Smart City (4%)”, “Geographic Information Systems (3%)”, and “Three-Dimensional Computer Graphics”. Other smaller but interesting clusters are “Information Management”, “Web Services”, “3D Modeling”, “Urban Growth”, and “Remote Sensing”. This image is a tree map created to graphically represent the dispersion and the frequency of a set of terms or categories. The size of each rectangle is proportional to the count of occurrences or the significance of the term represented; colors help to discriminate between different categories.

3.5. Main Future Research Directions in the Field of Spatial Data Infrastructure (SDI)

Figure 9 shows the trending keywords used in SDI and city research from 2003 to 2023. These keywords were of prime importance in their use during the formative time of SDI and city research for enhancing sustainable city development. Further, Figure 9 illustrates trending keywords for “SDI and City”, from the Biblioshiny application of the Bibliometric package in the R environment, which refers to the most frequent terms occurring in the field. These keywords represent the main topics that recently gained the most attention and influence in these SDI and urban studies. Based on Figure 9, keywords about cities’ sustainability enhancement were more prominent during the later stages of growth from 2016 to 2022. Among them are spatial data, spatial data infrastructure, geographic information systems, smart cities, 3D modeling, urban growth, and urban areas, which are apparent in SDI and city research.

A keyword analysis related to the scientific contributions presented in this literature review was conducted to indicate further research areas. Figure 7 depicts the 1194 most meaningful keywords representing the results. The thematic analysis provides a pictorial presentation of the trending themes in this research area [43]. Figure 10, a thematic map, categorizes the developing topics in SDI and urban studies, showing the emergence of and increase in some regions of research. It maps out the relationships between themes and allows the visualization of how these focus topics have shifted through time. This map may reveal some clustering of related keywords or topics, showing the relationship between such concepts as smart cities, the interoperability of data, urban planning, GIS, and sustainability. As illustrated in Figure 10, the quadrant in the bottom right identifies the foundational themes representing the established research issues in the area. According to this, the main themes are “geographic information systems”, “spatial data infrastructure”, “spatial data”, “3D modeling”, “photogrammetry”, and “urban planning.” SDI, GIS, and urban planning are fundamental ideas in the research context. Through thematic analysis, the roles of “smart city initiatives” and “3D computer graphics” are expounded, which are essential in fields that deal with SDI improvement. These themes are relevant in the actual application and visualization of geographic data. They set the grounds for constructing sophisticated applications and technology in SDI. The upper-right corner of the map highlights themes that have gained significance in recent years [43]. The fact that “location-based services” and “mobile navigation systems” are only some of the more

prominent specializations proves that they are niche areas of study by themselves. These may grow in the future as technologies and applications evolve.

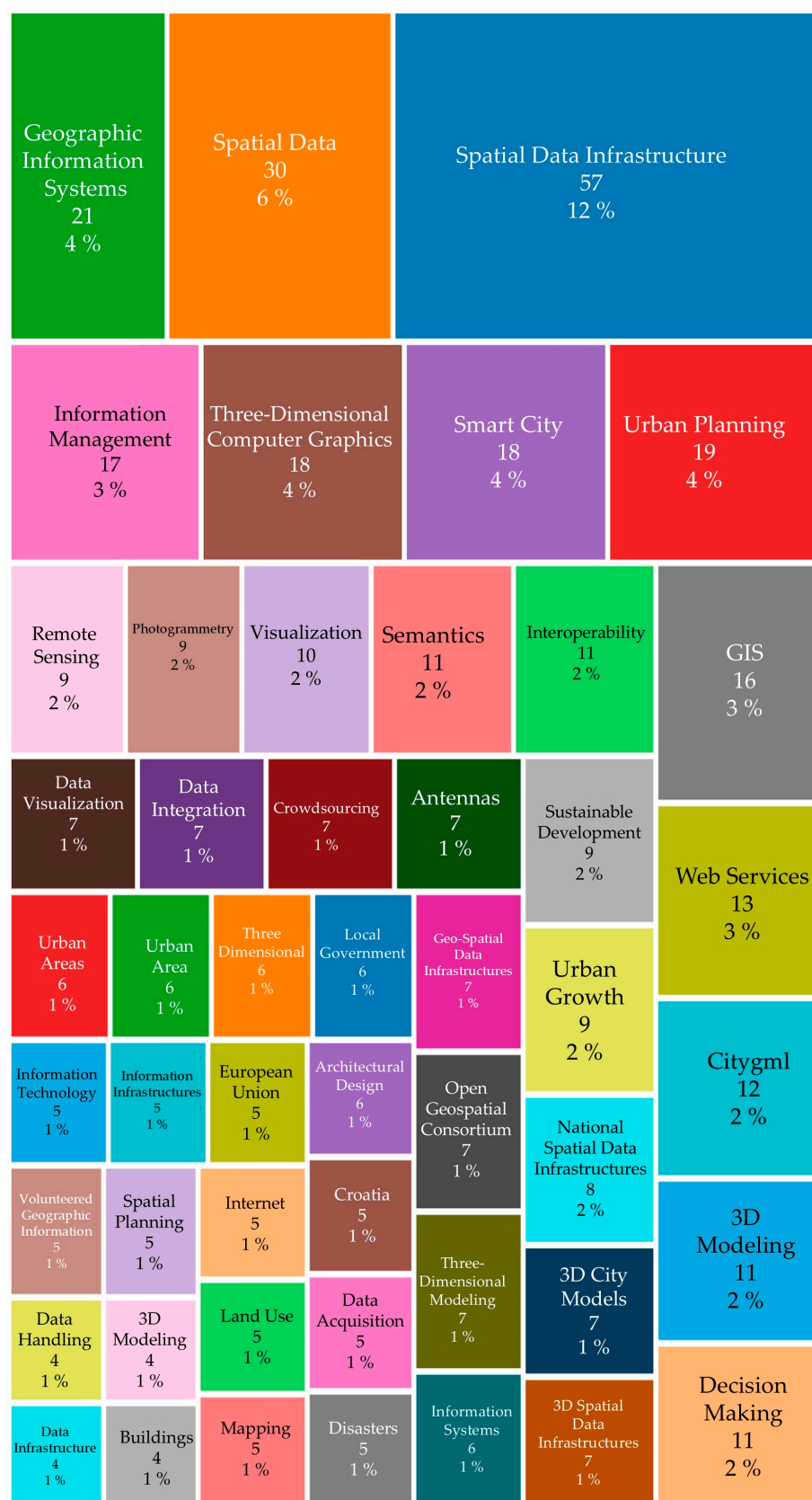


Figure 8. Word treemap of high-frequency keywords in research field of SDI and cities.

