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Review

The Role of Diversified Geo-Information Technologies in Urban Governance: A Literature Review

Ying Li [1], Yani Lai [1,*] and Yanliu Lin [2]

[1] Department of Construction Management and Real Estate, Shenzhen University, Shenzhen 518052, China; 2200474003@email.szu.edu.cn
[2] Department of Human Geography and Planning, Utrecht University, 3584 CB Utrecht, The Netherlands; y.lin@uu.nl
* Correspondence: lai.yani@szu.edu.cn; Tel.: +86-134-1743-0930

Abstract: Global urbanization has made urban governance a crucial aspect of sustainable urban development. While geo-information technologies have emerged as indispensable tools for effective urban governance, a comprehensive analysis of their application in this context remains lacking. This study seeks to review and assess the pivotal role of geo-information technologies in the field of urban governance. A total of 219 related studies were used for bibliometric analysis and key content analysis. Planning Support Systems (PSSs), Participatory Geographic Information Systems (PGISs), Building Information Modeling (BIM), and City Information Modeling (CIM) are identified as the main information technologies progressively employed across diverse stages of urban planning and construction over recent decades. These advancements have propelled the digital and intelligent management of urban areas, yielding significant benefits such as enhanced visualization, informed decision-making, and increased opportunities for citizen participation. However, a noticeable disparity between supply and demand during the application process arises from a lack of transdisciplinary cooperation. This study sheds light on the existing literature and offers policy implications and recommendations for more effective utilization of geo-information technologies in future spatial governance.

Keywords: urban governance; geo-information technology; PSS; PGIS; BIM; GIS

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1. Introduction

With the accelerated pace of global urbanization, the imperative of urban governance has emerged as a central concern for societal development and sustainability. A projection by the United Nations indicates that, by 2050, global cities and urban agglomerations will encompass 68% of the worldwide population [1]. This rapid urbanization underscores the indispensability of spatial governance within national governance frameworks. Urban governance refers to the process through which relevant actors within urban areas collectively manage public affairs, including policy formulation, resource allocation, and problem-solving, to achieve sustainable urban development [2,3]. Therefore, it signifies collaborative coordination among government entities, the public, and diverse stakeholders throughout the stages of planning, construction, renewal, and management of urban governance. This involves the integration and allocation of urban spatial resources, aimed at achieving sustainable development across multiple dimensions of the economy, society, and environment [4–6]. Currently, urban governance confronts unprecedented challenges, including the escalating scarcity of land resources [7], ecological pollution, carbon emissions [8,9], insufficient infrastructure and services [10], and the depletion of agricultural land [11,12]. At the same time, the surge in urban information and data [13] and the need to achieve a balance of multiple interests has made urban governance increasingly complex [14]. The effectiveness of urban governance is closely linked to the well-being and quality of life of urban residents, profoundly influencing the sustainability of urban planning, development, and social stability [15]. Consequently, scholars and nations are actively exploring more efficient and intelligent urban planning and governance systems [16–19].

Geo-information technologies play a crucial role in addressing growing complexity and emerging challenges within urban governance [20–22]. Urban governance is a complex process involving extensive collaboration, limited resources, and the pursuit of multiple goals. Firstly, it requires judicious and strategic distribution of essential urban resources, such as land, capital, information, labor, and technology, especially in the context of resource scarcity exacerbated by relentless urbanization [23]. Secondly, urban governance encompasses various stakeholders, including governmental agencies, private sector (e.g., developers and construction companies), planners, and the public [24]. These stakeholders possess divergent objectives and demands, necessitating careful orchestration and reconciliation within the governance framework. Finally, due to the differences in multiple interests, urban governance must balance the realization of various goals, such as economic development, social equity, environmental protection, and quality of life of residents. These goals often constrain one another, and urban governors have been striving to achieve a balance among them [25]. In recent decades, the multifaceted functionalities of geo-information technologies have provided a range of tools and resources for various stakeholders involved in urban management [26,27]. By collecting, processing, and analyzing data [28,29], geo-information technologies create new avenues for urban managers to gain a deep understanding of the current state of and central challenges faced by the city, thereby facilitating scientifically informed decision-making [30]. Furthermore, geo-information technologies foster an environment conducive to communication and collaboration, encouraging interaction and feedback among various stakeholders [18]. This not only enhances spatial governance in cities but also drives the continued evolution of urban governance toward digitization and intelligence.

In recent decades, the amount of literature exploring the application of various information technologies in urban governance has been increasing, with numerous information technologies playing pivotal roles in this domain [17–19,31]. As a foundational technology in urban governance, the origins of GIS can be traced back to the 1960s [32]. Subsequent developments in geo-information technologies for urban governance have primarily been based on GIS. In the 1980s, PSS was developed to provide enhanced decision support for land use planning and other domains [33]. Empirical evidence demonstrates that PSS has played a significant role in urban planning, transportation planning, and urban management. In the following decades, scholars focused on enhancing the usability of PSS [34]. However, an implementation gap for PSS still exists due to discrepancies between the demand and supply of technology in practice [35]. In the early 1990s, the concepts of PGIS and PPGIS were introduced, which catalyzed a progressive redirection of research emphasis toward participatory planning and public engagement in the planning process [36–38]. The use of these tools has significantly enhanced the involvement of diverse stakeholders, with a specific emphasis on public participation, thereby increasing the transparency and fairness inherent in the planning process. At the beginning of the 21st century, BIM, developed from CAD, has been widely researched and gradually applied. BIM plays a crucial role in architectural design, construction management, and operational maintenance in urban development. Scholars have focused on improving the intelligence and refinement of urban construction management and project coordination during the construction, operation, and maintenance phases [39,40]. In recent years, the concept and applications of CIM have gradually emerged, primarily utilized in urban infrastructure management and smart city operations. Research has focused on establishing its concepts and exploring initial practical applications. [29,41]. Against this evolutionary background, the application of these technologies in urban governance has grown increasingly diverse and in-depth. In summary, geo-information technologies have added significant value to planning practice and urban governance, but there have also been new challenges. This necessitates a comprehensive understanding of the role of geo-information technologies in urban governance. However, until now, there has been a lack of systematic review and analysis of the characteristics and effects of existing geo-information technology applications.

This study aims to investigate the application characteristics and key roles of core geo-information technologies in urban governance. The paper begins by presenting the historical background of geo-information technology applications in urban governance. The subsequent section delineates the research methodology employed in this study, providing a comprehensive understanding of the approach taken. Following this, the third section presents a bibliometric analysis, contributing to a quantitative evaluation of the scholarly landscape in this field. The fourth section conducts an in-depth examination of the application of four key information technologies: (1) PSS, (2) PGIS, (3) BIM, and (4) CIM. The fifth section discusses the research findings, while the final section concludes the paper.

2. Research Methods

According to Figure 1, the literature review process has four distinct steps. Initially, relevant keywords were meticulously selected for a comprehensive literature search on the Web of Science (WOS), a global database covering important journals and literature resources in several fields. This step aimed to gather literature on urban governance and core information technologies, forming the foundation for subsequent analyses. The search process involved several steps.

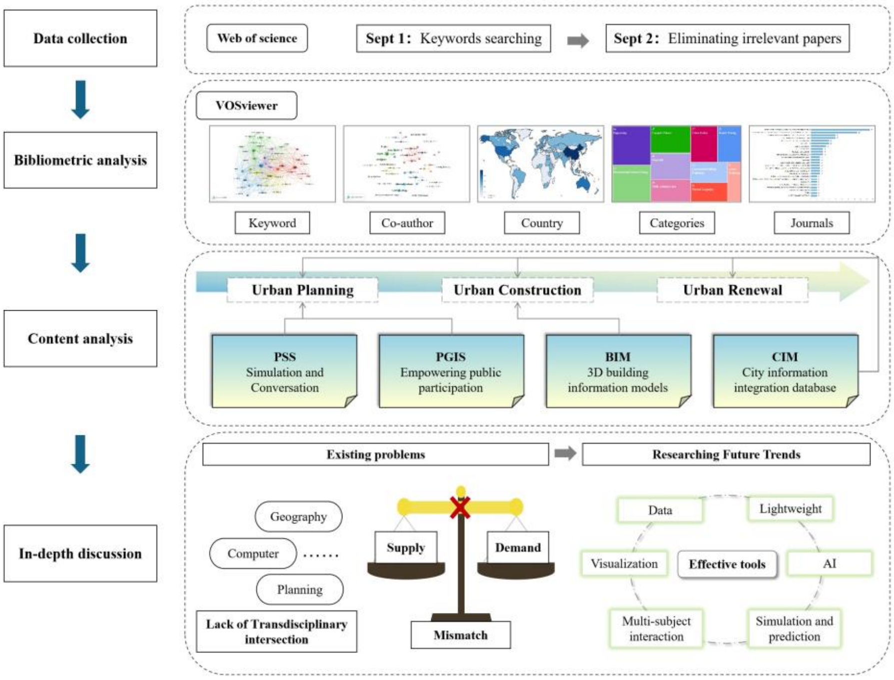


Figure 1. Research process.

The search was initiated by selecting keywords related to geo-information technologies and urban governance in the WOS. Each keyword was expanded with synonyms. In our study, we contend that it is crucial to integrate urban governance with three main domains (urban planning/design, urban construction, and urban renewal/regeneration/redevelopment) to provide a comprehensive understanding of how geo-information technologies operate in practice. These three domains are the main application fields of geo-information technologies in urban contexts. Therefore, we searched keywords, such as "urban governance", "urban planning", "city planning", "urban design and planning", "urban construction", "urban development", "urban renewal", "urban regeneration", or "urban redevelopment", combined with "geographic information technology". The initial search did not have a timeframe limitation to ensure retrieval of the maximum relevant literature. Table 1 presents the specific keywords, resulting in 2144 relevant studies.

