

Integration of Spatial Data Infrastructures in Smart City Development: A Review

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ABSTRACT

Spatial Data Infrastructure (SDI) has become important in developing Smart Cities initiatives to incorporate different types of spatial data, sensors, and technologies to optimise services for residents, via leveraging technological advancements across various fields. SDI support the to enable spatial data availability and access. However, integrating SDI into smart city development faces challenges due to a lack of standardized practices, technical interoperability issues, and diverse data governance policies among cities. These challenges hinder policymakers from effectively using spatial data to enhance urban services and sustainability. To address these issues, a comprehensive review is needed to propose strategies for the successful integration of SDIs into smart city initiatives. This study aims to review current developments in SDI integration within Smart City initiatives, identify key areas of focus, and suggest future directions for improvement. This study uses comparative analysis to synthesize the issues, challenges, findings, and future directions in integrating SDI-Smart Cities initiatives. The review identifies issues related to spatial data integration, technology compatibility, data management, metadata analysis, and institutional frameworks. Improvements in integrating SDI-Smart City initiatives can be directed towards spatial data integration, technological advancements, and institutional reforms. This study highlights the importance of SDI integration in Smart City development by providing a robust spatial data foundation, contributing to sustainable urban growth.

Keywords: Spatial Data Infrastructures; SDI; Smart City; SDI integration; SDI and Smart City; spatial data sharing

INTRODUCTION

The rapid development of smart cities has necessitated the integration of advanced technologies and data-driven approaches to enhance urban living and sustainability (Halegoua 2020a). One of the key components in this evolution is the incorporation of Spatial Data Infrastructures (SDI), which provide a framework for spatial data sharing and management (Rabelo et al. 2017a). SDI enable smart cities to leverage Geographic Information Systems (GIS) and other spatial technologies for efficient urban planning, resource management, and decision-making (Chaturvedi et al. 2018a).

The Smart City Initiative is a global movement that aims to leverage technology and data to improve the quality of life for citizens, enhance sustainability, and drive economic growth (Halegoua 2020b). The goal of the initiative is to create cities that are more efficient, resilient, and responsive to the needs of their inhabitants (Lacinák

& Ristvej 2017; Ristvej et al. 2020). Smart City also knowns as a systematic integration of technological infrastructures that relies on advanced data processing, with the goals of making city governance more efficient, citizens happier, businesses more prosperous and the environment more sustainable (Yin et al. 2015).

A Smart City utilizes advanced technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and big data analytics to optimize the delivery of public services and improve the overall urban experience (Silva et al. 2018). This includes a wide range of areas such as transportation, energy, water management, waste management, public safety, and healthcare (Halegoua 2020b; Mohamed & Alosman 2024).

The concept of smart cities is gaining traction due to the rapid urbanization and the challenges that come with it such as congestion, pollution, and resource scarcity (Halegoua, 2020b; HamaMurad & Jusoh, 2022; Yin et al. 2015). The initiative is being pursued by governments,

urban planners, private sector organizations, and citizens all around the world.

The ultimate goal of the Smart City Initiative is to create sustainable, liveable, and resilient urban environments that provide a high quality of life for citizens while also driving economic growth and development (Halegoua 2020b).

Smart City rely heavily on the availability and accessibility of Spatial Data Infrastructure (SDI) (Rabelo et al. 2017b; Roche 2014). SDI refers to a framework of policies, standards, data, and technologies that facilitate the sharing and use of geospatial information (Rajabifard & Williamson 2002). Spatial information includes data related to the location and attributes of physical features such as buildings, roads, and public spaces, as well as data related to social, economic, and environmental factors (Bernhardsen 2002).

SDI enables Smart City to collect, analyse, and visualize spatial data related to various urban systems and services, such as transportation, energy, water, and waste management (Roche 2014). With the use of SDI, smart cities can create geospatial models that integrate and analyse this data to identify patterns, trends, and insights that can inform decision-making and policy development.

Despite the potential benefits of integrating Spatial Data Infrastructures (SDIs) into smart city development, there are significant challenges and gaps that hinder effective implementation. The lack of standardized practices, technical interoperability issues, and varying data governance policies across different cities create barriers to the seamless integration of SDIs. This hinders the ability policymakers to utilize spatial data efficiently for enhancing urban services and sustainability. A comprehensive review is needed to address these challenges and provide strategies for successfully integrating SDIs in smart city initiatives.