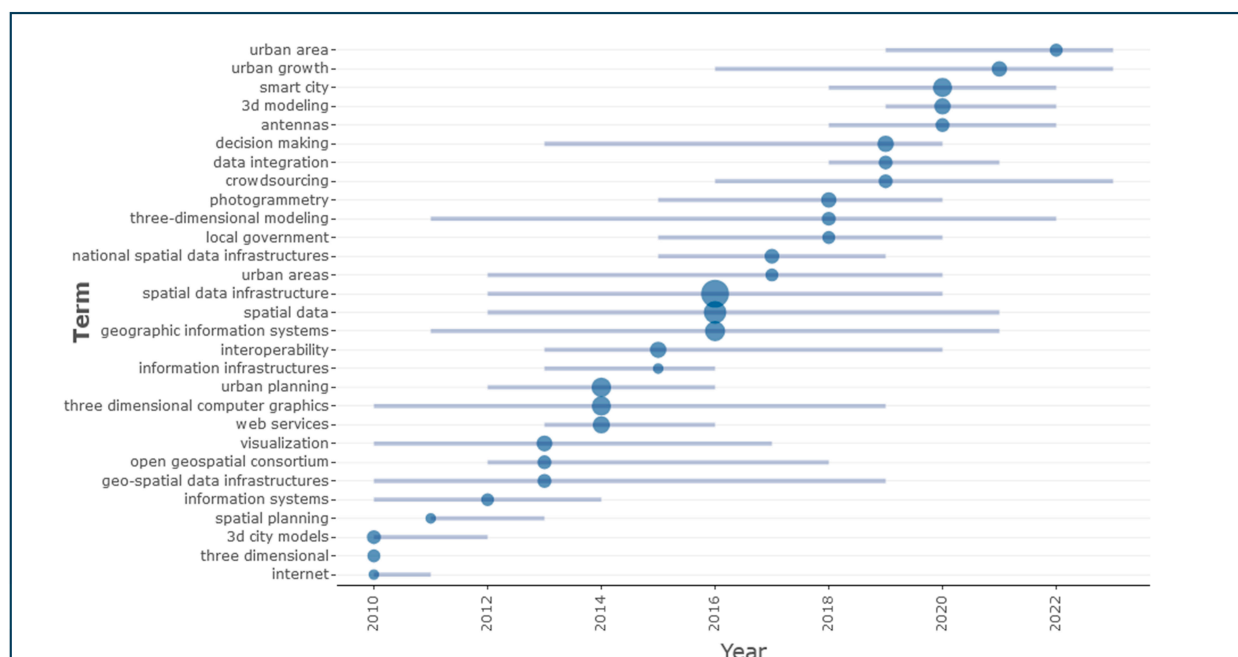


Figure 9. Trending keywords in SDI and city research derived from the Biblioshiny application of the Bibliometric package in the R software environment.

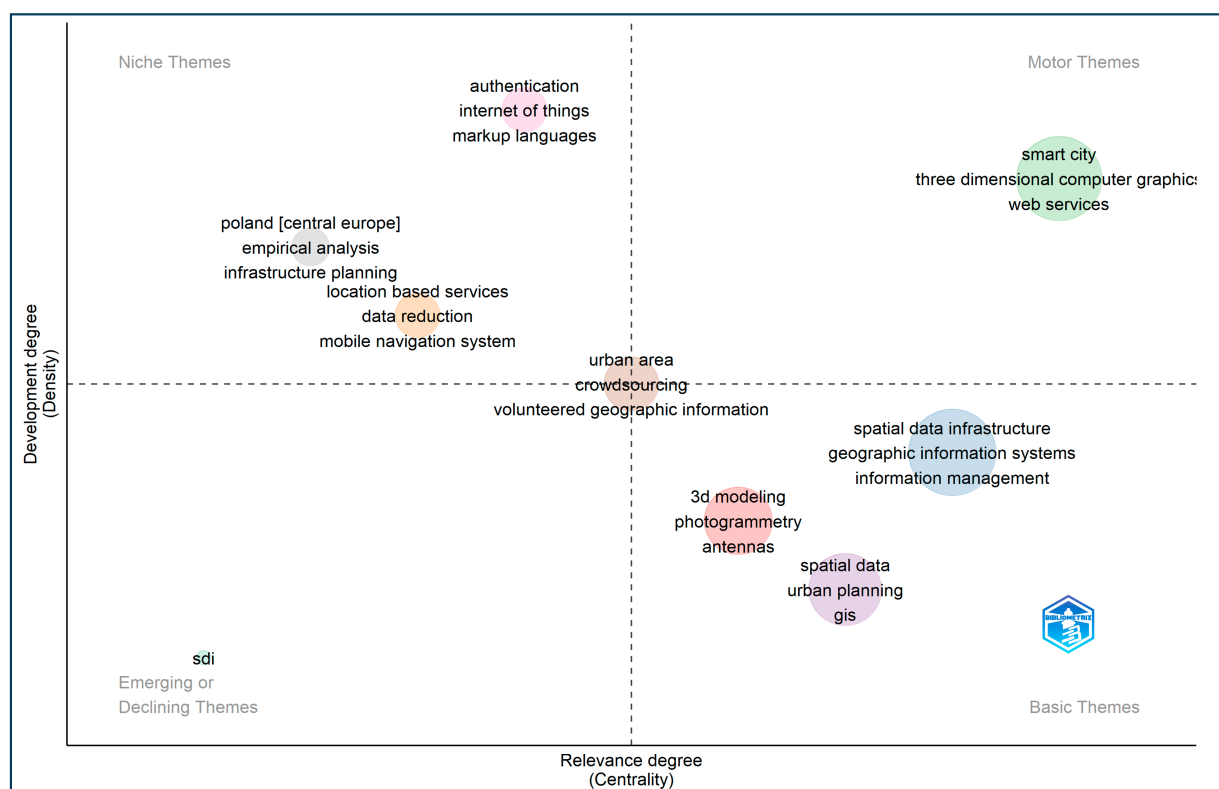


Figure 10. A thematic map of spatial data infrastructure and city research between 2003 and 2023, derived from the Biblioshiny application of the Bibliometric package in the R software environment.

The integration of results from Bibliometrix and VOSviewer fairly strengthened this study. Coupling the strong points of each, we executed a more far-reaching bibliometric analysis that could guarantee greater depth and accuracy regarding identifying publication trends, key research themes, influential authors, country-level collaborations, and thematic

structures. In performing so, findings could be cross-validated using the combined approach to reduce possible biases arising from reliance on a single software tool. Such a dual-software methodology enhanced the robustness of the analysis and offers the reader a more rounded, fine-grained, detailed presentation of the SDI and city research landscape.

3.6. Qualitative Analysis of Highly Cited Scholarly Works

Highly cited papers are essential in advancing spatial data infrastructure and city research knowledge. These works are also influential contributions that shape research directions, provide insights into foundational ideas, and drive innovative applications. This section overviews the ten most-cited research articles on spatial data infrastructure (SDI) in urban studies from 2003 to 2023. Appendix A summarizes the highly cited articles in this field of study. As is the usual practice used by most past researchers, the title, objectives, methodology, and main findings are the common elements of qualitative analysis [35,43]. While considering these common elements, we add the *relevance of these studies* as a new element, providing the reader with additional insights beyond the traditional methodology. This method ensures a more comprehensive understanding of the subject matter by incorporating emerging research and expanding the scope of information presented.

Geography Mark-up Language (GML), which provides a standardized geometry model, is vital in creating and sharing 3D city models globally with Open Geospatial Consortium (OGC) standards. Gerhard Gröger and Lutz Plümer [44] studied “CityGML—Interoperable semantic 3D city models” and described how City GML could define the following:

“geometry”, “topology”, “semantics”, and appearance of urban objects at multiple levels of detail; hence, it is semantically much more prosperous than simple geometric models. It is expected to be available for use in several sophisticated applications like urban planning, navigation, and environmental simulation or facility management. To what extent does geography mark-up language enable extensive application in supporting interoperable data exchange, stimulate broad adoption, and considerably impact scientific studies, such as noise simulation, energy assessment, or disaster management? The vast extent of usage of CityGML worldwide in most urban modeling projects and data exchange projects explains its key role in developing 3D city modeling technologies globally.

Further, Kolbe et al. (2005) [45] researched “CityGML interoperable access to 3D city models”, aiming to present CityGML as a standardized data model and exchange format for representing 3D city models. In this respect, the authors, Thomas H. Kolbe, Gerhard Gröger, and Lutz Plümer, motivated the need for interoperable access to up-to-date 3D city models, in particular for disaster management. Geography Mark-up Language enhances syntax and semantic interoperability in various systems. CityGML considers the geometric and semantic modeling of urban features in five levels of detail (LoDs). The application of CityGML is further demonstrated in disaster scenarios, such as flood simulations or evacuation planning, through its use in enabling precise spatial analysis and integrating multiple data sources. The authors finally concluded the assessment process for CityGML, which remains unfinished because it is part of a pilot project in several German cities; thus, it has higher applicability in urban planning and disaster response.