Table 1. Search keywords and results.

	Keywords	Number
Search 1	(TS = (Information technology OR Geo-information technology OR Information and Communication technologies)) AND TS = (Urban governance OR Urban planning OR City Planning OR Urban Design and Planning OR Urban construction OR City construction OR Urban renewal OR Urban regeneration OR Urban Redevelopment)	2144
Search 2	(TS = ("Building information model" OR "Building information modelling" OR "Building information management" OR "BIM" OR "Planning support systems" OR "PSS" OR "City information modelling" OR "City information model" OR "CIM" OR "Participatory geographic information system" OR "PGIS" OR "PPGIS" OR "Public participation geographic information system")) AND TS = (Urban governance OR Urban planning OR City planning OR Urban design and planning OR Urban construction OR City construction OR Urban renewal OR Urban regeneration OR Urban redevelopment)	462

A summary analysis of the 2144 studies, based on titles and abstracts, highlighted diverse attempts to apply information technologies in urban governance. This study reviewed the existing literature according to specific criteria. The frequent mention of these technologies in the literature indicates their widespread attention and recognition in the academic community. These technologies have been broadly applied, demonstrating their effectiveness and reliability in practical applications. Significant results have been achieved in various geographic information application scenarios, and these technologies have been successfully utilized across multiple fields. Therefore, four key geo-information technologies emerged: planning support systems, participatory GIS, building information modeling, and urban information modeling.

A more targeted literature search was conducted based on the four identified key technologies and keywords related to urban governance. Distinctions were made between the full names and abbreviations of the keywords for these technologies. To capture recent trends, the search primarily considered studies from the last ten years (2013–2023), resulting in 462 relevant studies.

The final step involved screening the literature based on titles, abstracts, and keywords to exclude content unrelated to the application of geo-information technology in urban governance. A total of 219 pieces of literature were finally selected for subsequent bibliometric analyses and content analysis.

In the second step, bibliometric analyses were applied to the selected 219 documents. Visualizations in network diagrams, facilitated by VOSviewer1.6.20, encompassed keyword co-occurrence analysis, co-author analysis, country–region analysis, and literature category and journal analysis. These analyses aimed to unravel the current research status, revealing key themes and research trends. In the third step, a thorough review of the specific contents of these studies was conducted, followed by a detailed content analysis of the roles played by four key information technologies in urban governance: Planning Support Systems (PSSs), Participatory Geographic Information Systems (PGISs), Building Information Modeling (BIM), and City Information Modeling (CIM). Finally, the study concludes with reflections on the effectiveness of geo-information technologies in urban governance and proposes future research agendas.

3. Bibliometric Analysis

3.1. Overview

Figure 2 presents a comprehensive trend analysis of the academic literature dedicated to the study and application of information technology in urban governance. Spanning a decade, from 2013 to 2023, the graph delineates an upward trajectory in the volume of publications, indicating a growing interest and investment in this field by researchers. Initially, the number of publications was relatively modest, reflecting the early stages of this transdisciplinary area. However, as the years progressed, a noticeable increase was observed, with a significant surge in the publication count in recent years. The research trend underscores the dynamic evolution of this field. It suggests a promising future where geo-information technologies continue to play a pivotal role in shaping urban governance toward more efficient, sustainable, and inclusive urban environments.

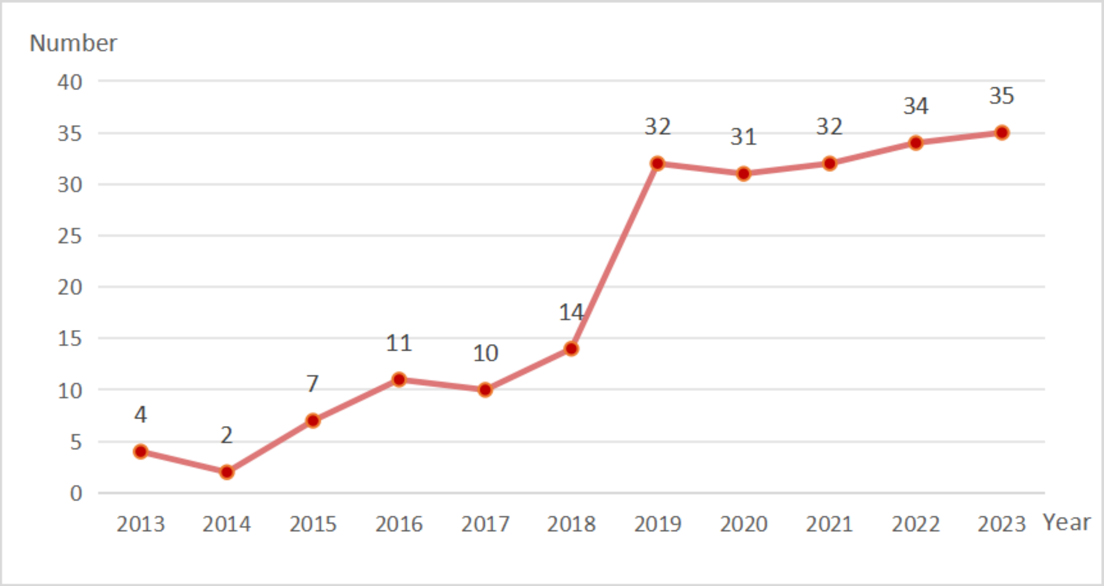
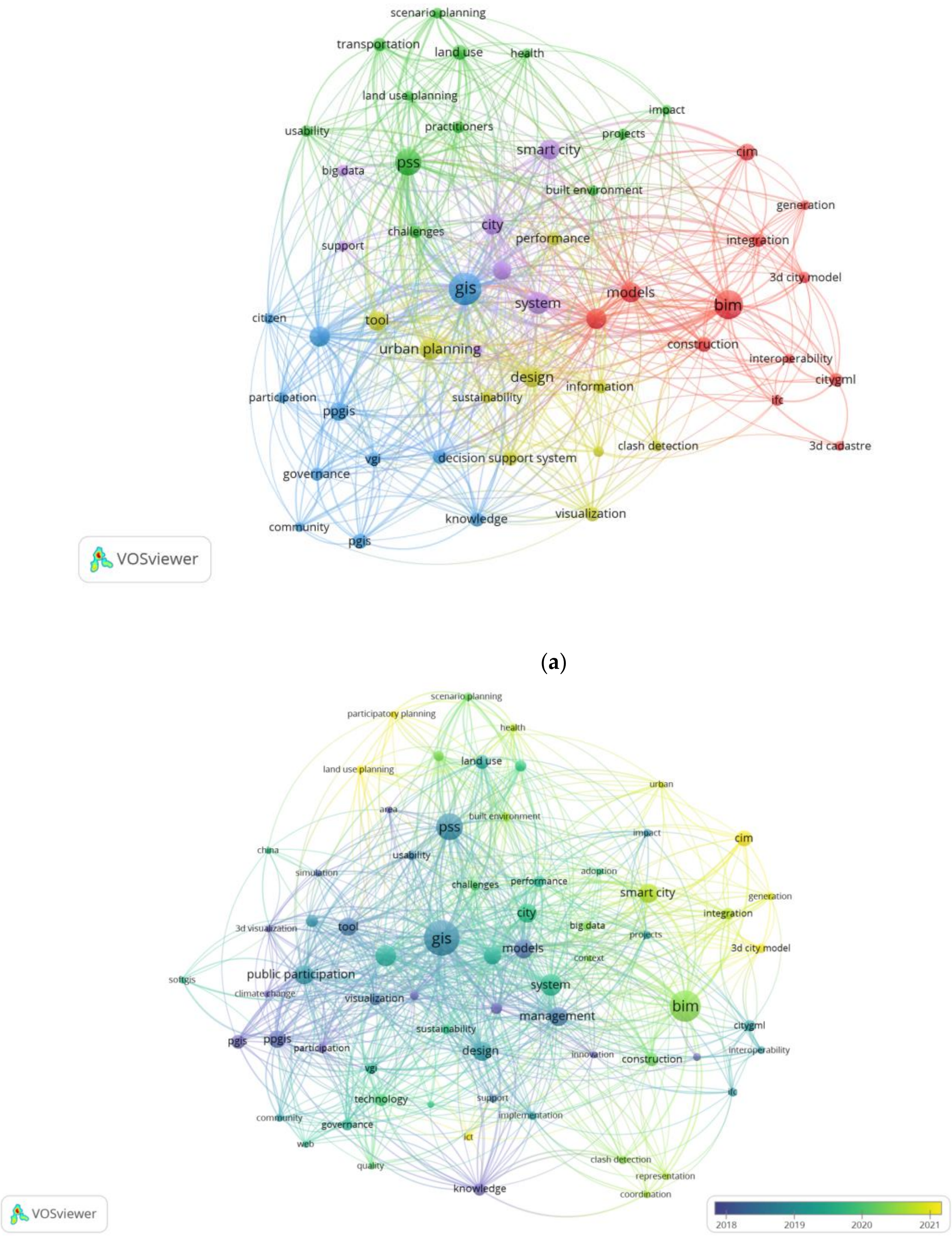


Figure 2. The number of publications from 2013 to 2023.