This study aims to review the current development on integration of SDI in Smart City initiatives, understanding and identifying the key focus in these studies, and finding future directions in improving SDI integration in Smart City development.

This review using comparative analysis to differentiate and synthesis the gaps, issues, findings, and methods used in previous studies. This review also focused on the recent publications, starting 2017 until 2024, and considering the paper availability and the language used.

This review started with literature on the background on smart cities development, followed by discussions on previous studies on SDI implementation in smart cities development, and thorough discussions on the issues, gaps, and future directions for SDI integration in smart cities development.

LITERATURE REVIEW

The literature on SDI integration in smart city development is extensive and reflects a growing recognition of the importance of spatial data in urban management. Early research focused on the technological advancements and components of smart cities, including sensor networks and data platforms. However, recent studies emphasize the integration of these technologies within a cohesive spatial data framework. This shift underscores the necessity of aligning SDIs with smart city objectives to harness the full potential of urban data.

This literature review aims to explore the intersection of SDI and smart city development by examining the evolution of both concepts and their interrelationship. The review will cover the foundational principles of smart city development, the role of SDIs in supporting smart city initiatives, and the challenges and opportunities that arise from their integration. By analysing key research findings and theoretical perspectives, this review seeks to provide a comprehensive understanding of how SDIs contribute to the effectiveness and sustainability of smart city projects.

SMART CITIES DEVELOPMENT

The idea of Smart City has started in 1990s, with various definition and characteristics has been defined (Shayan et al. 2020). Rabela et al. (2017) define Smart City as an initiative to align technology and sustainable development, where the Open Geospatial Consortium (OGC) defines a smart city as “the integration of physical, digital, and human systems to develop urban areas aiming to create a more prosperous, sustainable, and inclusive future” (Percivall et al. 2015). Smart City utilizing and systematically integrating the digital and technological infrastructure, various type of data, and ubiquitous computing in foster efficiency in city management and governance, towards improving urban resident’s quality of life (Halegoua 2020b; Yin et al. 2015).

Throughout the years, a number of other cities around the world began to explore the potential of Smart City design and implementation, with Masdar City project in Abu Dhabi launched in 2008, followed by European Union launched the Smart Cities and Communities initiative, and then followed by United States in 2011 (Shayan et al. 2020). These initiatives aimed towards zero-carbon, sustainable city, and using cutting edge technologies to reduce energy consumption, carbon emissions, improve transportation, reduce congestion, etc (Lacinák & Ristvej 2017).

The concepts of Smart City also have been evolved, with different characteristics, factors, concepts, dimensions,

goals, and forces has been developed and proposed (Figure 1) (HamaMurad & Jusoh 2022). However, all these studies still focusing in improving the current state of Smart City development, into a better integrated, adaptable towards technologies in managing and governs the city area.

Anthopoulos (2017) proposed 7 main components of Smart City; smart infrastructure, smart transportation, smart environment, smart services, smart governance, smart people, and smart economy (Anthopoulos 2017). All these components need to be interconnected, and required data collection, good ICT infrastructures, to address and deliver smart services, that have actors and governances (Figure 2).

However, HamaMurad and Jusoh (2022) has further studied previous Smart City initiatives, and have identified, discussed, and formulated four keys dimension of Smart City; Social Infrastructure, Information Infrastructure, Physical Infrastructure, and Open Government. These key dimensions are incorporated with functions such as Intelligent City, Digital City, Live City, and Open City (Figure 3). These dimensions also aligned with the

dimensions from previous studies, only being rearrange to support the factors in Smart City development.

Overall, the evolutions of the smart city initiative show the potential for technology to improve urban life, but also highlights the need for careful planning and consideration of the potential risks and challenges involved.

However, the concepts and implementations of Smart Cities also faces some challenges, including concerns about privacy and data security, as well as issues related to equity and access. Besides that, Smart City also need to cater the issues with spatial data, especially on spatial data quality, format, interoperability, and data sources. Governance and administration in Smart City (also known as Smart Governance) also facing challenges, especially in cooperation and collaboration within and between organizations and personnels. Besides that, the vast and rapid technological development also facing difficulties in the integration of data from various sensors or the latest equipment, with technologies that slightly behind the latest one.



FIGURE 1. Summary of chronology on Smart City framework development (HamaMurad & Jusoh 2022).