Over et al. [46] conducted a study based on CityGML’s different aspects, titled “Generating web-based 3D city models from the open street map (OSM): The current situation in Germany”. They used OSM datasets in the study for 3D visualizations in general, pointed out some of their potential, and summarized the pros and cons of using volunteered geographic information. Some major AI use cases in partial urban planning for street grid design and navigation are traffic management and mission-critical first-responder communications combined with SDI. The research reviewed some approaches to integrating OSM

data with the digital elevation model (DEM). It showed the added value from synergy when combined with higher-resolution DEMs for improved visualization, which is essential for preparing SDI systems in any urban context. The authors demonstrated that sophisticated OSM attributes bring about accuracy in 3D city models.

A scholarly work titled “An open-science Crowdsourcing Approach for Producing Community Noise Maps Using Smartphones” [47] was developed in an open science framework using a smartphone app for noise capture to gather physical and perceptual data about noise in the environment (noise levels, GPS data) and how people perceive it (people’s pleasantness rating of locations/times). The investigation revealed that the participatory strategy could handle usually constrained simulation boundaries and highly simplified emission models of traditional noise-mapping methods. The authors described (1) a stepwise methodological process with transferable protocols and (2) technological settings for a local multi-level data capturing system with a geographic information system (GIS) as a means of SDI for geo-data management. Preliminary analyses of the data collected to date generally supported the feasibility and utility of this approach despite concerns regarding data quality and user engagement. It provided a case for when community-driven data collection has potential added value in the scale, realism, and precision of environmental noise mapping for broader scientific or urban planning applications.

In another research work titled “Integration of aerial oblique imagery and terrestrial imagery for optimized 3D modeling in urban areas”, Wu et al. [48] presented a novel method of incorporating two image types through automatic feature matching and joint bundle adjustment among them and used the combined results to optimize the geometry and texture of the 3D models generated from aerial oblique imagery. They used high-resolution aerial imagery and terrestrial imaging to improve 3D modeling in challenges within an urban setup. Three-dimensional modeling is a critical approach in SDI research that brings virtual reality to urban areas. Investigational analyses were conducted on two datasets of aerial and terrestrial images collected in Dortmund, Germany, and Hong Kong. The outcomes indicated that the proposed approach efficiently integrated images from the two platforms, thereby improving 3D modeling in urban zones [48]. The research handled occlusion problems between the data obtained from the street facades’ sides and the geometry’s complex structures under consideration. It addressed, therefore, the merging of aerial data with terrestrial data. The proposed method of automatic feature matching and combined bundle adjustment could improve the accuracy and details of 3D models. Real experimental studies based on Dortmund, Germany, and Hong Kong datasets demonstrated the improvement of the fidelity of the geometric shape and the textural quality. These urban data types hold massive potential in 3D city modeling to benefit domains like urban planning, management, and environmental studies by creating highly accurate photorealistic models.

Guillaume et al. [49] carried out a study titled “Noise Mapping based on Participative Measurements”. It aimed to address the frustrations of conventional noise mapping techniques that are simulation-based, have poor temporal and spatial resolution, and are only statically mapped. The system filters raw measurements in real time and excludes outliers, synchronizing noise samples to geographical regions or statistical areas. The system is based on open-source software and on implementing the openness for spatial data interoperability standard recently released by the Open Geospatial Consortium to calculate advanced indicators related to environmental noise. They depict the ability of such a system to aid in improved accuracy and realism in noise maps while highlighting that the expectations for crowdsourcing use demand trustworthy approaches to information collection and input techniques by communities. The research indicates that participatory methods in data collection databases support traditional methods and further employ feed-

back to assist users in urban planning activities for environmental management programs. The proposed architecture rests on outsourced processes that filter outlier sensors and untrustworthy data, cross-reference delocalized noise measurements with geographical and statistical data to provide higher-level indicators, and map the collected and processed data based on web services (ref. [48]), which is similar to the functionality of the SDI system.

Volkan Cagdas [50] researched “Application domain extension to CityGML for immovable property taxation in Turkey”. The study recognizes the need for an efficient inventory system that links the legal, administrative, and spatial information required for property taxation. The application domain extension (ADE) defines legal and economic aspects according to Turkish law in CityGML for representing the walls of cadastral parcels as they are in reality, therefore fitting real-world boundaries accurately for parcel building condominium units. It enables geo-information integration between municipal systems for urban planning and facilities management or another administrative services. The research highlighted that City GML is a strong foothold for other municipal, practical applications similar to property tax records. The study presents the design of an ADE for immovable property taxation, which extends the data model of CityGML to include concepts of immovable property coming from Turkish law. The study further shows that such an ADE could play the role of an SDI model for municipal information systems in supporting efficiency in the processes of taxation, urban planning, facility management, and other municipal services [50].

Chaturvedi et al. (2019) completed an important study titled “Securing Spatial Data Infrastructures for Distributed Smart City Applications and Services” [51]. The authors deliberately avoided generalizing the SDI and combined different systems, sensors, and applications under a unique framework. They considered the interoperability and safety of connections regarding different data sources. The research presented the concept of the security of distributed applications and services in such data infrastructure of smart cities. This proposed concept ensures privacy, security, and controlled access to all stakeholders and components through appropriate authorization and authentication mechanisms. The approach facilitates Single-Sign-On (SSO) authentication by a novel combination using state-of-the-art security concepts [51]. It is implemented as a framework in London’s Queen Elizabeth Olympic Park, proving that it is a means to allow secure, standardized access to geographically distributed resources while attending to privacy regulations. Thus, this focus furthers the need for strong security mechanisms to protect sensitive information in smart city applications, which are also a hot topic in SDI research in the urban context. This demonstrates that their approach is more effective for managing urban data through the SDI system.

The “3D web visualization of huge City GML models” by Prandi et al. [52] also brings up some important facts about 3D cities and SDI. The authors presented the evolution of a 3D web-based visualization system oriented to large City GML models, describing the main challenges related to efficient web visualization and discussing interoperability issues. In this context, they proposed a service-oriented architecture (SOA) framework compliant with Open Geospatial Consortium (OGC) standards to manage and visualize large-scale 3D city models. The system keeps geometric and semantic data apart, and it could be an additional middleware layer at each level between the storage and the application, which would serve as a bridge to the data access. In the first stage, a framework was designed to meet the OGC’s proposed 3D Portrayal Service specification. The second main focus was on developing an effective web client for the efficient rendering of 3D city models. The work constitutes an example of the potential to be tapped from integrating modern web technologies and open standards for improving visualization and access to 3D city models via web interfaces as an application of SDI.

Notably, the systematic review conducted by Loo and Tang [53] on “Mapping Smart Cities” articulates how digital maps and spatial data infrastructure evolved in the process of supporting smart cities, showing how digital maps and GIS moved from mainframe computers into web GIS and mobile applications, highlighting their key role in integrating, visualizing, and analyzing spatiotemporal data produced by IoT devices. They focus on four extensive research directions in innovative mapping: common spatial data standards and platforms, generating collective intelligence, empowering citizens in urban planning, and monitoring city performance. Such research is vital for providing the first comprehensive snapshot of the potential role of maps within smart cities, where valuable real-time socio-temporal data are continuously produced yet often remain underutilized or entirely unused by critical stakeholders in the pursuit of smart city goals [53].

These results were produced with the light limitation of extracting the data only from the Scopus database. However, the results or discussion will not have a significant effect because many scholarly works have followed the same methodology worldwide, and references can be found elsewhere [54–57].

4. Discussion

Our research explores the literature on spatial data infrastructure and urban research from 2003 to 2023, utilizing multi-level bibliometric approaches. The research identified the existing knowledge and methodological gaps in SDI and city research that may be of consequence to the academic discourse in this area. The unique output of this study provides a foundation for the following discussion.