3.2. Keyword Analysis

Keyword co-occurrence network visualization of the core literature, conducted using the VOSviewer, involves preprocessing data for keywords with abbreviations such as “PSS”, “PGIS”, “BIM”, and “CIM”, along with synonyms. Keywords with a frequency of four or higher are selected for visualization. In Figure 3a, the network graph consists of 64 nodes and 816 edges. Different colors indicate different clusters, grouped into three major clusters: (1) BIM (marked in red), (2) PSS (in green), and (3) PGIS (in blue). Despite a limited presence of CIM-related papers that precluded the formation of a separate cluster, keywords associated with CIM are shown to intersect with “BIM”, “GIS”, and “3D city model” and to be relevant to applications for “smart cities”, “design”, and “urban planning”, among others. GIS emerges as a central node, intricately linked with all other clusters, underscoring its foundational role in urban governance. It serves as the bedrock upon which many subsequent technologies rely or integrate. As shown in Table 2, the core keywords for BIM primarily focus on its critical applications during the construction and management phases, particularly in conflict detection, multi-party coordination, and enhancing interoperability. Furthermore, there is a direct link between the keywords BIM and CIM, emphasizing the interwoven relationship between these two technologies. The PSS cluster reflects its functional attributes in simulation and scenario planning. Similarly, the PGIS cluster primarily highlights its nature of participatory planning. PPGIS is categorized within the PGIS cluster due to its shared goal of participatory planning. In fact, PPGIS serves as a broader umbrella under which many tools have been further developed [42]. Various PSS applications provide distinct support for specific planning tasks, with some focusing on analysis, modeling, and simulation of urban development. Conversely, PGIS is specifically designed to enhance participatory planning processes. Thus, to comprehend their unique roles, PSS and PGIS should be examined independently. Notably, the core technology keywords are interconnected with “big data”, underscoring the essential role of data support in contemporary geo-information technologies. This interconnectivity reflects the complex and symbiotic nature of the technologies that drive innovation in urban governance.



(**a**)

(**b**)

Figure 3. Keyword co-occurrence visualization (**a**) network visualization (**b**) overlay visualization.

Table 2. Keywords: main clusters and nodes.

Numbers	Clusters	Nodes
1	BIM	"integration", "interoperability", "management", "construction", "clash detection", "coordination", "IFC", "3D city model", "CIM", "CityGML", "generation", "3d cadastre", "models"
2	PSS	"scenario planning", "transportation", "land use planning", "land use", "practitioners", "usability", "challenges", "health", "built environment", "projects", "impact"
3	PGIS	"GIS", "PPGIS", "citizen", "participation", "vgi", "governance", "community", "knowledge"

Figure 3b presents a dynamic visualization of the temporal evolution of keywords, offering insights into the trajectory of geo-information technology development in urban governance. Figure 4 further illustrates the applications of these four key geo-information technologies in urban governance. Firstly, GIS undeniably stands out as the core technology spanning both past and present. Secondly, PGIS, which integrates GIS with participatory concepts, emerged as a significant advancement [43]. This early phase underscores the emphasis researchers placed on participatory planning processes. PPGIS specifically focuses on public participation in planning. Concurrently, with the robust development of GIS, PSS has emerged for urban planning purposes, engineered to provide planners with capabilities for data visualization, urban planning simulation, prediction, and multi-party communication and collaboration [44,45]. In contemporary construction engineering, research emphasis has migrated from traditional 2D modeling methods, such as CAD, to the adoption of 3D modeling. BIM acts as a shared repository that consolidates extensive digital information pertinent to the physical and functional characteristics of a construction project, epitomizing the trend of integrating industrialization with information technology within the construction sector [46]. Furthermore, CIM, an extension of 3D city modeling, has emerged as the latest focal point in urban planning, facilitating comprehensive synthesis of urban data and information across various sectors and domains. CIM integrates BIM and GIS to comprehensively capture the physical characteristics and related information of urban facilities. It not only efficiently stores and organizes complex data from multiple sources, but also serves as a powerful visualization tool [47,48].

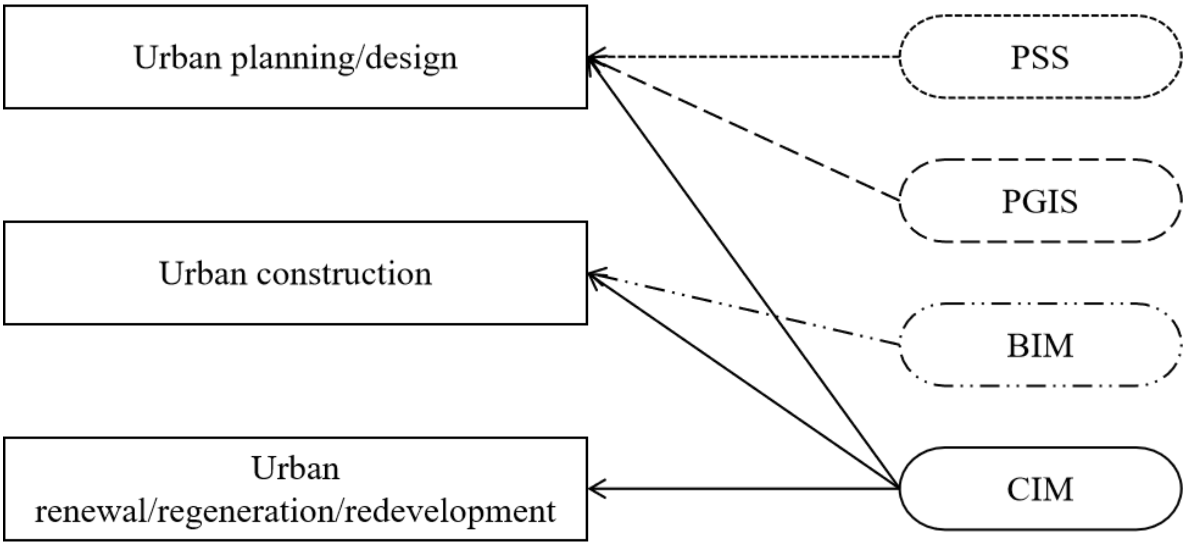


Figure 4. Main areas of application of geo-information technology.

3.3. Co-Author Analysis

The author co-occurrence network, comprising 55 nodes and 81 edges (Figure 5), presents different cooperative groups in various colors and exhibits a pattern of sparsity and dispersion, indicating the somewhat isolated development of geo-information technology within the context of urban governance. Within the PSS domain, author co-occurrence groups are concentrated in the Netherlands, Australia, Sweden, and Spain. These authors, primarily from disciplines such as geoscience, spatial planning, 3D geographic information, and digital media, form distinct clusters. This suggests a strong foundation of specialized knowledge and expertise in these groups, contributing significantly to advancing PSS applications in urban governance. In contrast, the author collaboration groups in the BIM domain are characterized by smaller, loosely connected networks of authors rather than focusing on specific research topics. This pattern may reflect the more technical and applied nature of BIM research, which often involves practical implementation and case-specific studies. The PGIS and CIM literature, on the other hand, shows a predominance of single-author contributions or small-scale collaborations, with a noticeable absence of larger, more tightly-knit collaboration groups. This may indicate a less established research community or a field still in the early stages of transdisciplinary integration. Analysis of the co-authorship network reveals a degree of isolation and fragmentation in the development of geo-information technologies within urban governance.