FIGURE 2. Smart City Conceptual System (Anthopoulos 2017).

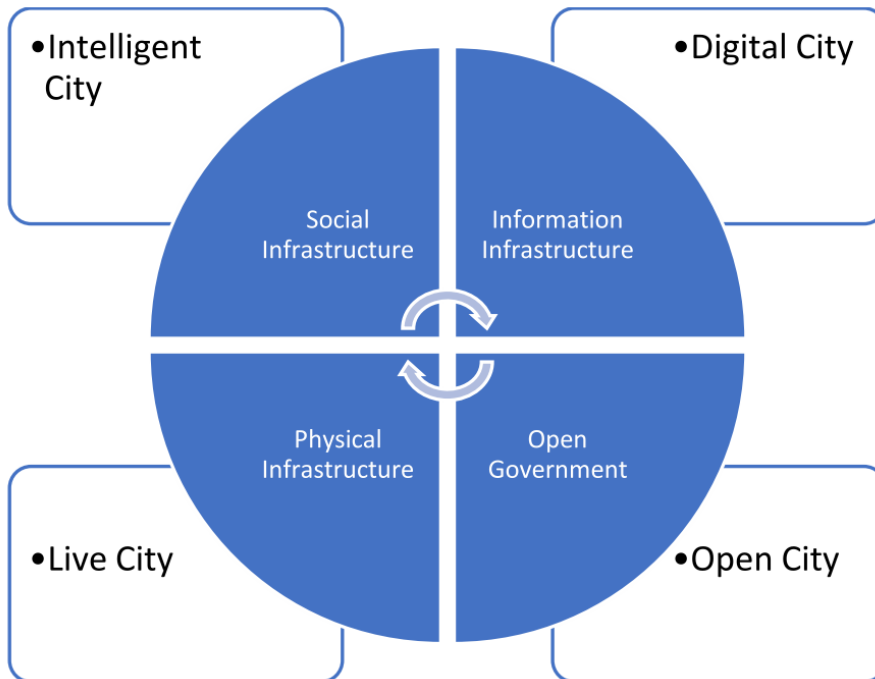


FIGURE 3. Smart City functions; four key dimensions (HamaMurad & Jusoh, 2022).

As a result, the Smart City movement continues to evolve, with cities around the world experimenting with different approaches and solutions to address these challenges. One of the movements in improving these challenges, is via integrating Smart City initiatives, with SDI.

SDI is critical for Smart City planning as it allows for the integration and analysis of diverse data sources, such as satellite imagery, geospatial data, and sensor data, to support evidence-based decision making.

For example, a Smart City might use SDI to create a real-time traffic management system that integrates data from sensors, cameras, and other sources to optimize traffic flow and reduce congestion. Similarly, SDI can be used to create a smart grid system that uses spatial data to monitor and manage energy consumption across the city. SDI can help address these issues by facilitating the integration and analysis of diverse data sources, enabling evidence-based decision making, and supporting the development of innovative solutions for sustainable and inclusive urban development.

SDI is also critical for citizen engagement and participation in the Smart City initiative. By making geospatial information accessible to citizens through online portals and other tools, SDI can enable citizens to better understand the city's systems and services, provide feedback and suggestions, and even participate in co-creation of Smart City solutions. SDI is a critical component of the Smart City initiative, providing the foundation for the collection, analysis, and visualization of spatial information that is essential for creating sustainable, liveable, and resilient urban environments.

PREVIOUS STUDIES ON INTEGRATION OF SDI WITH SMART CITY INITIATIVES

One of the main focuses in Smart City development is data, especially in spatial data integration (Roche 2014). Advance implementation of Smart City initiative required data from various sources, sensor, technologies, and stakeholders (Nagaraja et al. 2020). To support the capabilities and interoperability of various spatial data format, SDI integration is an important aspect to be discover in Smart City initiatives.

Several studies on integration of SDI in Smart City initiatives have been developed. The development of SDI integration with Smart City initiatives can be grouped into 3 main aspects; spatial data integration, technologies advancement, and institutional reform.

SPATIAL DATA INTEGRATION

Spatial data integration is one of the importance aspects in integrating SDI in Smart City initiative. Smart City initiative required various type of data, including spatial and non-spatial data, data from various type of sensor, and from different systems (Ghosh & Mukherjee 2022; Hoang et al. 2022; Iban & Aksu 2020; Moshrefzadeh et al. 2017; Nagaraja et al. 2020).