4.1. Research Overview of Spatial Data Infrastructure and City Research

This review of the trends of scholarly works on “spatial data infrastructure systems and cities” from 2003 to 2023 indicates an upward tendency toward growing research activity and interest in the domain. From 2000 to 2012, this topic received less attention, as evidenced by the few articles published, which indicates that those were the early stages of its formation. This was further divided into three stages (Figure 3). Of these phases, Stage I in 2010 had the maximum publications. Stage II’s peak of publications in the successive stages was in 2013, while Stage III’s was in 2019. This ranged from 2013 to 2019, with steady expansion to an average of about ten articles per year and then a radical jump to 19 in 2019. The trend indicates a renewal of interest in the subject, probably propelled by both technological progress and growing requirements in terms of complexity for the management of towns and cities. Most studies indicate that the focus on developing sustainable and green cities has increased over the past five years [58].

The high and stable increase year by year since 2020 already denotes the development of this area and increasing awareness about its necessity. The excellent annual growth rate and number of references (4229), with an average number of 12.79 citations per document, indicate the growing academic relevance of spatial data infrastructure systems in an urban environment. This is a developing trend; hence, the future looks promising with continuous discoveries and improvements in the subject, led by scientific curiosity and critical urban feasibilities. Uncontrolled growth affects healthy urban development. It is of great practical importance to understand the trends in urban development and forecast future urban spatial patterns [59].

4.2. The Conceptual Foundation of Spatial Data Infrastructure and City

The analysis of author contributions and citation trends in the literature available on spatial data infrastructure and city studies from 2003 to 2023 depicts a highly collaborative and impactful research environment. Among the four hundred and sixteen writers, the

five most cited have a considerable academic impact. Gorger and Plumer are in the first place, with the same number of citations, totaling 848. Co-citation analysis, including 6808 authors with at least 19 citations, shows the presence of four key groupings. Based on Figure 3, the red cluster is the largest group with the most frequent references, intensely collaborating in a network with focal influences on research subjects.

In contrast, the blue cluster extends the influence of the red one, meaning that both have complementary study focuses. The green cluster, led by Luthe T., is oriented toward urban spatial data and GIS applications, outlining the latter's role in urban planning approaches. The smaller, independent yellow cluster symbolizes specialized data integration and 3D modeling effort. This bibliometric coupling thus points out the key contributions made by the red cluster to the field, substantiating its critical contributions to SDI and urban studies. This interconnection, together with the prominence of key authors (Figure 3) and clusters (Figure 4), underlines this field's dynamic and collaborative character, which supports the development of urban spatial data infrastructure. With globalization growing, this trend of collaborative studies is anticipated to increase geographical diversity for collaborators, be it individuals, laboratories, or even institutes [60].

This research has substantiated that a strong academic community is also highly networked globally, with 12 countries represented and at least five publications organized into three distinct groups. The red cluster (Figure 5), dominated by Italy and Croatia, shows a significant contribution and collaborative strength. The plot visualizes one extensive network covering all continents, with countries from Asia (China, Hong Kong, Malaysia), Europe (Germany, Spain, Croatia, Italy), North America (the United States), and South America. Among these lines are solid academic ties representing remarkable cooperation, such as between Croatia and Belgium and between Croatia and Slovakia, both present twice. Although such connections exist, the low figure of wide collaborative networks among the countries under study indicates a need for stronger international cooperation.

Generally, international collaboration results in a considerably more significant and broader readership for the authors due to an increased extent of networking, a characteristic of the global nature of research. In the present case, this is a nationwide and united undertaking in the context of a leading, internationally oriented field of science with a high level of scientific quality [61]. This global distribution, paired with current but limited links, underscores the need for strengthened cross-regional cooperation to improve SDI and city research for better knowledge exchange and innovation. Based on Figure 7b, a timeline from 2014 to 2020 shows early topics of research, such as "information infrastructures" and "data integration", from 2014 to 2016, giving way to more recent interests in smart cities, open data, and crowdsourcing, marking an increase in practical implementations and emphasis on community involvement. The high ranking of the terms "spatial data infrastructure", "smart city", and "GIS" in the network underlines their crucial role and continuous relevance for SDI and city research, thus representing a vibrant, changing research environment driven by technological developments and urban applications. Spatial data are fundamental in the creation, management, analysis, and visualization of space with the use of geospatial technology. The management of smart cities and their functional applications all need a combination of geospatial data and technology [62]. Smart cities rely on smoothly integrating physical and digital infrastructure layers [63].

This points out the relevance of smart city initiatives and 3D computer graphics in the practical application and visualization of geographic information. Development towards smart cities has quickly emerged as the most current global trend, and it will likely continue shortly [18]. The improvement of the performance and usability of SDI systems is grounded in these two critical areas. SDI, GIS, and urban planning are principles that provide a basis necessary for developing intricate SDI technologies and applications.

Urban planners employ GIS in monitoring, developing, and implementing their projects for decision-making [64]. The spatial data become relevant to support decisions, planning, and managing cities. In this sense, safe, uninterrupted, and accurate spatial data must be available for city managers and planners to carry out sustainable management and planning [65]. Moreover, the dominance of specialized industries, including location-based services and mobile navigation systems, underlines their distinct but essential role. These industries are likely to grow along with technology; hence, these specialized applications will find increased implementation in SDI systems.

Further research is necessary to identify how best to develop and organize SDI. The establishment of SDI has significantly grown in several countries, particularly at the national level, though in most cases, this has been in regional or local government jurisdictional areas. However, an emerging trend exists in engaging various user communities, including public and non-governmental organizations, to realize the full benefits of spatial data development investments [66]. The current best solution to such spatial community concerns continues to be SDI. Finally, those involved in the SDI development must take optimum advantage of alternative information sources, including remotely sensed data and substitutes for traditional survey methods. Such an approach can help achieve considerable progress without experiencing long delays characteristic of the conventional database development process [67].

4.3. Research's In-Depth Analysis

The studies highlight that CityGML and SDI are essential in enabling forward-looking urban planning, management, and research. The works underline that integrating and sharing such complex spatial data through solid, interoperable frameworks like CityGML will allow a whole range of different domains and thus realize a broad scope of urban applications from traffic management to disaster response. The research also highlights participatory approaches where community-driven data facilitate the increased precision and relevance of urban assessments, particularly in noise mapping and environmental management. The findings also demonstrate the importance of implementing stringent security mechanisms within the SDI to protect sensitive data in urban areas, especially smart cities. These studies guide developing cost-effective, scalable, and more inclusive SDIs oriented around modern web technology interoperability, security, and integration. Hence, the findings will significantly contribute to the further evolution of the SDI, which is a practical tool for optimizing the use of resources, ensuring their sustainability, and improving the quality of life in urban environments by empowering more informed and effective decision-making processes.

This set of studies highlights the growing role of SDI, 3D modeling, and participatory approaches for urban spatial planning, environmental monitoring, and smart city applications. The articles jointly emphasize the flexibility and adaptability of frameworks such as CityGML to support various use cases that range from property taxation [50] to semantic 3D modeling [44]. These frameworks allow for the combination of geometry, topology, and semantic information, which are becoming crucial in urban management and disaster response. Integrating aerial and terrestrial imagery [48] and using crowdsourced OpenStreetMap data for 3D modeling [46] illustrate technological developments to improve the accuracy, accessibility, and cost-efficiency of urban data infrastructures. Studies on participatory noise mapping and community engagement, such as [47,49], provide novel ways of tackling environmental challenges through citizen contributions to enhance the temporal and spatial depth of data capture. Equally important are the security concerns, as noted in [51], which propose robust authentication frameworks for protecting sensitive data in smart city SDI.