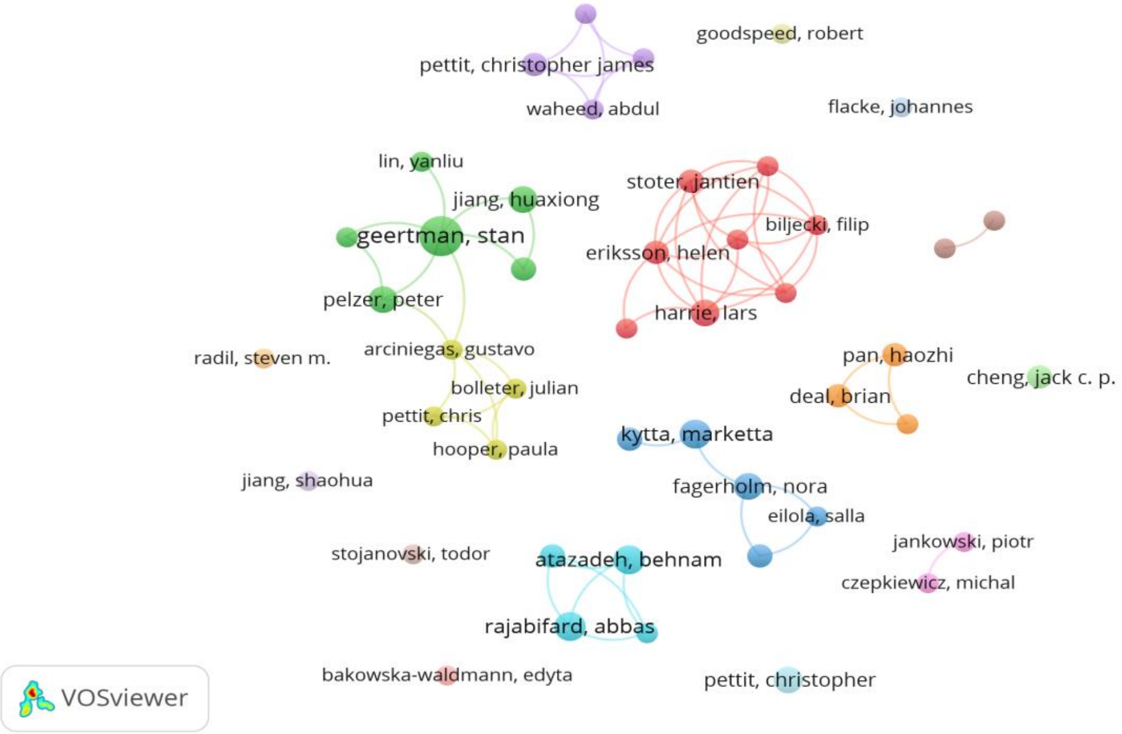
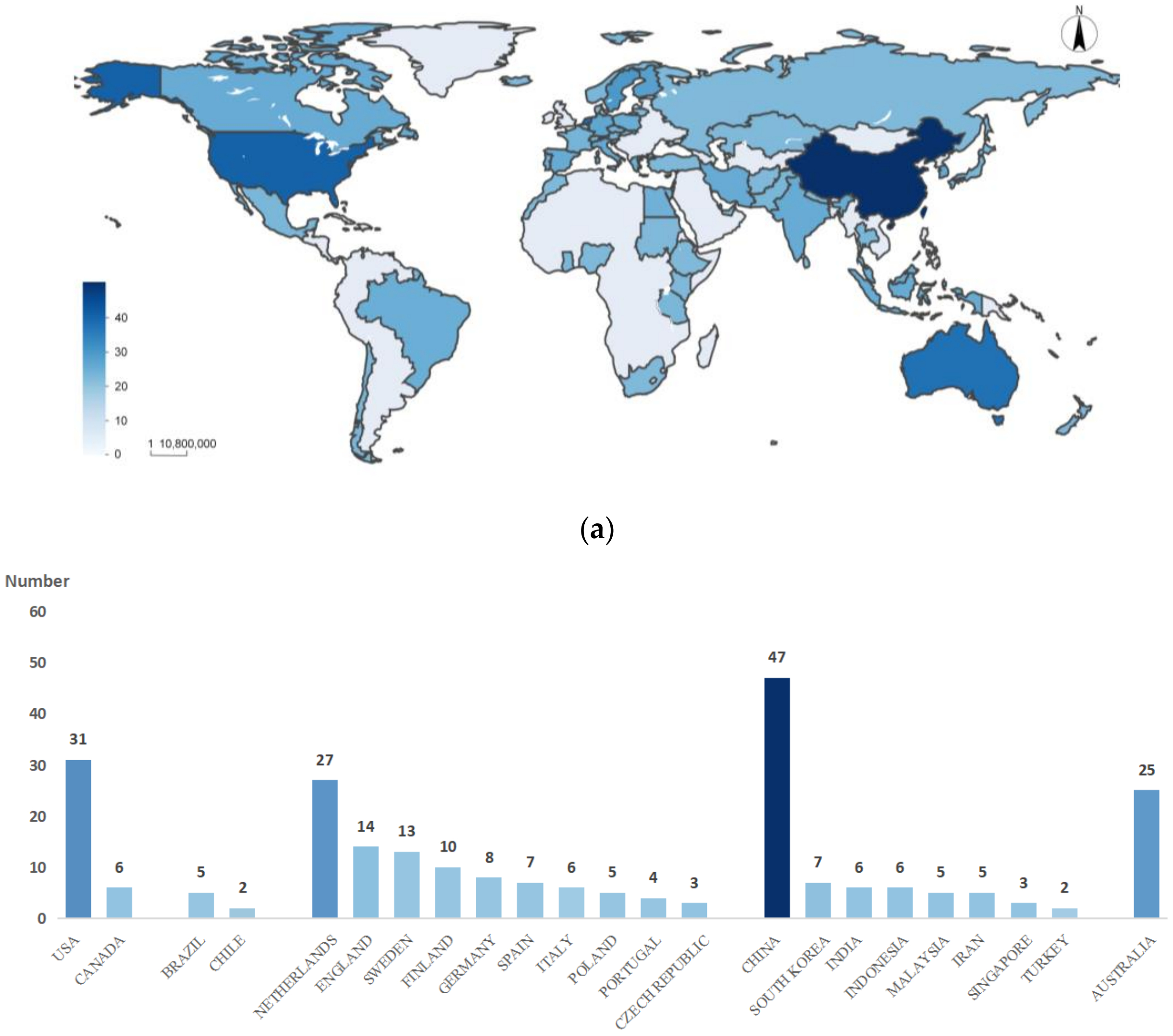


Figure 5. Co-authorship analysis network visualization.

3.4. Country Analysis

Figure 6a illustrates the differences in attention and research investment in geo-information technology in urban governance across different regions. The visualization indicates a significant concentration of research interest and activity in Asia, Europe, North America, and Australia. At the same time, areas such as South America and Africa exhibit a lesser degree of engagement in this field. A more detailed examination, as shown in Figure 6b, reveals specific insights into the distribution of research efforts across these regions. In Asia, China is identified as a leading force in relevant research. Other nations in the region, including South Korea, India, and Malaysia, also contribute to the discourse, though their research output is relatively smaller in comparison. In Europe, relevant research is evenly distributed, with the Netherlands emerging as the primary contributor of pertinent literature, followed by countries like the UK and Sweden. In North America, research is concentrated in the United States, with relatively low contributions from other countries. Additionally, Australia has been relatively active in research on geo-information technology in urban governance. This regional analysis underscores the uneven global distribution of research interest. It reflects the diverse priorities and resources allocated to this field across different parts of the world.



(**a**)

(**b**)

Figure 6. Distribution of surveyed literature in different countries. (**a**) Publish the distribution map. (**b**) Number of publications in different countries.

3.5. Literature Categories and Journals Analysis

According to Figure 7, the research areas concerning the role of geo-information technologies in urban governance span multiple disciplines, including engineering, environmental sciences, computer science, geography, public administration, urban studies, and architectural technology. This diversity underscores the complexity and multidisciplinary nature of urban governance, necessitating the integrated application of knowledge and methods from various fields. Transdisciplinary collaboration refers to cooperative effort among experts and stakeholders from different domains, including professional urban planners and architectural engineers, experts in computer science, and end-users like the public and government entities. This approach is crucial because it combines professional knowledge and technical expertise with practical insights and stakeholders' needs, thereby enhancing the overall effectiveness and efficiency of urban governance. A significant portion of the literature falls under categories such as "Environmental Studies", "Regional Urban Planning", and "Urban Studies", which highlight the application areas of geo-information technologies. Additionally, categories like "Geography", "Geography Physical", and "Remote Sensing" occupy prominent positions, highlighting the pivotal role of geographic information in the application of geo-information technologies in urban governance. Categories such as "Computer Science Transdisciplinary Applications" and "Geosciences Multidisciplinary" emphasize the transdisciplinary nature of the tools used, focusing on integrating computer science and geography. This indicates that the application of geo-information technologies in urban governance extends beyond traditional domains, intricately blending computer science with geographic information science. In summary, this transdisciplinary approach highlights the various fields and methods involved in applying geo-information technologies to urban governance, emphasizing the necessity of transdisciplinary collaboration to effectively address complex urban challenges.

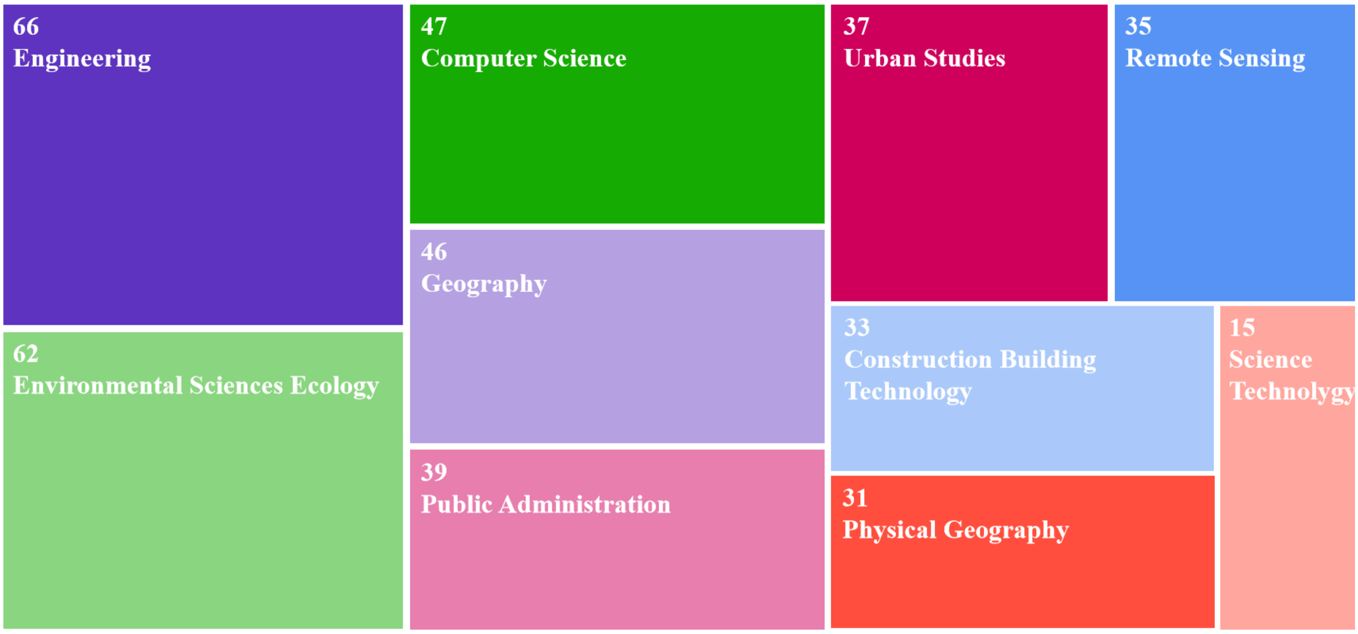


Figure 7. Distribution of surveyed literature in different disciplines.