One of the studies is by Moshrefzadeh et al. (2017), that aims to proposed a conceptual framework for smart data infrastructure developed for Smart District from five viewpoint (Enterprise, Information, Engineering, Computational, and Technology Viewpoint), known as Smart District Data Infrastructure (SDDI). The issues highlighted in this study is the data that have been used in the Smart and Sustainable Districts (SSD) implementation were not interoperable between different SSD's stakeholders, such as owners, administration, services owner and providers, and also citizens (Moshrefzadeh et al. 2017). This led to the urgent need of a platform that provides links to various data sources, but the same time reliable, interoperable, and available. SDDI consists of 4 components: Actors, Application, Urban Analytics Toolkit, Virtual District Model, and Sensor. Other improvement suggested is to institutionalize data maintenance, and ICT sustainability (hardware, software, and network infrastructure).

Besides that, Iban and Aksu (2020) have implemented a study that aims to create a conceptual model for big-rural spatial infrastructure to support Turkish land management agenda, especially rural land use. The issues highlighted in this study are data not integrated vertically and horizontally, the relationship between data and data users are not dynamic, not shared common language toward integration and interoperability, and data flow and capabilities cannot support various type of sensor (Iban & Aksu 2020). This model using Unified Modelling Language (UML) to shows the syntactic and semantic framework. The main component of this model is *RuralParcel* feature type, with 4 sub-features which is Agricultural lands, Meadowlands, Forest lands, and Sensor data. This conceptual model merges the management of rural lands, and has architecture to support international data exchange.

Hoang et al. (2022) also highlighted issue on the importance of large education campus to manage devices, buildings, and assets to manage and monitor various systems that related to Smart City concept. To handle these issues, this study aims to proposed an architecture of smart campus that based on SDI and distributed ontology, to integrated two groups of IT system (Hoang et al. 2022). This architecture consists of 2 layers: the theoretical and

conceptual layer (including 3 foundations: Distributed Ontology, SOA, and SDI), and technological layer (divided into non-spatial system and spatial systems). This architecture enable connection between spatial and non-spatial systems, using distributed ontology, SDI and Service-Oriented Architecture (SOA) based approach to link spatial objects and their features.

Another initiative has been implemented is by Ghosh and Mukhrjee (2020), that focus on issues related to information of resources to cater pandemic Covid-19, including the facilities such as health facilities, transportation etc., the information of COVID-19 infection and it's spreading, and also information about patients (health status, mobility, etc.). These issues lead to difficulties in analysing and managing the huge amount of data generated. To handle these issues, this study proposes a unified framework known as end-to-end Spatial Data Infrastructure Enabled Cloud–Fog–Edge Computing framework for COVID-19 pandemic management (STROVE) (Ghosh & Mukherjee, 2022). This framework consists of 3 main components: (1) SDI for spatio-temporal information management, storage, analysing, and data sharing, (2) mobility and context analytics module to analyse appropriate route and nearby healthcare for suspected people, and (3) Cloud-Fog-Edge-based architecture for patient's health data analysis. This study used different type of health's sensor to monitor patient's conditions, that will be send to the STROVE for further analysis and next course of action. Via using the proposed framework, it can assist identification of individual COVID-19 suspects, constantly monitor home-quarantined patients, and reduce pressure on health resources. Further improvement can be done via enhancing the monitoring module for other diseases, or monitoring senior citizen's health remotely.

Another study was done by Nagaraja et al. (2020), where it highlighted the environmental data was collected from various sources, are not integrated. The aims of this study are to design air monitoring system that based on air pollution components, real-time air quality and the impact to environment to support smart city applications (Nagaraja et al. 2020).

Spatial data integration has been identified as one important aspect in Smart City development, as discusses in the previous studies. Most of the studies focused on the data integration from different systems, using different type of methods, architecture, or framework. The main aims of all these studies are to ensure data from various sources, or systems can be access, that are based on the SDI main framework.

TECHNOLOGIES ADVANCEMENT

Besides spatial data integration, the other aspect of SDI integration in Smart City initiatives in on the technology's advancement. Technologies advancement has become priorities in previous studies due to increasing challenges in supporting spatial data integration for urbanization and effective sustainable Smart City development. In recent years, there's a significant advancement in technology that can enhance the integration of SDI in Smart City initiative (Bhattacharya & Painho 2017; Chaturvedi et al. 2019; Rabelo et al. 2017b; Rajaram et al. 2018). These technological advancements have revolutionized the way Smart Cities are designed, built, and managed, making them more intelligent and responsive to the needs of their citizens.