Despite these valuable contributions, many considerable challenges and limitations have emerged for these studies. For instance, the application of CityGML requires great computational resources and expertise and can hardly be adopted in resource-limited situations [44,45]. Equally, the variable quality and coverage of crowdsourced data [46] and citizen-contributed noise data [49] raise concerns about their reliability and standardization. Integrating aerial and terrestrial imagery for 3D modeling [48] is promising but computationally demanding, potentially excluding smaller municipalities. Additionally, while participatory approaches foster inclusivity, they face challenges in maintaining engagement and ensuring data accuracy [47]. Security frameworks, although robust, may be complex and costly for smaller municipalities to adopt [51]. Lastly, the conceptual nature of studies such as [53] also has limited practical applicability in diverse global contexts. All these, put together, bring out the need for scalable, inclusive, and context-sensitive solutions in advancing SDIs and urban data management frameworks.

After mentioning the above high-impact scholarly literature, most scholars mention and focus their research on subjects regarding 3D modeling and its related technologies, such as CityGML. Based on an overview of their analysis, one can deduct an apparent lack of emphasis concerning integrating spatial data infrastructure systems within an urban planning context. Moreover, the concepts of SDI systems are emerging as a point of interest among scholars, as reflected in their research themes. This underlines the increasing recognition of the importance of SDI in addressing challenges in urban planning and smart city management.

Bibliometric analysis guides future SDI and city development research by showing trends, influential studies, and new areas of interest. The analysis extracts the most impactful publications, productive authors, and collaborative clusters that drive development in these fields by studying citation patterns, co-authorship networks, and keyword analysis. For example, understanding how the research focus evolved from the foundational concepts of SDI to the integration of 3D city models and smart urban planning may aid in setting future research agendas. In this respect, CityGML is investigated regarding the practical challenges of large city models and their interoperability with potential future extensions of GML. Further, bibliometric analysis might indicate gaps in the literature that set researchers on unexplored topics or innovative approaches with the promise of advancing state-of-the-art research. It will engender interdisciplinary collaboration and ensure the focus of research efforts on the most critical challenges in urban development and SDI.

Most research in the city development and urban management realms, including areas like spatial data sharing, is focused on the issues related to spatial data. Thus, spatial data management systems constitute a significant backbone in decision-making processes in several fields crucial for sustainable city development. SDI is one of the most widely deployed data management systems that efficiently manage geographical or spatial data. Therefore, our discussion of smart cities focuses on SDI.

5. Conclusions

This research reflects on a bibliographic analysis of spatial data infrastructure and city research, giving a fundamental view of trends and influential elements. It is vital to identify the most cited articles, top authors, and major academic journals because they reveal primary knowledge centers and main personalities that drive SDI and city research. Finally, the trends in rising themes in research related to spatial data infrastructure and city themes such as “spatial data infrastructure”, “spatial data”, and “geographic information system” have been understood to be of great importance. These characterize the active domain of research and innovation where progress is envisaged.

This can also demonstrate collaboration trends between scholars and institutions in SDI and urban studies. Planners, policymakers, and professionals in the city management dimension might relate to such data when searching for collaborations with academic institutions, technology companies, and other industry players to exchange information, access cutting-edge technologies, and create new solutions to urban challenges.

From the practical implications viewpoint, within the realm of spatial data infrastructures and urban management, city planners and policymakers will be better placed to translate the findings of their urban development strategies to improve the quality of life for citizens. This will give them a competitive edge in managing smart cities and sustainable urban environments. In summary, the acquired knowledge will allow city planners and policymakers to harness SDI and other related technologies in urban management for effective, responsive, and resilient cities. These identified trends, gaps, and recommendations are the rich sources that decision-makers use to design and implement strategies, combining technological advancements with data-driven approaches in urban planning and policy-making. This way ensures that policies comply with the dynamic needs of the urban environment for sustainable city development. Since urban development is a changing area, continuous attention is essential to remain up to date with emerging trends, new technological developments, and regulation changes. Such insights will thus enable stakeholders to make informed decisions, thereby improving collaboration in research and applications related to urban planning and smart city management.

Author Contributions: The corresponding and first author, D.D., proposed the topic, spearheaded the data processing and analysis, and wrote the manuscript with the collaboration of M.R. and H.D. Other authors, including J.J., P.R., N.H., S.A.M. and W.W., helped design this research, and A.P. and Y.H. supported research activities. All authors have read and agreed to the published version of the manuscript.

Funding: The authors acknowledge the financial support provided by the Research and Publication Committee, Faculty of Social Sciences and Humanities, Rajarata University of Sri Lanka, for the Environmental Management Department's research project (RJT/R&PC/2024/R/FSSH/03).

Acknowledgments: The authors express their gratefulness to the anonymous reviewers for their valuable comments and suggestions.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table 1. Main scientific research in the field of SDI and cities, categorized by authors, titles, objectives, methodology, main findings, and relevance to this study.

Authors	Title	Objectives	Methodology	Main Findings	Relevance to This Study
Gerhard Gröger, Lutz Plümer [44]	City GML—Interoperable Semantic 3D City Models	Present City GML as the OGC standard for 3D city models. Emphasize semantic aspects that should, more broadly, be on semantic issues of 3D city models and their structures, taxonomies, and aggregations.	Review of City GML with comparison to other models compared to purely geometrical/graphical models such as KML, VRML, and X3D.	City GML allows interoperable data exchange and has been applied in many applications. Advanced analysis and visualization tasks of the different levels of detail of application domains in which CityGML is being used at present date are urban planning, indoor and outdoor pedestrian navigation, environmental simulations, and cultural heritage preservation.	This paper points out the actual significance of City GML in the SDI development process and city research through the firm and interoperable framework, which enables a great range of urban applications and integration of complex spatial data across various domains.
Thomas H. Kolbe, Gerhard Gröger, and Lutz Plümer [32]	CityGML—Interoperable Access to 3D City Models	Introduce CityGML as a standardized data model and exchange format for 3D city models, especially in disaster management.	It uses Geography Mark-up Language (GML3) for syntactic and semantic interoperability. It provides five levels of detail about geometric and semantic modeling.	CityGML enables correct spatial analysis with data integration and is considered for evaluation in a pilot project involving a couple of German cities for urban planning.	It provides a standardized framework to integrate distributed data sources within spatial data infrastructures, which is crucial in urban planning, disaster management, and research to develop interoperability in cities.
M. Over, A. Schilling, S. Neubauer, A. Zipf [46]	Generating Web-based 3D City Models from Open Street Map: The Current Situation in Germany	Test how to generate 3D city models from OSM and public height data. Check the OpenStreetMap data for the appropriateness and quality for 3D visualizations of traffic infrastructure, buildings, and POIs.	Reviewing OSM data and the implementation of web services. The use of standards and draft specifications from the Open Geospatial Consortium for all applied web services of the 3D spatial data infrastructure.	OSM provides opportunities for 3D visualization; specialized web services developed for data processing are available. This research demonstrates how the differences in coverage and accuracy vary regionally within the OSM data. In some cases, the quantity of roads far outstrips that of any commercial or government dataset.	This contributes significantly to SDI development in a cost-effective manner and contributes to more participation in creating interoperable, multi-level city models, thus allowing a high coverage of urban applications, from traffic management to disaster response.
Judicaël Picaut, Nicolas Fortina, Erwan Bocherb, Gwendall Petitc, Pierre Aumonda, and Gwenaël Guillaumed [47]	An open-science crowdsourcing approach for producing community noise maps using smartphones	Harnessing crowdsourced data on citizens' noise recordings made using a mobile app. Alternative solutions for simulations for achieving the high temporal and spatial granularities recommended by European regulation in environmental noise mapping.	The development of cell-phone applications and open-source tools and the application of spatial data infrastructure. Adopting the spatial data infrastructure concept to modularize the business modules for sound-level data acquisition, analysis, and mapping.	Architecture filters out unreliable data and cross-referencing measurements and promotes citizens' participatory sensing. This allows the mapping of collected and processed data by web services, promoting participatory sensing by citizens with urban environmental observatories.	It contributes significantly to SDI through a transferable protocol and GIS-based data management framework, which can integrate local multi-level data into an assessment. Through this approach, urban noise assessments are more accurate and participatory, offering a new avenue of citizen engagement in urban planning processes related to city research and bringing environmental noise management closer to reality and the public's perceptions.