Figure 8 presents a comprehensive overview of the distribution of surveyed literature across various academic journals. These journals cover multiple domains, with a particular emphasis on urban studies and those that intersect with it, such as geographic information science, computer science, and their related domains. Prominently, the ISPRS International Journal of Geo-Information stands out for its substantial contribution to the discourse, indicating a strong correlation between the application of information technologies in urban governance and the field of GIS and spatial analysis. Furthermore, the presence of journals such as Computers, Environment and Urban Systems and Automation in Construction, which are closely linked to the realms of computer science and automation, also exhibit a notable number of scholarly articles. This underscores the significant role that computational and automated technologies play in shaping the urban landscape and managing its spatial dimensions. The transdisciplinary approach to urban governance, as evidenced by the range of journals publishing research in this field, reflects the complex interplay between technology, urban development, and spatial management. This underscores the need for continued scholarly dialogue and cooperation across disciplines to fully harness the potential of geo-information technologies in urban governance.

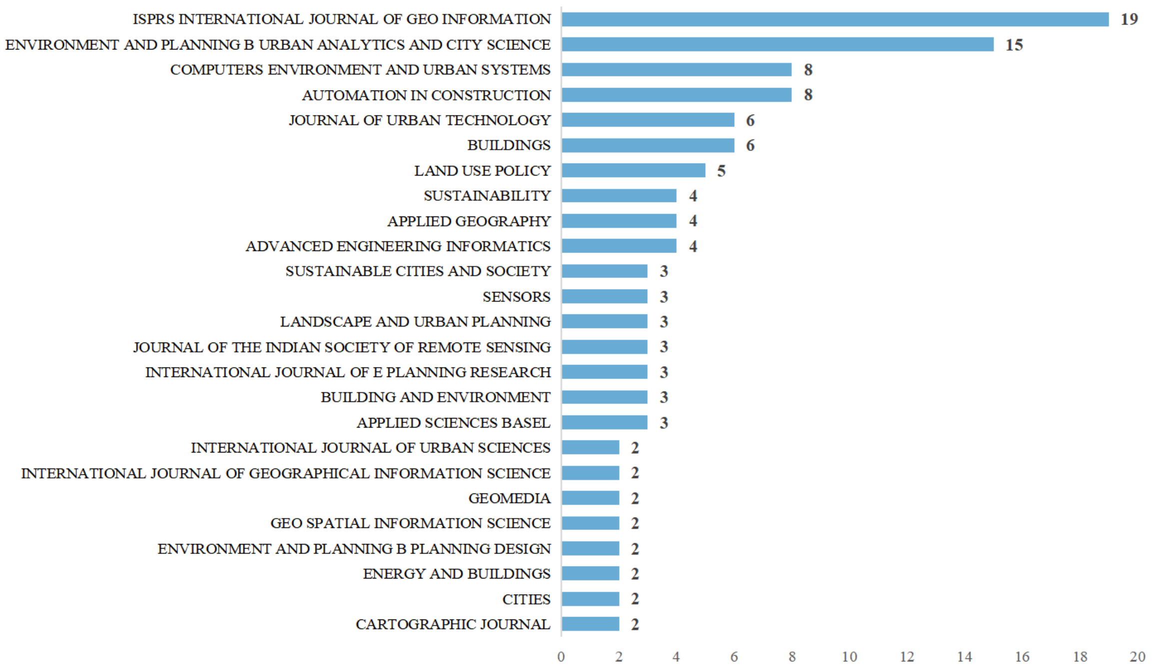


Figure 8. Distribution of surveyed literature in different Journals.

4. The Role and Challenges of Geo-Information Technologies in Urban Governance

4.1. PSSs: Simulation and Communication

At the close of the 20th century, PSSs were developed to support specific planning tasks [49,50]. In recent decades, PSSs have increasingly emerged as vital tools for supporting urban planning decisions and analyzing complex issues [51], continuing to garner widespread attention in the academic community. PSSs, based on GIS and planning models, offer functions like data visualization, simulation prediction, impact assessment, and multi-subject communication to improve planning efficiency and quality [44,45]. PSSs' visualization capabilities have been extensively utilized and highly commended by planners. PSSs encompass geographic, statistical, user, and modeling data, commonly transmitted using the CityGML standard [44]. PSSs excel in visualizing urban elements, including fundamental physical geographic features, land use, building layouts, transport networks, green and public spaces, and even population distribution and social data [44]. PSSs also effectively present data analysis outcomes, scenario simulations, and planning scenarios. As shown in Figure 9, PSS visualization has extended from 2D to 3D, incorporating virtual reality technology in recent years [52]. This evolution in functionality enhances planners' capacity to comprehend and communicate complex data and information, thereby providing robust support for informed planning decisions.

A substantial portion of PSSs are primarily used for simulation and prediction, with significant applications in Europe, the United States, and Australia. Utilizing urban spatial data and historical urban data, PSSs employ computer models and algorithms to simulate various urban scenarios under distinct planning conditions. PSSs empower planners to anticipate both short- and long-term consequences of different planning decisions, aiding them in formulating and selecting more rational planning scenarios [53]. Over decades of development, numerous mature models have been integrated into PSS practices. Table 3 illustrates the primary simulation and prediction functions of various PSSs. It is crucial to note that, in practical applications, the efficacy of PSS predictions heavily relies on the quality of data and models. For instance, the Southeastern Michigan Council of Governments (SEMCOG) found that UrbanSim's limitations in simulating human behavior led to inaccurate predictions [54]. Planners must exercise caution in evaluating data selection, making model choices, and conducting sensitivity analyses to understand the impact of model uncertainty on simulation results.

(a)

(b)

(c)

(d)

Figure 9. PSS visualization interfaces: (**a**) What If? [51], (**b**) ENVISION [51], (**c**) Urban Strategy 2D & 3D [55], and (**d**) Urban Strategy 3D [55].

Communicative PSSs, a sub-group of PSSs, facilitate multi-actor communication and are extensively used, especially in the Netherlands [56,57]. Interactive PSSs foster collaborative among planners and have been adopted by at least 15 planning organizations in the Netherlands [58,59]. Place-bound PSSs are face-to-face collaboration tools tailored to specific locations [60]. The MapTable PSS is a typical interactive place-bound tool [61]. Participants use printed maps or electronic screens for sketching activities with stickers and markers [62]. With the evolution of technology, interactive tools have become more informative, with the introduction of tablet-based tools [63]. Place-bound PSSs are common tools in planning workshops, facilitating face-to-face interaction among planners. For instance, Arciniegas et al. [64] utilized collaborative planning workshops to assess land use allocation issues in the Netherlands, employing a ‘Touch table’ and a spatial tool based on CommunityViz Scenario 360TM. Debnath et al. [65] demonstrated that PSSs can effectively support stakeholder collaboration in informing urban disaster resilience planning.

Table 3. The main PSS tools and their simulation prediction capabilities.

PSS Tools	Simulation Forecasting Function	References
Land-use Evolution and impact Assessment Model (LEAM)	Simulates land use evolution, population growth, and infrastructure needs.	[66]
What If?	Facilitates interactive user engagement and excels at comparing the impacts of multiple scenario planning proposals.	[67]
ENVISION	Weighted parameter scenario planning, emphasizing sustainability.	[68]
ENVISION Scenario Planner (ESP)	A web-based 3D visualization and assessment system that facilitates collaborative decision-making in urban infill development, supporting the preparation and exploration of redevelopment scenarios using 3D visualization and performance assessment techniques.	[69]

Table 3. *Cont.*

PSS Tools	Simulation Forecasting Function	References
ENVISION Tomorrow	Capable of conducting scenario planning assessments based on multiple indicators, primarily utilizing spreadsheets and GIS.	[70,71]
CommunityViz	Data analysis and scenario construction adaptable for transportation planning, natural resource planning, land development suitability evaluation, and urban economic development analysis.	[72]
UrbanSim	Integrated simulation planning model that comprehensively considers the interplay between land use, transportation, environmental quality, and economy.	[70,73]
Cube Land	Land use assessment, evaluating changes in urban policies and transportation investments.	[74]
CityEngine	Three-dimensional visualization of buildings, blocks, and cities.	[75]
Urban growth models (UGM)	Simulates and predicts changes in land use or cover, analyzing interactions in urban space.	[65]
Urban Strategy	Provides a wide range of computer models covering urban dynamics, from transportation to air quality and groundwater levels.	[57]