One of the studies in integrating SDI in Smart Cities in the topic of technologies advancement is by Rabelo et al. (2017). This study proposes a collaborative architectural model that combines SDI and VGI (Volunteer Geographic Information) from the Enterprise viewpoint (EV), in order to allow small and medium-sized cities to start their transformation into smart cities (Rabelo et al. 2017b). This study proposed a model consists of new physical actors called Sensor, that have its role, contracts and policies for each actor. The model includes 3 main units; Controlling unit, Pacifying Unit, and Passive unit.

Besides that, another study is by Bhattacharya and Painho (2017) that aims to create an integration between SDI with the sensor web development. This study proposed are based on architecture of SMACiSYS (Smart City Intelligence System), which consist of Governance, User Communities, Economy, Built Environment, Natural Environment, Technology, Organization, Policy, and Regional Modelling Parameters. This study also integrates between SMACiSYS with SENSIDI to enable sensor web, with the efforts to improve the integration and utilization of sensor data within SDI (Bhattacharya & Painho 2017).

Bhattacharya and Painho (2018) continued its study but highlighted the other issues, which is current web-enabled sensor information system that cannot handle data output in real-time (temporal data). This study aims is proposing SmaCiSENS, a generalized system that integrate several Sensor-Web (SW) with SDI (Bhattacharya & Painho, 2018). This platform enables integration of several other developed platforms such as automated natural hazard monitor webGIS with internet-SMS warning, climate monitoring, to urban design, intelligent transportation systems, and disaster management SDI. This approach has GIS-GUI module, input module, understanding module, wireless communication module, and expert module. This

enable different sensor, platform, hardware and software to be integrated in one platform.

Another study is from Chaturvedi et al. (2019) that proposed a concept for securing distributed applications and services of SDI for Smart City scenarios based on Smart District Data Infrastructure (SDDI) framework. This study highlighted the issues of lack security measure, issues with data sharing and data control (Chaturvedi et al. 2019). This study suggests a single user login (Single-Sign-On, SSO) that enable easy integration with external authentication services in enhancing the security issues of SDI in Smart City design. To increase the security of SDDI implementation, this study proposed 3 methodology steps of implementation; Single-Sign-On, linked the protected data, and setting up the core security services.

Besides that, to improve technologies related to Smart City, Rajaram et al. (2018) suggest a computational framework for Geospatial Metadata by integrating TopicMaps and Hypergraphs (Hypergraph-based Topic Map framework for Geospatial Metadata, HXTM) that are based on the metadata elements and dependency relationships. This study is based on the issues of processing analysing metadata to fit into any computational techniques (Rajaram et al. 2018). The computational framework consists of 4 major building blocks: Geospatial Metadata, Metadata Quality Metrics, TopicMaps, and Hypergraph. This framework enabled users for better search and analysis on the geospatial metadata based on different criteria. To further improve this implementation, the integration of neural networks to process these metadata has been suggested by authors.

Another study that related to Smart City but focusing on data on sustainable energy which is solar energy has been done by Rao et al. (2018). This study aims to identify the suitable area for solar photovoltaic using the SDI tools for supporting smart cities development (Rao et al. 2018). Using the analysis defined in this study, it can evaluate the solar PV potential especially in Chennai City urban region. From the analysis, it shows that different date of the year affected the tilt degree of the solar panel, and an inclination angle of 14 degree can produced the best output yearly.

Another study to increase technologies advancement in Smart City are related to various issues with implementation of sensor data sharing in smart cities development, such as vulnerability of privacy leakage, information inferring, untrusted or unauthorized disclose, besides data sharing and access control (Chaturvedi et al. 2018b). To solve these issues, this study proposed an approach of securing data, via proper authorization and authentication to increase privacy, security, and controlled access of the data. The proposed approach is based on SDDI implementation, with implementing Single-Sign-On and linked protected data. The results shows that the

security level was increase in a distributed, heterogeneous systems.