Table 1. Cont.

Authors	Title	Objectives	Methodology	Main Findings	Relevance to This Study
Bo Wu, Linfu Xie, Han Hu, Qing Zhu, and Eric Yau [48]	Integration of Aerial Oblique Imagery and Terrestrial Imagery for Optimized 3D Modeling in Urban Areas	Integrate aerial oblique and terrestrial imagery to optimize 3D models. Crop the geometry and texture in 3D models generated from aerial oblique images in an urban area with densely distributed high-rise buildings.	Automatic feature matching, combined bundle adjustment. Experimental analysis on datasets of aerial and terrestrial images in Dortmund, Germany.	Integration improves the accuracy of 3D models and visual quality, enabling urban applications. The proposed technique can develop the 3D urban models into more accurate and visually good models. Hence, it would be more appropriate for urban planning, management, monitoring, and environmental studies.	The research supports SDI development by providing a fixed framework through integrative multiple sources of city thematic data, thus achieving improved interoperability and the usability of 3D models in many applications.
Gwenaél Guillaume, Arnaud Can, Gwendall Petit, Nicolas Fortin, Sylvain Palominos, Benoit Gauvreau, Erwan Bocher, and Judicaël Picaut [49]	Noise mapping based on participative measurements	To study the potential of participative measurement through smartphones for environmental noise mapping and develop a system to enhance the accuracy and relevance of these maps by using crowdsourced data.	The OnoM@p system is described in the context that the citizens are responsible for noise data collection, hence requiring them to use smartphones as an acquisition tool. By the standards of interoperability, the filtering and treatment exhibited by the open-source tools account for noise maps, hence sharpening the accuracy and realism of the noise maps. This has already been demonstrated with the added-on advanced data processing features by participatory sensing technology, upon which this method for deriving more precise, high-resolution noise maps is developed, compared to those based on traditional noise-mapping simulation techniques, from which several limitations follow. It presents such opportunities with crowdsourced data in environmental monitoring and urban planning.	It proposed the OnoM@p system, which is developed based on the idea of engaging citizens in collecting noise data with smartphones as an acquisition tool. OFCM uses open-source tools based on interoperability standards for filtering or processing collected data to develop noise maps that refine the precision and realism of the noise map. The research shows how participatory sensing, combined with sophisticated data processing, can generate more accurate high-resolution noise maps, hence avoiding the limitations of characterizing traditional noise mapping simulation-based methods. It shows such possibilities with crowdsourced data in environmental monitoring and urban planning.	The study depicts how integrating community-driven data into traditional methods can achieve more robust and detailed urban noise maps in SDI development. Such noise maps are highly instrumental in giving insights into city research for urban planning and environmental management programs by enhancing the possibility of making effective decisions with the full involvement of communities.

Table 1. Cont.

Authors	Title	Objectives	Methodology	Main Findings	Relevance to This Study
Volkan Çağdaş [50]	An Application Domain Extension to City GML for Immovable Property Taxation: A Turkish Case Study	Implement an ADE for property taxation and extend City GML by legal and administrative concepts.	The taxation system of Turkey and development of ADE in Turkey. The use of City GML in the context of the semantic and 3D geometrical representation of physical objects in urban areas.	ADE is a 3D national data model enabling efficient taxation and municipal services. It provides for the creation of comprehensive registers and inventories to make full and fair records concerning taxed property, including its legal and economic attributes.	It has also increased the potential of City GML—ADE to support SDI development through a robust framework that enables managing and sharing complex urban data for further research on cities and effective municipal governance.
Kanishk Chaturvedi, Andreas Matheus, Son H. Nguyen, and Thomas H. Kolbe [51]	Securing Spatial Data Infrastructures for Distributed Smart City Applications and Services	Secure distributed applications and services in smart city SDI. Provide privacy, security, and controlled access to all stakeholders and respective components through proper authorization and authentication mechanisms.	SDI concept development and the implementation of SSO authentication. The implementation of Single-Sign-On authentication based on a new combination of state-of-the-art security protocols, including SAML.	Ensures privacy, security, and controlled access with the assurance of security and enhancement of usability of smart city applications. The approach allows users and applications to conveniently interoperate with all systems using SSO authentication, which improves security and usability for distributed smart city applications and services.	It provides basic mechanisms of security in managing urban data and forms a significant basis for the advancement of SDIs with respect to smart cities. It plans a blueprint for enhancing data security and interoperability in city research and development.
F. Prandi, F. Devigili, M. Soave, U. Di Staso, and R. De Amicis [52]	3D Web Visualization of Huge CityGML Models	Create and develop a 3D web-based city model visualization system. Develop web-based efficient visualization systems and interoperable frameworks for access to city models in a standardized way.	Design an architectural framework. The development of web clients. Develop a suitable web client to represent the 3D city model in an appropriate form meaningful to the user.	Very efficient visualization, thus making the 3D models available. The view developed by the system clearly visualizes 3D city models and opens them to a broader audience than only a few experts.	This work establishes the backbone of city research. It will enhance the interoperability and usability of 3D city models, supporting more effective urban planning, management, and decision-making processes through advanced, web-based visualization techniques.
Becky P.Y. Loo and Winnie S.M. Tang [53]	Mapping smart cities	Review the role of digital maps and spatial data infrastructure in smart cities. Identify major research directions of smart mapping to support smart city initiatives further.	Conceptual framework: case studies. This concern examines the roles of digital maps and spatial data infrastructure in smart cities.	Digital maps and SDI are crucial for smart cities; four major research directions identified. This then involves smart mapping to optimize resources and maintain sustainability and quality of life within urban environments.	The work offers valuable insights to city planners and researchers on how SDI is potentially positioned to optimize resources, sustainability, and quality of life in urban setups.