Despite technological advancements making PSSs more accessible, an implementation gap persists [51,76,77]. Planners are not sufficiently aware of the experience and potential of PSS use. Russo et al. [68] conducted a study of 35 planners from Australia, Italy, and Switzerland. They found that most planning professionals stated that they were not aware of the term PSS. On the one hand, PSSs cobbled together by geographic disciplines and software development companies do not seem to understand and meet the needs of planners and the public for planning aids [68]. Most currently available PSSs are complicated to use, such as UrbanSim, Metronamica [78], SLEUTH, and CommunityViz. From the planners' perspective, the lack of a user-friendly interface for PSS tools becomes a hindrance to use. There are several problems with current PSS tools, including the complexity of data entry, mismatch in tool use, and complexity in analyzing and presenting results. Firstly, most PSS software lacks built-in data preprocessing tools. For example, SLEUTH accepts input data in GIF image format. However, it requires the user to use an external tool to convert the input layers into a rasterized grid with the same extent, resolution, and geographic projection [79]. While UrbanSim data can be loaded into the simulation framework through the ORCA or Pandas data frameworks, which provide data connectivity modules to obtain data from multiple data sources, including HDF5 files, CSV and Excel files, DBF databases, etc., these data preparation mechanisms do not have a graphical user interface and require users to have the ability to use Python [80]. LandUse Scanner (Ruimtescanner) provides a framework for land use change modelling using GeoDMS as its modelling software to process, compute, and visualize datasets [81]. Nonetheless, there are also software programs such as Metronamica and Index and tools such as CommunityViz that have some form of inbuilt data preparation tools. Consequently, this heightened complexity in data conversion and preparation imposes limitations on user access, potentially undermining model accuracy and reliability. Secondly, data entry and processing in some PSS tools are often time-consuming. For example, the UAZ file conversion generated by the online What If? Tool must be in Shapefile format and loaded into the OWI tool, and the setup process will have to be restarted if the geometry of the project changes. In contrast, UrbanCanvas uses a cloud platform for computation, which is faster and more efficient than running open-source models locally. Overall, the problem of mismatch in tool usage is mainly because PSS is usually developed and experimented on by individuals with academic research backgrounds and geography professionals [82], resulting in the fact that most of the PSS tools are not user-friendly for those who lack a geography background, and that users need to spend a great deal of time learning about GIS. In contrast, ArcGIS's powerful toolkit can sometimes make them focus on finding GIS commands and geoprocessing tools at the expense of solving the planning problem at hand [83]. Finally, PSS analyses can yield valuable results, but not all users fully understand the results of PSS tools. As the process of analyzing PSS tools is often perceived as a "black box", the process is difficult to interpret and can be easily questioned regarding reliability. For example, when Urban Strategy was applied in Cartesiusdriehoek, the group evaluation pointed out its opacity in terms of the structure of the analyses, the models, and the calculation rules, and wished for a better understanding of how it works [55]. Zhang et al. [84] investigated the usability of the web-based PSS "Crowd Planning Wuhan", which was developed to support citizen participation in the Wuhan East Lake Greenway planning project. They found that this PSS provided new functionalities in eliciting ideas from citizens in the early stage of the planning process but required a high level of computer experience and domain knowledge, restricting its use to "professional citizens".

4.2. PGISs: Empowering Public Participation in Planning Decisions

In recent decades, public participation has become increasingly important in urban planning. PGISs, derived from GISs, enhance public participation in planning decisions compared to traditional GISs [43]. In the 1990s, PGISs were applied in various urban planning projects, including disaster risk assessment and mitigation, land use planning, natural resource management, and land and conflict resolution [85]. PGISs are interactive tools for experts and the public to share geo-information, exchange ideas, and foster a more inclusive planning process. Public participation in PGISs often uses markers and questionnaires on maps. PGIS map data helps confirm land use suitability, identify local value hotspots, and pinpoint potential conflicts.

Early PGISs relied on traditional, non-digital mapping and manual data collection. As technology advanced, map visualization evolved from traditional paper-based collaborative mapping, known as participatory mapping (PM), to methods utilizing high-resolution remote sensing images such as satellite, drone, and aerial images [86]. These new PGIS tools reduced labor-intensive and time-consuming manual georeferenced data acquisition, resulting in higher-quality spatial data for analysis and decision-making. For example, Yu et al. [87] used a virtual globe-based 3D GIS for rural public participation in Xiafan Village, Ningbo, China. The results indicated that 3D visualization provides a more intuitive experience. Similar to traditional PSSs, Geography Markup Language (GML) is commonly used for data exchange in PGIS. However, with the advent of internet technology, web-based PGISs have become more accessible and shareable [88,89]. This shift lowers the usage threshold and technical requirements for users, enabling more people to easily access and utilize geographic data, overcoming geographic and device limitations [90].

PGISs have been extensively studied and applied in Europe. PGISs place a strong emphasis on interaction, which plays a central role in facilitating the participatory planning process by enabling effective communication among stakeholders. PGISs have been widely utilized in various regions for urban planning and land management. They allow citizens to characterize their land tenure, use, and value through media such as paper, ground, or satellite imagery [38]. Additionally, the technology has been applied in regions such as Africa and Australia. For example, in peri-urban areas of northern Ghana, local people were trained to delineate land rights and land use through satellite imagery maps. This facilitated the land adjudication process of customary land and encouraged high levels of participation from the local community [38].

Public engagement in planning processes is facilitated through PPGIS, as evidenced by studies [91,92]. For instance, the Finnish government developed national PPGIS software, and Helsinki became the first city to use PPGIS in a city plan, collecting over 32,000 citizen observations in 2013 [93]. In Copenhagen, PPGIS engaged residents in mapping marginalized areas, revealing meaningful places and empowering communities to achieve more just outcomes [94]. PPGIS captured local spatial information from stakeholders, creating a spatial database with local characteristics. Planners can use this information to foster synergies among different stakeholders and promote convergence of interests [95]. In Australia, the web-based PPGIS for Parks Victoria allowed participants to map study area attributes using Google Maps [96]. In contrast, public participation in China's urban planning remains limited, adhering to the traditional top-down model. Public involvement is often confined to the public announcement stage. Despite recognizing the importance of public participation, existing tools like "Crowd Planning Wuhan" mainly cater to professional teams. However, these tools lack the anticipated online functionality for broader public participation, thereby limiting realization of effective and inclusive engagement in planning.

However, PGISs still have certain application limitations [97]. Firstly, the application of PGISs is constrained by factors such as regional availability of human resources, infrastructure conditions, and associated costs. In certain regions, the promotion and implementation of PGISs may be hindered due to inadequate human resources, suboptimal technical infrastructure, or financial limitations. Particularly, facilitating public participation often necessitates guidance and communication efforts, which may entail additional investments in human resources, hardware facilities, and technical support. Secondly, PGISs are resisted by some who believe that planning decisions should be made by specialized professionals [96]. They argue that public participation could introduce complications and delays in the decision-making process, potentially diminishing the quality and professionalism of planning initiatives. Public-contributed data is often subjective and may exhibit inconsistencies, leading to inaccuracies. Furthermore, public involvement may be influenced by personal biases and localized interests, compromising the objectivity and scientific rigor of planning decisions. Lastly, since the general public typically lacks geographic expertise, not all participants are proficient in understanding and creating participatory maps [98]. Moreover, operational challenges may arise during the application process, often requiring specialized operators for PGIS operation. To overcome the limitations of PGISs, simplicity and a low threshold should be emphasized. Zolkafli et al. [99] evaluated PGISs for land use planning in Malaysia, and the results showed that a simplified PGIS process produced higher quality spatial data. Therefore, relatively simple interactive PGISs are more likely to produce sound decisions compared to complex PGISs. In summary, PGIS, as a tool to promote participatory urban planning, not only facilitates the collection and analysis of data and information, but also promotes public participation in planning through interactive features such as participatory mapping, thereby playing a positive role in urban planning and governance.

4.3. BIM: 3D Building Models for the Planning and Implementation Phase

BIM stands as a cornerstone technology in the architecture, engineering, and construction (AEC) sectors, demonstrating substantial promise for urban construction. Originating in the late 1970s, BIM's broader integration into industry practices accelerated notably during the 1990s, driven by the evolution of computer hardware capabilities. BIM constitutes a shared database encompassing digital information about the physical and functional attributes of facilities (construction projects). This repository typically includes detailed geometric, descriptive, and spatial information, frequently utilizing standards like Industry Foundation Classes (IFCs) or Construction Operations Building information Exchange (COBie) to foster seamless data exchange and integration [46]. Throughout a construction project's lifecycle, BIM empowers stakeholders with functionalities such as 3D visualization, collision detection, and quantity calculation, facilitating informed decision-making and collaborative cooperation [100]. In urban governance, BIM is applied in the planning and execution phases of building or project scales.

BIM's 3D modeling, visualization, and collision detection offer robust solutions for coordination issues common in traditional 2D drafting [101,102]. Firstly, BIM's 3D modeling and visualization are recognized as the most mature and widely adopted functionalities [103]. BIM facilitates a comprehensive, multifaceted view of a structure's data and information, covering both physical and technical aspects throughout the entire lifecycle of a project. For instance, Faraji et al. [104] created a BIM-driven model to support the assessment of constructability in urban land regeneration projects in Tehran. Secondly, the collision detection and conflict resolution capabilities of BIM are highly effective in preventing coordination errors and play an essential role in fostering transdisciplinary collaboration, especially during the planning and execution phases [105]. Collision detection distinguishes between hard clashes, which pertain to the physical collision of internal building components, and soft clashes, which relate to the alignment of various regulatory standards. In the past, communication gaps and 2D design have been primary contributors to clashes, given the relative independence of designers from different disciplines. The amalgamation of drawings often exposes issues leading to unnecessary rework [106], particularly within MEP systems. BIM effectively addresses the limitations of traditional methods in terms of efficiency and automation [107,108], enabling early identification and mitigation of conflicts, which can lead to substantial savings in both time and resources. A case in point is a substantial hospital project where BIM-facilitated design coordination allowed stakeholders to identify and resolve over 2.4 million clashes before construction [109]. Chahrour et al. [110] simplified classification and cost estimation of collisions in BIM, forecasting savings of 20% of the contract value.