Technologies advancement is crucial in enhancement of Smart City initiatives, where technologies always advancing from various aspects, and the data usage, and integration between technologies need to become one of the priorities. Technologies can support Smart City with integration of tools, sensors, and systems (Bhattacharya & Painho, 2017; Chaturvedi et al. 2018b; Rabelo et al. 2017b), increasing the security of spatial data and networks (Chaturvedi et al. 2019), or applying Smart City concepts in applying and supporting the sustainability of Smart City initiatives (Rao et al. 2018).

INSTITUTIONAL REFORM

Besides spatial data integration and technologies advancement, another important topic on SDI integration in Smart City initiatives is the institutional reform. Spatial data integration enables different data from various sources to be implemented in Smart City initiatives, technologies advancement supporting various systems, tools, and sensors to be included and supporting Smart City initiatives, institutional reform also important as part of human-part in enabling the implementation of Smart City initiatives. Smart City initiative required peoples, organisations, and agencies or known as human resources to be part of the initiatives, and these can be critical success factors for Smart City because human resources that initiate, manage, implement, and monitor the success of Smart City initiative.

The first study related to institutional reform is by Kim et al. (2019). This study has identified the issues related to implementation of Local SDI (LSDI) in Seoul, South Korea where the current LSDI implementation has lost its expertise and independent status, with departments in Seoul Metropolitan Government (SMG) developing their own separated GIS project and system (Kim et al. 2019). The aims of this study are to improve current LSDI implementation via proposing 5 strategies for leaping to the advanced LSDI. To achieved this, this study reviewed the theoretical background of LSDI, using case study from different LSDI development in USA and Canada, analysed the budget, management, and related laws on previous LSDI, and proposed 5 strategies for advanced LSDI implementation in SMG. These strategies are human resources, organization, cost benefit analysis of the LSDI, governance and systematic LSDI plan development. These strategies were derived from studies from previous theories, benchmarking of LSDI implementation from USA and Canada, and assessment on current implementation of LSDI in MSG.

Besides that, Rabelo et al. (2017) also suggest an institutional reform to align with the technologies advancement, where it proposed a role, contracts and policies to support the architectural model (Rabelo et al. 2017b). This model is a collaborative model that also integrate volunteers for spatial data collection, where it needs for improvement of institutional reform to enhance the current Smart City initiatives.

The main discussions on institutional reform are based on institutional strategies to improve the current Smart City implementation (Kim et al. 2019), besides enhance the collaboration between human resources inter-related with the Smart City initiatives.

DISCUSSIONS

THE IMPORTANCE OF SDI IN SMART CITIES DEVELOPMENT

This study aims to review the importance of SDI implementation in smart city development. Several studies have been conducted, particularly focusing on the integration and implementation of SDI concepts in smart city design. Table 1 summarizes previous studies on the integration of SDI in smart cities, detailing the focus, findings, and approach of each study.

TABLE 1. Summary of previous studies on SDI integration in Smart City Development

Citation	Title	Focus	Findings	Approach
(Ghosh & Mukherjee, 2022)	STROVE: spatial data infrastructure enabled cloud-fog-edge computing framework for combating COVID-19 pandemic	Spatial Data integration	Difficulties in managing and analysing huge amount of health data	Using SDI and Cloud-Fog-Edge computing framework
(Hoang et al. 2022)	Towards a Novel Architecture of Smart Campuses Based on Spatial Data Infrastructure and Distributed Ontology	Spatial Data integration	Need for big data management especially for campus's assets	Using SDI and distributed ontology architecture to integrated spatial and non-spatial systems
(Iban & Aksu, 2020)	A model for big spatial rural data infrastructure in Turkey: Sensor-driven and integrative approach	Spatial Data Integration and Governance Strategy	Relationship between data and data users not dynamic, not integrated and not interoperable	Using UML for syntactic and semantic design
(Nagaraja et al. 2020)	Spatial Data Infrastructures for Urban Governance Using High-Performance Computing for Smart City Applications	Spatial data integration	Data from various sources not integrated especially in air monitoring	Designing integrated air monitoring from various spatial data sources
(Chaturvedi et al. 2019b)	Securing Spatial Data Infrastructures for Distributed Smart City applications and services	Spatial data security	Need more secure implementation on sensor data sharing in SDDI	Proper authorization and authentication for SDDI
(Kim et al. 2019)	The strategies of advanced local spatial data infrastructure for Seoul Metropolitan Government	Governance strategy	Need to improve LSDI implementation in SMG	Framework that are integrated based on theoretical background, case studies, and budget, management and laws analysis
(Chaturvedi et al. 2018b)	Securing spatial data infrastructures in the context of smart cities	Spatial data security	Need for security enhancement for SDDI implementation	Increase SDDI security with SSO, linked protected data, and secure core services
(Rao et al. 2018)	City - Scale spatial data infrastructure for solar photovoltaic energy generation assessment	Spatial data analysis	Need to find most suitable area for solar photovoltaic optimum's location	Using SDI to analysed most suitable tilt of solar panel and the most suitable locations