References

1. UN Department of Economic and Social Affairs. *World Urbanization Prospects*; UN Department of Economic and Social Affairs, World Urbanization Prospects: New York, NY, USA, 2018; Volume 12, ISBN 9789211483192.
2. Estoque, R.; Murayama, Y. Monitoring Surface Urban Heat Island Formation in a Tropical Mountain City Using Landsat Data (1987–2015). *ISPRS J. Photogramm. Remote Sens.* **2017**, *133*, 18–29. [\[CrossRef\]](#)
3. Arundel, R.; Ronald, R. The Role of Urban Form in Sustainability of Community: The Case of Amsterdam. *Environ. Plan. B Urban Anal. City Sci.* **2017**, *44*, 33–53. [\[CrossRef\]](#)
4. De Vos, J.; Van Acker, V.; Witlox, F. Urban Sprawl: Neighbourhood Dissatisfaction and Urban Preferences. Some Evidence from Flanders. *Urban Geogr.* **2016**, *37*, 839–862. [\[CrossRef\]](#)
5. Ewing, R.; Hamidi, S.; Grace, J.B.; Wei, Y.D. Does Urban Sprawl Hold down Upward Mobility? *Landsc. Urban Plan.* **2016**, *148*, 80–88. [\[CrossRef\]](#)
6. Dissanayake, D. Land Use Change and Its Impacts on Land Surface Temperature in Galle City, Sri Lanka. *Climate* **2020**, *8*, 65. [\[CrossRef\]](#)
7. United Nations Development Programme (UNDP). *Sustainable Urbanization Strategy—UNDP’s Support to Sustainable, Inclusive and Resilient Cities in the Developing World*; United Nations Development Programme: New York, NY, USA, 2016; p. 60.
8. Palevičius, V.; Burinskiene, M.; Antuchevičienė, J.; Šaparauskas, J. Comparative Study of Urban Area Growth: Determining the Key Criteria of Inner Urban Development. *Symmetry* **2019**, *11*, 406. [\[CrossRef\]](#)
9. Ranagalage, M.; Murayama, Y.; Simwanda, M. The Impacts of Landscape Changes on Annual Mean Land Surface Temperature in the Tropical Mountain City of Sri Lanka: A Case Study of Nuwara Eliya. *Sustainability* **2017**, *11*, 5517. [\[CrossRef\]](#)
10. Dissanayake, D.M.S.L.B.; Morimoto, T.; Murayama, Y.; Ranagalage, M.; Perera, E.N.C. Analysis of Life Quality in a Tropical Mountain City Using a Multi-Criteria Geospatial Technique: A Case Study of Kandy City, Sri Lanka. *Sustainability* **2020**, *12*, 2918. [\[CrossRef\]](#)
11. Surabhi Shanker, S.B. The Effect of Technological Advancement on Building a Sustainable City. *Stud. Indian Place Names (UGC Care J.)* **2020**, *40*, 935–940.
12. Mondschein, J.; Clark-Ginsberg, A.; Kuehn, A. Smart Cities as Large Technological Systems: Overcoming Organizational Challenges in Smart Cities through Collective Action. *Sustain. Cities Soc.* **2021**, *67*, 102730. [\[CrossRef\]](#)
13. Tirla, M.-L.; Manea, G.; Vijulie, I.; Matei, E.; Cocos, O. Green Cities—Urban Planning Models of the Future. In *Cities in the Globalizing World and Turkey: A Theoretical and Empirical Perspective*; University Press: Sofia, Bulgaria, 2014; pp. 462–479.
14. Pace, R.; Churkina, G.; Rivera, M. *How Green Is a “Green City”? A Review of Existing Indicators and Approaches*; IASS: Potsdam, Germany, 2016. [\[CrossRef\]](#)
15. Mouratidis, K. Urban Planning and Quality of Life: A Review of Pathways Linking the Built Environment to Subjective Well-Being. *Cities* **2021**, *115*, 103229. [\[CrossRef\]](#)
16. Ozkaya, G.; Erdin, C. Evaluation of Smart and Sustainable Cities through a Hybrid MCDM Approach Based on ANP and TOPSIS Technique. *Heliyon* **2020**, *6*, e05052. [\[CrossRef\]](#) [\[PubMed\]](#)
17. Moura, F.; de Abreu e Silva, J. Smart Cities: Definitions, Evolution of the Concept, and Examples of Initiatives. In *Industry, Innovation and Infrastructure*; Springer International Publishing: Cham, Switzerland, 2021; pp. 989–997. [\[CrossRef\]](#)
18. Myeong, S.; Park, J.; Lee, M. Research Models and Methodologies on the Smart City: A Systematic Literature Review. *Sustainability* **2022**, *14*, 1687. [\[CrossRef\]](#)
19. Kandt, J.; Batty, M. Smart Cities, Big Data and Urban Policy: Towards Urban Analytics for the Long Run. *Cities* **2021**, *109*, 102992. [\[CrossRef\]](#)
20. Wu, Y.C.; Sun, R.; Wu, Y.J. Smart City Development in Taiwan: From the Perspective of the Information Security Policy. *Sustainability* **2020**, *12*, 2916. [\[CrossRef\]](#)
21. Lim, Y.; Edelenbos, J.; Gianoli, A. What Is the Impact of Smart City Development? Empirical Evidence from a Smart City Impact Index. *Urban Gov.* **2024**, *4*, 47–55. [\[CrossRef\]](#)
22. Zhu, H.; Shen, L.; Ren, Y. How Can Smart City Shape a Happier Life? The Mechanism for Developing a Happiness Driven Smart City. *Sustain. Cities Soc.* **2022**, *80*, 103791. [\[CrossRef\]](#)
23. Rajabifard, A.; Williamson, I.P. Spatial Data Infrastructures: Concept, SDI Hierarchy and Future Directions. In *Proceedings of the GEOMATICS’80 Conference*, Tehran, Iran, 29 April–2 May 2001; Volume 10.
24. Ray, N.; Lacroix, P.; Giuliani, G.; Upla, P.; Rajabifard, A.; Jensen, D. Open Spatial Data Infrastructures for the Sustainable Development of the Extractives Sector: Promises and Challenges. In *Spatial Enablement in a Smart World*; GSDI Association Press: Reston, VA, USA, 2016.
25. Olfat, H.; Rajabifard, A.; Qureshi, F.M. Facilitating Urban Management through Local SDI Case Study: The Municipality of Tehran Facilitating Urban Management Through Local SDI Case Study: The Municipality of Tehran. In *Proceedings of the GSDI 11 World Conference*, Rotterdam, The Netherlands, 15–19 June 2009.