The BIM-based Quantity Takeoff (QTO) program is currently the most widely used model in the AEC sector. Calculating the bill of quantities is an essential component of construction projects [110]. Traditionally, estimators have relied on drawings and engineering cost standards for quantifying construction tasks, often employing Microsoft Excel. This manual process, which requires adjusting formulas and entering data, can be labor-intensive and prone to errors, especially when dealing with complex or irregular shapes that defy straightforward measurement. In contrast, generating bills of quantities through BIM models proves more efficient and accurate than traditional methods [111]. For instance, CostX enables the extraction of detailed quantity data from models, leading to more precise estimations of materials, labor, and costs, which is vital for optimal project management and financial oversight [39]. Moreover, some BIM design software incorporates built-in quantity estimation functions. Autodesk Revit, for example, allows the extraction of quantity estimation information from the building model [112]. With the generated bill of quantities, users can estimate costs by entering unit prices. Efficient bill of quantities calculation not only enhances project cost estimation but also provides more accurate material and volume information for construction waste management [113].

Urban-scale BIM application has propelled research on integrating BIM and GIS for urban studies [114,115]. Supported by standardized data exchange protocols such as CityGML and IFC, these systems form an interoperable link between individual buildings or projects and the broader urban context [116]. BIM–GIS integration enhances urban visualization, facilitates infrastructure planning, aids urban road construction, and supports building stock prediction. Fernandez-Alvarado et al. [117] demonstrated 3D urban modeling capabilities by integrating BIM with GIS and leveraging LiDAR data on Google Earth. Marzouk et al. [118] used BIM–GIS integration to plan and forecast utility infrastructure needs for urban extensions and emerging cities. Moreover, the advent of IoT-IBIM, an advanced iteration of BIM informed by the Internet of Things, has been highlighted in recent studies. This innovation embeds environmental data and IoT sensors into projects, fostering sustainable management for smart cities [119].

The application of BIM confers a multitude of benefits, with North America leading the way in its widespread adoption. Many Asian and European countries have also demonstrated notable advancements in the promotion and application of BIM. Although its inception was delayed, China’s BIM technology is experiencing swift growth, driven by robust policy backing, the formulation of all-encompassing BIM standards, and the successful deployment of sophisticated BIM applications within extensive projects [120]. However, slower adoption is observed in some small-scale projects. Despite growing interest from users and researchers, the application of BIM faces some challenges. One impediment stems from stakeholders’ inadequate proficiency and understanding of BIM technologies, hindering its use for communication and collaboration. Concurrently, BIM is confronted with interoperability challenges, as discrepancies during data exchange between diverse software applications and versions can engender considerable economic detriment. While IFC data standards have been adopted to address interoperability issues, they have not been fundamentally resolved. Muller et al. [121] evaluated the interoperability of BIM in the structural domain twice at five-year intervals in terms of four dimensions—Global Unique Identifier (GUID), spatial arrangement, geometric composition, and material properties—and found considerable improvements in interoperability. However, some major issues remain, such as overlapping of structural components. Taken together, although BIM has showcased numerous advantages in the implementation phase of urban planning and is extensively utilized at architectural and project scales, there remains a pressing need to actively promote its broader adoption across the industry, particularly in addressing urban challenges where BIM exhibits significant potential.

4.4. CIM: City Information Integration Database for Urban Governance

CIM was first introduced by Lachmi Khemlan in 2007 [122]. CIM was initially defined as the integration of BIM and GIS [47,123]. According to the Ministry of Housing and Urban-Rural Development (MOHURD), CIM is based on BIM, Digital Twin, GIS, and the IoT. It integrates multidimensional data, including aboveground, underground, indoor, outdoor, and temporal aspects of the city. It aims to represent city information in a 3D digital space, covering planning, construction, and management processes. CIM integrates BIM and GIS to form a seamless digital model, capturing the physical and informational aspects of urban facilities. This technology is invaluable for urban planning, construction, and redevelopment, offering an integrated methodology for managing urban infrastructure and operations. It is a visualization model that stores and organizes data from diverse sources [47,48].

The essence of CIM is its role as an all-encompassing database for urban information integration. Its establishment involves data collection, storage, standardization, and visualization [124]. CIM is distinguished by its transdisciplinary integration of spatial data models, including geometric, semantic, geographic, and urban information. The urban information component integrates various data types, including urban planning and regulatory data, engineering and construction project details, public thematic datasets, and IoT-derived sensory information [125]. The integration of diverse data is facilitated by industry-standard formats such as IFC and CityGML.

CIM development is still in its nascent stages globally. Exploring digital transformation through CIM is a prevalent trend, especially in developed countries like Finland, Japan, the UK, and France. These cities have introduced innovative possibilities for urban governance by integrating large-scale spatial data. For instance, since the 1980s, Helsinki has constructed a 3D city model with a visual reality grid and a semantic model. This model, open to the public, serves as a resource for advancing digital city construction. Similarly, Japan implemented “i-Urban Revitalization” (i-UR), a comprehensive initiative for urban planning [126]. This system enables the analysis and visualization of urban planning for Japanese government authorities. In the UK, the Lancaster City Information Model (LCIM) is one of the most extensive 3D open city datasets published from 2019–2021. LCIM addresses data inequality, providing architects, planners, and stakeholders with 3D models and urban analytics. Al Jurdi et al. [124] developed a CIM prototype integrating tangible and intangible datasets, providing visualization capabilities. Their work in Lille, France, highlights CIM’s potential in supporting planning through practical applications. CIM, as a large-scale database, can combine with other technologies to support urban carbon evaluation, building stock assessment, and asset management. Su et al. [127] used CIM with Dynamic Life Cycle Assessment (DLCA) to establish a regional carbon impact assessment model. They extracted geometric and semantic data from CIM. Harter et al. [128] used a CityGML-based 3D model for life cycle assessment of Munich’s building stock.

In addition, Lawal et al. [129] proposed a blockchain-based CIM for managing urban assets. This approach is characterized by its transparency, distribution, and immutability. They developed a framework for integrating heterogeneous CIM, utilizing multi-level nested data environments that combine BIM, GIS, and blockchain technologies. Several renowned foreign developers are creating tools for CIM, providing essential hardware support. For instance, ESRI is constructing 3D city maps in Hawaii and Portland, USA [130]. CIM models are visualized on Simstadt, a CityGML-based city simulation platform [131]. Autodesk has conducted case studies on urban 3D modeling in Copenhagen, Barcelona, and U-City in South Korea [132]. Cityzenith (Switzerland), CyberCity 3D (USA), and Agency9 (Sweden) have contributed to visualizing intelligent 3D city models. In summary, the application of CIM varies across countries, with different degrees of implementation. However, CIM has garnered significant attention and demonstrated active exploration and practical application. Notably, most CIM applications are initiated by cities, highlighting the initiative and innovation of city managers in digital transformation. In September 2020, the China Housing and Urban Renewal Authority (CHRA) unveiled the "Technical Guidelines for the Basic Platform for City Information Modeling", providing essential recommendations for the foundational framework of CIM platforms. Cities across China are proactively establishing their distinctive local CIM models, with a particular focus on first- and second-tier cities. Leading cities in CIM application include Guangzhou, Beijing, Nanjing, and Xiamen. China's domestic CIM platforms actively integrate vast city-related data. This includes white and fine BIM models of urban buildings, topographic and geomorphological data, planning results, energy consumption, population, and IoT-related data like surveillance video and smoke sensors [125]. For instance, the Guangzhou CIM platform includes 7434 km^2 of survey data, 3D topography, white and fine BIM models, and public security cameras. This integration of diverse data enables exploration of CIM applications in urban governance. Currently, CIM platforms in China are mainly used for construction project approval and urban renewal. The application in project approval involves 3D digital reviews of BIM declarations. Although planning review on CIM platforms is not fully realized, reviews of design schemes, construction drawings, and acceptance filings have gradually been implemented. By the end of 2021, Guangzhou's 3D digital review system, launched in October 2020, had processed 393 BIM projects involving 231 construction units, 173 design units, and 21 reviewing organizations [133]. CIM combined with urban renewal, known as CIM + Urban Renewal, incorporates data collection, economic measurement, quantity measurement, site plan, and 3D urban regeneration [134]. Currently, the CIM platform for urban renewal in Guangzhou empowers the renewal and transformation of Jinzhou and Chongwei villages in Nansha District [135]. This mainly aids renewal planning, though communication with stakeholders could improve.

Despite the prominent functional position assigned to the CIM in the existing literature, practical application does not entirely align with its asserted capabilities. Presently, CIM is in a pre-exploratory stage, functioning primarily as an integrated city database aimed at providing rich data for urban governance across various fields. However, there are notable challenges and limitations hindering the full development of CIM. Firstly, the diverse nature of the data involved in CIM necessitates addressing the issue of synergy and integration across multiple disciplinary fields. The underlying data formats originate from BIM, GIS, and IoT, each with relatively independent structures and lacking a unified data expression framework [136]. Secondly, the sensitiveness of CIM data presents an obstacle, as the right to use these data remains primarily within the purview of the government. The absence of well-defined access mechanisms and channels for social entities to collaborate with the platform restricts the comprehensive application of CIM in actual governance. Lastly, the current development of CIM is limited in terms of application scenarios, focusing on integrating collectible data into a unified platform. However, it falls short of realizing the full potential of data utilization. In summary, future development efforts should aim to overcome these existing limitations to achieve a more comprehensive application of CIM in governance.

4.5. Challenges and Strategic Responses

Based on in-depth analysis, core geo-information technologies have been confirmed as functional and effective in urban governance. However, significant challenges also exist in application. The application of geo-information technologies in urban governance often shows a disconnect between the tools' functional support and users' actual needs. The evolution of these tools typically demands transdisciplinary collaboration, involving developers who are often experts in GIS or computer science. These developers are proficient in software development but may lack expertise in the urban governance area. Conversely, users of these tools are usually professionals in urban governance, including government roles or public representation. The disparity between the technical developers and end-users may lead to communication and comprehension challenges, ultimately resulting in tools that fail to align with the diverse needs of users. This persistent disconnection signifies an enduring gap between the software crafted by tool developers and the specific requirements of end-users.