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(Rajaram et al. 2018b)	A novel computational knowledge-based framework for visualization and quantification of geospatial metadata in spatial data infrastructures	Metadata search and analysis	Need to enhance metadata processing and analysis	Integrating topic maps and hypergraphs for spatial metadata
(Bhattacharya & Painho, 2018)	Location intelligence for augmented smart cities integrating sensor web and spatial data infrastructure (SmaCiSENS)	Sensor and SDI integration and Spatial data integration	Need GIS-GUI module to enable integration of different sensors, platform, hardware and software	Generalized system that integrate sensor-web with SDI
(Bhattacharya & Painho, 2017b)	Smart Cities Intelligence System (SMACiSYS) Integrating Sensor Web with Spatial Data Infrastructures (SENSDI)	Sensor Integration	Need sensor-web enabler	Integrate smart city intelligence system architecture with sensor-web access with spatial data
(Rabelo et al. 2017b)	An architectural model for intelligent cities using collaborative spatial data infrastructures	Spatial Data integration and Policies	Need new physical actors called Sensor to enhance medium cities to smart cities	Using Enterprise Viewpoint to combines SDI with VGI
(Moshrefzadeh et al. 2017)	Integrating and Managing the Information for Smart Sustainable Districts - The Smart District Data Infrastructure (SDDI)	Data interoperability	Need for data interoperability between stakeholders in SSD.	SDDI framework that are based on 5 viewpoints for managing and collaboration

Previous studies on integrating the SDI framework into smart city initiatives highlight the importance of SDI in supporting smart city development, particularly through the integration of spatial data, technology, and institutional governance. This is evident when comparing the findings of each study, which emphasize the role of SDI in facilitating spatial data integration and interoperability within smart city development.

ISSUES IN INTEGRATION OF SDI IN SMART CITY

Based on the table 1, most of these studies focused on the issues on spatial data integration as shown in table 1 (column focus), where in Smart City initiatives, data can be collected, manage, store, and processes using different tools, format, sensors, etc. Main issues related to spatial data integration are data format, data quality, and data interoperability. Study from Moshrefzadeh et al (Moshrefzadeh et al. 2017), Nagaraja (Nagaraja et al. 2020), Ghosh and Mukherjee (Ghosh & Mukherjee, 2022) shows that data used in Smart City need for integration, to enable data interoperability horizontally and vertically, because of issues related to spatial data.

Besides that, another issue on data is on the sensor integration with current Smart City data (Bhattacharya & Painho, 2018; Iban & Aksu, 2020; Rabelo et al. 2017b). The SDI implementation is needed where it can support

the sensor infrastructure, Smart City architecture, and spatial data, which related to sensor locations and the other related locations (communities, housing, land use, etc.).

Spatial data management in Smart City initiatives also need to be improve (Ghosh & Mukherjee, 2022; Moshrefzadeh et al. 2017). Spatial data management should include the guideline, or procedure of spatial data collection, storage, processing, analysing, and distribution or visualization. Guidelines or procedures are one of the components in SDI, where it can facilitate to establish a framework for Smart City's management in managing and maintaining the spatial data quality, accessibility, security and interoperability (Chaturvedi et al. 2019b).

Another interesting issues that previous study has cater is on the metadata improvement, where current development of metadata standard, are not dynamic, and require improvement for better searching and analysis (Rajaram et al. 2018b). The improvement on including topic map and hypergraph to see and map the relationship between topics in metadata. Via improving the metadata, the relationship between topics in the metadata can be analyse, hence improve the connectivity and searching, and topic analysis.

Other issues are related to institutional and governance of SDI in Smart City (Iban & Aksu, 2020; Kim et al. 2019). The cross institutional management required a legal, policy and organizational framework to ensure the effective communication and collaboration horizontally and vertically. The institutional reform should include the

governance, policies, legal, stakeholders' engagement, and sustainability framework necessary for a successful integration of SDI in Smart City development.