26. Qureshi, F.M.; Rajabifard, A.; Olfat, H. Facilitating Urban Planning and Management at Local Level through the Development of SDI (Case Study of Lahore-Pakistan). In Proceedings of the GSDI 11 World Conference, Rotterdam, The Netherlands, 15–19 June 2009.
27. Longley, P.A.; Goodchild, M.F.; Maguire, D.J.; Rhind, D.W. New Developments in Geographical Information Systems. In *Geographical Information Systems: Principles, Techniques, Management and Applications*, 2nd ed.; John Wiley & Sons Inc.: Hoboken, NJ, USA, 2001; p. 404.
28. Donthu, N.; Kumar, S.; Mukherjee, D.; Pandey, N.; Lim, W.M. How to Conduct a Bibliometric Analysis: An Overview and Guidelines. *J. Bus. Res.* **2021**, *133*, 285–296. [\[CrossRef\]](#)
29. Aria, M.; Cuccurullo, C. Bibliometrix: An R-Tool for Comprehensive Science Mapping Analysis. *J. Informetr.* **2017**, *11*, 959–975. [\[CrossRef\]](#)
30. van Eck, N.J.; Waltman, L. Software Survey: VOSviewer, a Computer Program for Bibliometric Mapping. *Scientometrics* **2010**, *84*, 523–538. [\[CrossRef\]](#)
31. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *J. Clin. Epidemiol.* **2009**, *62*, 1006–1012. [\[CrossRef\]](#) [\[PubMed\]](#)
32. Ferreira, D.R.; Valdati, J. Geoparks and Sustainable Development: Systematic Review. *Geoheritage* **2023**, *15*, 6. [\[CrossRef\]](#)
33. Németh, B.; Németh, K.; Procter, J.N. Informed Geoheritage Conservation: Determinant Analysis Based on Bibliometric and Sustainability Indicators Using Ordination Techniques. *Land* **2021**, *10*, 539. [\[CrossRef\]](#)
34. Zakharovskiy, V.; Németh, K. Systematic Literature Review of the Natural Environment of the Coromandel Peninsula, New Zealand, from a Conservation Perspective. *Conservation* **2021**, *1*, 270–284. [\[CrossRef\]](#)
35. Dissanayake, H.; Popescu, C.; Iddagoda, A. A Bibliometric Analysis of Financial Technology: Unveiling the Research Landscape. *FinTech* **2023**, *2*, 527–542. [\[CrossRef\]](#)
36. Chen, C. Science Mapping: A Systematic Review of the Literature. *J. Data Inf. Sci.* **2017**, *2*, 1–40. [\[CrossRef\]](#)
37. Delecroix, B. Co-Word Analysis for the Non-Scientific Information Example of Reuters Business Briefings. *Data Sci. J.* **2004**, *3*, 80–87. [\[CrossRef\]](#)
38. Durieux, V.; Gevenois, P. Bibliometric Indicators: Quality Measurements of Scientific Publication. *Radiology* **2010**, *255*, 342–351. [\[CrossRef\]](#)
39. Carrera-Rivera, A.; Ochoa, W.; Larrinaga, F.; Lasa, G. How-to Conduct a Systematic Literature Review: A Quick Guide for Computer Science Research. *MethodsX* **2022**, *9*, 101895. [\[CrossRef\]](#)
40. Župič, I.; Cater, T. Bibliometric Methods in Management and Organization. *Organ. Res. Methods* **2015**, *18*, 429–472. [\[CrossRef\]](#)
41. Xie, H.; Zhang, Y.; Wu, Z.; Lv, T. A Bibliometric Analysis on Land Degradation: Current Status, Development, and Future Directions. *Land* **2020**, *9*, 28. [\[CrossRef\]](#)
42. Moral-Munoz, J.; Herrera-Viedma, E.; Espejo, A.; Cobo, M. Software Tools for Conducting Bibliometric Analysis in Science: An up-to-Date Review. *Prof. Inf.* **2020**, *29*, 3. [\[CrossRef\]](#)
43. Dissanayake, H.; Iddagoda, A.; Popescu, C. Entrepreneurial Education at Universities: A Bibliometric Analysis. *Adm. Sci.* **2022**, *12*, 185. [\[CrossRef\]](#)
44. Gröger, G.; Plümer, L. CityGML—Interoperable Semantic 3D City Models. *ISPRS J. Photogramm. Remote Sens.* **2012**, *71*, 12–33. [\[CrossRef\]](#)
45. Kolbe, T.H.; Gröger, G.; Plümer, L. CityGML: Interoperable Access to 3D City Models. In *Geo-Information for Disaster Management*; Springer: Berlin/Heidelberg, Germany, 2005; pp. 883–899. [\[CrossRef\]](#)
46. Over, M.; Schilling, A.; Neubauer, S.; Zipf, A. Generating Web-Based 3D City Models from OpenStreetMap: The Current Situation in Germany. *Comput. Environ. Urban Syst.* **2010**, *34*, 496–507. [\[CrossRef\]](#)
47. Picaut, J.; Fortin, N.; Bocher, E.; Petit, G.; Aumond, P.; Guillaume, G. An Open-Science Crowdsourcing Approach for Producing Community Noise Maps Using Smartphones. *Build. Environ.* **2019**, *148*, 20–33. [\[CrossRef\]](#)
48. Wu, B.; Xie, L.; Hu, H.; Zhu, Q.; Yau, E. Integration of Aerial Oblique Imagery and Terrestrial Imagery for Optimized 3D Modeling in Urban Areas. *ISPRS J. Photogramm. Remote Sens.* **2018**, *139*, 119–132. [\[CrossRef\]](#)
49. Guillaume, G.; Can, A.; Petit, G.; Fortin, N.; Palominos, S.; Gauvreau, B.; Bocher, E.; Picaut, J. Noise Mapping Based on Participative Measurements. *Noise Mapp.* **2016**, *3*, 140–156. [\[CrossRef\]](#)
50. Çağdaş, V. An Application Domain Extension to Citygml for Immovable Property Taxation: A Turkish Case Study. *Int. J. Appl. Earth Obs. Geoinf.* **2013**, *21*, 545–555. [\[CrossRef\]](#)
51. Chaturvedi, K.; Matheus, A.; Nguyen, S.H.; Kolbe, T.H. Securing Spatial Data Infrastructures for Distributed Smart City Applications and Services. *Futur. Gener. Comput. Syst.* **2019**, *101*, 723–736. [\[CrossRef\]](#)
52. Prandi, F.; Devigili, F.; Soave, M.; Di Staso, U.; De Amicis, R. 3D Web Visualization of Huge CityGML Models. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. ISPRS Arch.* **2015**, *40*, 601–605. [\[CrossRef\]](#)
53. Loo, B.P.Y.; Tang, W.S.M. “Mapping” Smart Cities. *J. Urban Technol.* **2019**, *26*, 129–146. [\[CrossRef\]](#)
54. Ng, S.L. Bibliometric Analysis of Literature on Mountain Tourism in Scopus. *J. Outdoor Recreat. Tour.* **2022**, *40*, 100587. [\[CrossRef\]](#)

55. Feitosa, B.F.; Barros, J.H.T.; Feitoza, J.V.F. Pseudocereals—A Bibliometric Analysis and Literature Review on the Potential for Manufacturing Flours, Bakery Products and Milk Analogues. *NFS J.* **2024**, *34*, 100163. [\[CrossRef\]](#)
56. Palumbo, R.; Manesh, M.F.; Pellegrini, M.M.; Caputo, A.; Flamini, G. Organizing a Sustainable Smart Urban Ecosystem: Perspectives and Insights from a Bibliometric Analysis and Literature Review. *J. Clean. Prod.* **2021**, *297*, 126622. [\[CrossRef\]](#)
57. Dissanayake, H.; Dissabandara, H.; Ajward, R.; Perera, W. SPIRITUALITY AND SUSTAINABILITY: A BIBLIOMETRIC REVIEW. *Agora Int. J. Jurid. Sci.* **2024**, *18*, 165–184. [\[CrossRef\]](#)
58. Javidroozi, V.; Carter, C.; Grace, M. Smart, Sustainable, Green Cities: A State-of-the-Art Review. *Sustainability* **2023**, *15*, 5353. [\[CrossRef\]](#)
59. Id, Y.Z.; Zhao, L.; Zhao, H.; Gao, X. Urban Development Trend Analysis and Spatial Simulation Based on Time Series Remote Sensing Data: A Case Study of Jinan, China. *PLoS ONE* **2021**, *16*, e0257776. [\[CrossRef\]](#)
60. Beaver, D. deB The Many Faces of Collaboration and Teamwork in Scientific Research: Updated Reflections on Scientific Collaboration. *Collnet J. Sci. Inf. Manag.* **2013**, *7*, 45–54. [\[CrossRef\]](#)
61. Van Raan, A.F.J. The Influence of International Collaboration on the Impact of Research Results: Some Simple Mathematical Considerations Concerning the Role of Self-Citations. *Scientometrics* **1998**, *42*, 423–428. [\[CrossRef\]](#)
62. Sharma, P.; Singh, R.; Srivastava, A. Analyzing the Role of Geospatial Technology in Smart City Development. In *Geospatial Technology and Smart Cities: ICT, Geoscience Modeling, GIS and Remote Sensing*; Springer: Berlin/Heidelberg, Germany, 2021; pp. 1–20. ISBN 978-3-030-71944-9.
63. Mortaheb, R.; Jankowski, P. Smart City Re-Imagined: City Planning and GeoAI in the Age of Big Data. *J. Urban Manag.* **2023**, *12*, 4–15. [\[CrossRef\]](#)
64. Xhafa, S.; Kosovrasti, A. Geographic Information Systems (GIS) in Urban Planning. *Eur. J. Interdiscip. Stud.* **2015**, *1*, 85. [\[CrossRef\]](#)
65. Rajabifard, A.; Sabri, S.; Chen, Y.; Agunbiade, M.; Kalantari, M. Urban Analytics Data Infrastructure: Critical SDI for Measuring and Monitoring The National and Local Progress of SDGs. In *Sustainable Development Goals Connectivity Dilemma*; CRC Press: Boca Raton, FL, USA, 2019; pp. 243–255. [\[CrossRef\]](#)
66. Kelly, P. Role of Spatial Data Infrastructures in Managing Our Cities. In Proceedings of the FIG Commission 3 2007 Annual Meeting and Workshop “Spatial Information Management Toward Legalizing Informal Urban Development”, Athens, Greece, 28–31 March 2007; pp. 1–11.
67. Ilic, M.; Kilibarda, M.; Sekulic, D. The Role of Spatial Data Infrastructures (SDI) in Smart City Development. *Sustainability* **2018**, *10*, 3120. [\[CrossRef\]](#)

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.