In order to overcome the current mismatch between supply and demand for geo-information technologies and create a truly effective tool for urban governance, corresponding measures and strategies need to be adopted. Firstly, transdisciplinary cooperation is vital, as it not only fosters collaboration across various academic disciplines, including urban planning, social sciences, and human–computer interaction, but also emphasizes the synergy between experts, stakeholders, and the public. By integrating these diverse fields of knowledge with geo-information technologies, we can achieve a more comprehensive and integrated approach to knowledge exchange and address complex societal challenges. The development team of the tool needs not only professionals who are proficient in computer software development, but also experts in the field of urban space, who need to work closely together to ensure that the design and development of the tool are professional and truly meet the diversified needs of users. In particular, there is no need for users to have different needs for urban governance tools. Therefore, it is important to ensure that there is feedback and input from a variety of users, such as planners, government administrators, the public, NGOs, etc., to ensure that the design and functionality of the tool are appropriate to the application and meet the needs of the different users. The development of geo-information technologies should integrate multiple disciplines. For example, technical developers, such as GIS specialists, computer scientists, and software developers, could provide technical implementation and tool development. Additionally, urban governance experts should play a role in guiding functional design to better align with needs. Moreover, user representatives, comprising government officials and public stakeholders, offer feedback and requirements based on actual usage. By integrating these diverse perspectives, the development process can ensure that the technologies are both technically robust and practically applicable. Certain foundations and conditions are required to achieve the integration of multiple disciplines. Firstly, it is crucial to establish various communication and collaboration channels to foster open exchanges and active cooperation across different disciplinary fields. For instance, developing advanced digital communication platforms and encouraging direct face-to-face interactions can help break down disciplinary barriers and enhance deeper knowledge sharing. Additionally, the key to successfully implementing a project is providing the necessary support resources. This includes securing sufficient funding, ensuring adequate time allocation, and offering reliable technical support. These elements are essential for facilitating transdisciplinary collaboration and ensuring the successful execution of projects. Secondly, the government plays a crucial role in this, and it needs to establish and improve appropriate policies and be able to provide internal data. In conclusion, a better transdisciplinary cooperation mechanism needs to be established, feedback from various users' needs to be actively met, and continuous improvements and innovations need to be made in order to create an effective urban governance tool that better matches functions and needs and supports the smart and digital transformation of urban governance.

5. Discussion and Conclusions

This study offers a comprehensive analysis of core geo-information technologies, including PSSs, PGISs, BIM, and CIM, within the domain of urban governance. The examination of 219 pertinent literature sources reveals that information technologies confer substantial advantages in spatial planning, construction, and urban governance renewal.

(1) Collectively, these information technologies offer significant advantages in data storage and visualization. PSSs, PGISs, BIM, and CIM each have unique and complementary strengths in data storage. PSSs provide detailed spatial planning data for planners [44]. PGISs leverage public input to offer locally unique spatial information for urban planning [56]. BIM consolidates spatial information during the construction phase, providing detailed building or project-level data [100]. Finally, CIM integrates urban data from various fields, offering city managers comprehensive data support [47]. Furthermore, the high visualization capability enhances the interpretability and utility of these data. In practical terms, these two advantages synergize, enabling city managers and planners to better comprehend and utilize urban spatial data.

(2) Both PGISs and PSSs are widely used in GIS-based spatial planning. While both emphasize participation and cooperation, they exhibit similarities and differences in their specific applications and functions. PSSs primarily support urban planners, enhancing planning efficiency and quality, with a focus on simulating and forecasting different scenarios [50]. However, only some PSSs support public participation [97]. In contrast, PGISs are inherently designed to encourage public involvement [85]. The accessibility of PGISs makes them particularly effective in fostering community engagement, driving community development, and improving the urban environment.

(3) BIM and CIM focus on 3D physical models and semantic information. BIM is primarily used during the construction phase, focusing on detailed building or project-level modeling [102]. Its application centers around collaborative efforts between the building team and relevant stakeholders, ensuring the efficient execution of the design and construction process. In contrast, CIM, managed by the government, serves as a repository for urban data, focusing on the holistic nature of the city. While CIM integrates some BIM data from a building or project, the overall level of detail is lower than that of BIM. It encompasses various city-related types of information like transport, environment, and energy, supporting cross-disciplinary urban planning. CIM helps planners understand the city's operation, challenges, and development potential.

However, the application of geo-information technology in urban governance faces challenges, primarily due to a mismatch between tool functionality and user needs. Developers are often technically proficient but lack expertise in urban governance, while users require highly practical tools. Additionally, stakeholders lack interdisciplinary collaboration. Therefore, we urgently need an effective tool for the governance of urban space. As shown in Figure 10, firstly, the data information used needs to be authoritative and accurate, and the source of the data credible, to provide a solid and reliable basis for urban space governance and decision-making. Secondly, the tool should have the ability to visualize and simulate analysis, presenting complex data information and analysis results in a visual way, which is more helpful for users to understand and analyze. At the same time, users can simulate different scenarios and decisions to better predict results. In addition, the tools must be interactive and have user-friendly functional interfaces so that non-professional users can easily use them without the need to have professional knowledge, which will promote wider participation and decision-making and help experts in various fields and the public to participate in urban governance. At the same time, multi-user collaboration is supported so that users with different expertise can communicate and collaborate on the same platform and share resources. Finally, lightweight tools can not only adapt to the complexity of cities of different sizes and resource conditions, making urban governance more flexible and efficient, but also reduce the hardware requirements for computing and storage resources. In addition, lightweight tools enable cross-platform compatibility, allowing users to use them on a variety of device platforms without the need for stringent hardware conditions, thus making it easier to participate in the process of urban governance. In summary, effective urban governance tools should have authoritative and accurate data information, have strong visualization, simulation, analysis, and interaction capabilities, and be lightweight.

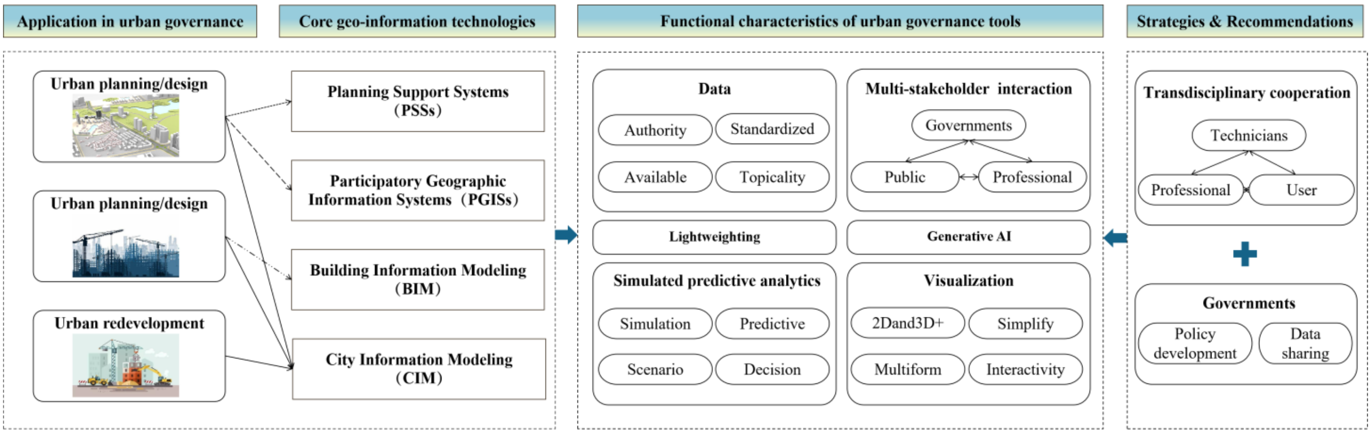


Figure 10. Applications and future of geo-information technologies in urban governance.

It is worth noting that, with the rapid development of Artificial Intelligence (AI) in recent years, the application of AI technology in urban governance has gained widespread attention. AI is capable of executing various complicated tasks, including perception, cognition, learning, decision-making, and communication. In particular, generative AI refers to the capability not only to analyze existing data but also to generate new, meaningful instances from the training data, such as content in the form of text, images, or audio [137]. In recent years, AI-assisted planning has also gradually entered the vision of planners. Compared with existing geo-information technologies tools, AI can handle a much larger amount of information, including data on urban traffic, environment, population, etc., and achieve more accurate predictions of land use, energy consumption, light conditions, climate, and economic simulation. AI can quickly generate diverse scenarios in line with the design planning and the needs of all parties, thus providing more accurate and scientific urban planning advice and intelligent decision support. Furthermore, the potential for improving user interfaces through AI should not be overlooked. By leveraging AI to create more intuitive and interactive interfaces, the usability of planning tools can be significantly enhanced. For users, the user interface will be simpler, more convenient, and visualized, with a lower threshold for learning and use. In the light of future prospects, with the further evolution of AI technology, its application in urban governance will continue to grow, providing more comprehensive and innovative solutions and programs for creating smarter and sustainable urban governance.

This study systematically analyzed and summarized the key information technologies applied to the field of urban governance through a review of the relevant literature, revealed the problems and challenges in their application, and provides a future outlook. This study also has some limitations, which are mainly reflected in the fact that the literature mainly comes from a single database and is selected from the last decade, so some relevant literature may not be included. Future research can further explore how to develop better tools for application in urban governance and how to promote transdisciplinary cooperation better, as only through effective cooperation between professionals in different fields can the potential of various information technologies be fully utilized.

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