Using the comparison analysis from previous studies, a way forward in integrating SDI in Smart City can be identified, and use for better improvement and development of Smart City in the future.

TOWARDS INTEGRATION OF SDI IN SMART CITY

From previous studies, it shows the issues related to data integration and interoperability, data management, data security, and also on the institutional management.

Smart City development required many aspects, including data collection, data streaming and processing, data security, monitoring, heterogeneity, adaptation, sustainability and interoperability (Rabelo et al. 2017b). This has led to issues in data integration and interoperability. To address the issues with data integration, adaptability and interoperability, several models and architecture was proposed that integrate of an SDI that can support spatial data inclusion and integration, with higher interoperability between institutions in Smart City initiatives (Bhattacharya & Painho, 2018; Hoang et al. 2022; Iban & Aksu, 2020; Nagaraja et al. 2020; Rabelo et al. 2017b).

Another issue discussed in previous studies is on the spatial data management in Smart City Initiatives (Ghosh & Mukherjee, 2022; Moshrefzadeh et al. 2017). Lack of procedures and policies related to governance and management on spatial data integration in Smart City initiatives has led to this issue. To manage this issue, a framework was proposed by Ghosh and Mukherjee (Ghosh & Mukherjee, 2022) that using SDI and computing framework to manage all of these big data.

Besides that, the issue with security of spatial data infrastructure was also being discussed and need to be address (Chaturvedi et al. 2019b). And to handle this issue, Chaturvedi et al (2019) has suggested a model with proper authorization and authentication for SDDI that can increase SDDI security with SSO, linked protected data, and secure core services.

The last issue discussed from previous studies is on the institutional aspect (Iban & Aksu, 2020; Kim et al. 2019). Smart City and SDI integration required for collaboration from various organizations, department, and individuals. Issues in institutional aspects more focused on communication and collaboration inter and intra organisations. Kim et al (2019) suggested a framework that are integrated based on theoretical background, case studies, and budget, management and laws analysis, for

better governance and management of SDI in Smart City initiatives.

More research is required to enhance the integration of SDI in smart city initiatives, particularly in the three key areas discussed above: spatial data integration, technological advancements, and institutional reforms.

In terms of spatial data integration, improvements can be made in both data enablement and interoperability. For technological advancements, the focus should be on enhancing the integration of various sensors and adapting new technologies using SDI to support smart city implementation. Additionally, the integration of machine learning (ML) and artificial intelligence (AI) can further expand SDI's role in smart cities by enhancing spatial data processing and analysis, enabling better understanding, management, and development of smart cities.

In terms of institutional reforms, the emphasis should be on strengthening institutional collaboration and cooperation by improving communication and engagement between and within agencies involved in smart city development.

In conclusion, the development of smart cities requires effective data integration, interoperability, management, security, and institutional collaboration. Previous studies have identified challenges in these areas, such as spatial data management, security, and institutional cooperation. To address these challenges, several models and frameworks have been proposed that leverage SDI, computing frameworks, and proper authorization and authentication methods to improve data integration, management, and security in smart city initiatives.

The integration of machine learning and artificial intelligence can also expand the capabilities of SDI in supporting smart city development. Overall, these efforts are critical to the successful implementation and sustainability of smart city initiatives. Further research is needed to advance SDI integration in smart cities, focusing on spatial data interoperability, technological advancements, and institutional reforms.

CONCLUSION

This study aims to review and assess the key aspects of integrating Spatial Data Infrastructures (SDI) with smart city initiatives. Several studies on the integration of SDI with smart cities have been reviewed, and key points have been identified.

This study has highlighted major issues in integrating SDI within smart city contexts, including spatial data and technology integration, management of various spatial and non-spatial data, searching and analyzing metadata, and

collaboration and institutional challenges. Additionally, this study compared several proposed models and frameworks for integrating spatial and non-spatial data, data from various types of sensors, ensuring data interoperability, and enhancing institutional and personnel collaboration.

Further findings from this study indicate that future directions for integrating SDI in smart city development are moving towards three main areas: (1) spatial data integration, (2) technological advancement, and (3) institutional reforms.

This study underscores the importance of SDI in smart city development, as it provides the foundation for integrating spatial data collection, processing, analysis, and visualization, thereby contributing to the creation of sustainable, livable, and resilient urban communities and environments.

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DECLARATION OF COMPETING INTEREST

None.

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