Data-Driven Approach in Knowledge-Based Smart City Management

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Abstract: The concept of smart city management is based on the implementation and use of advanced technologies, such as wireless sensors, intelligent vehicles, mobile networks, and data storage technologies. It involves integrating various information and communication technology solutions to efficiently manage a city's resources. Cities are investing in data-driven smart technologies to enhance performance and efficiency, thereby generating a large amount of data. Finding innovative ways to use this data helps improve city management and urban development. A data-driven city utilizes datafication to optimize its operations, functions, services, strategies, and policies. Datafication involves transforming various aspects of urban life into computerized data and extracting value from this information. This transformation is dependent on controlling the storage, management, processing, and analysis of the data, as well as utilizing the extracted knowledge to develop useful smart city solutions. Access to real-time data and information enables the provision of effective services that improve productivity, leading to environmental, social, and economic benefits. Both current and future smart cities have the potential to generate vast amounts of real-time data due to complex physical infrastructure and data-driven applications supported by social networks. This paper investigates how the emerging data-driven smart city is practiced and justified in terms of its innovative applied solutions. The aim of the paper is to explore the general conditions for implementing advanced data-driven technologies for smart city management, using knowledge from literature analysis and case studies. To understand this new urban phenomenon, a descriptive case study is used as a qualitative research methodology to examine and compare the possibilities of implementing data-driven approaches in knowledge-based smart city management. Seventeen case studies that use data-driven applications in real-world settings were identified from secondary sources and evaluated based on smart city indicators and related data-driven applications. Smart Cities were selected based on their rankings in the Digital Cities Index 2022, the Smart City Index 2022, and the IESE Cities in Motion Index 2022.

Keywords: Smart city, Data-driven applications, Smart applications, Knowledge-based smart city management, Datafication, Data-driven smart cities

1. Introduction

The development of technology provides opportunities to build smart cities. In the current understanding of the concept of a smart city, there is a focus on knowledge management because smart cities have the potential to generate large amounts of data. The management of this data creates opportunities for improving smart city solutions. Peng, Nunes, and Zheng (2017) defined a smart city as a city that utilizes advanced technologies such as wireless sensors, smart meters, intelligent vehicles, smartphones, mobile networks, or data storage technologies.

The concept of a Smart City aims to utilize modern technologies, particularly information technologies, to enhance the quality of life and support urban development. The idea of constructing data-driven smart cities is becoming a reality due to recent advancements in urban development practices and technological solutions. The data-driven city represents one of the newest and future manifestations of smart cities. Cities are investing in data-driven smart technologies to enhance performance and efficiency, as well as generate a significant amount of data.

The literature does not pay much attention to the organizational and managerial solutions during the transition from a classic city to a smart city, therefore the paper try to explore the potential of the data-driven applications in knowledge-based managing of urban development.

The motivation for this study is to identify the core dimensions of the emerging data-driven smart city and to use the outcome to analyze, investigate, and develop guidance for data-driven smart cities of the future in terms of its technological components.

The aim of this paper is to investigate the general conditions necessary for implementing advanced data-driven technologies for smart city management. This will be accomplished by analyzing literature and case studies. A descriptive case study methodology is adopted to examine and compare the possibilities of implementing data-driven approaches in knowledge-based smart city management, in order to gain a better understanding of this new urban phenomenon.

This study investigates the practices and justifications behind the development and implementation of innovative applied solutions in the emerging data-driven smart city. In order to achieve the aim of this paper, two research questions were defined:

RQ1. How are the selected data-driven application for Smart City management currently used in the world's best practice?

RQ2. How is it appropriate to implement data-driven approach for Smart City management in general?

The structure of the paper is as follows: After this introduction, the next section presents the research methodology in detail. Then, the selected smart city solutions connected with data-driven applications are presented in the form of a case study. Finally, the research findings are outlined and discussed, implications are explored, limitations and future research are described.

2. Theoretical Background

Cities have the potential to generate vast amounts of real-time data due to complex physical infrastructure and social networks that are supported by data-driven applications. Due to the accessibility of real-time data, individuals and communities are increasingly presented with opportunities to engage in a variety of issues and processes that concern their lives (Bakıcı et al., 2013; Anthony, 2022). Knowing the identified challenges and the expected increase in the number of urban residents around the world, there is an increasing need for new and innovative ways to manage the complexity of urban life. The importance of smart cities derives from the future projections of a growing urban population (Pašalić, Ćukušić, and Jadrić, 2021).

Researchers identified four components of a smart city: industry, education, participation, and technical infrastructure. This list has been expanded and consists six main components (Giffinger and Gudrun, 2010). These components are smart economy, smart mobility, smart environment, smart people, smart living, and smart governance (Woetzel et al., 2018) :

- Smart mobility - data-driven applications are used to offer and monitor complex multi-modality systems of transportation to achieve sustainable transport systems that are efficient. Smart parking and smart traffic management techniques that are used to coordinate and integrate different transportation modes are part of smart mobility applications (Kaluarachchi , 2022; Cai, Hong and Xiong, 2022).
- Smart economy - innovation and productivity are employed to adapt to the market and workers' needs to enhance new resilient global business models for competing both locally and globally. Entrepreneurial innovation hubs where start-ups and business incubators are encouraged also belong in smart economy context. Public and private initiatives that foster the development of new smart projects are an essential part in setting up a comprehensive smart city economic ecosystem. When private sector-initiated innovations spring up, regulating, assembling key actors, offering subsidies, or changing procurement decisions are some of the ways governments can contribute (Mora et al., 2017)
- Smart governance can be achieved when citizens and other stakeholders are part of operations in cities, contributing to planning, supporting key decisions, and making processes with the help of smart platforms and applications. The aim is to attain synergies through collaboration and improve public services and the transparency of institutions to promote sustainable communities. Technology helps policy makers to engage, survey, and obtain stakeholder opinions on a range of matters and to incorporate public feedback when improving systems, processes, and policies. To be successful, new initiatives need to be transparent and accountable, engaging citizens from the inception of the project (Ruhlandt, 2018).
- Smart environment -sensors and other innovative monitoring systems can be used to collect data from utility services and networks including energy, air, water, and waste management to provide a more efficient service, conserve energy, and improve the life of citizens while achieving environment sustainability. Big Data can help in the coordination of wind and solar energy with traditional energy sources. Smart sensor data can be processed to find out whether a renewable energy source operates correctly. They can also assist in reducing pollution and promoting biodiversity. The availability of data and new analytical algorithms provide the ability to forecast and obtain a better idea of the impact that climate and environmental changes may have on human health. With this knowledge, the potential natural disasters can be more accurately identified, and cities can become better equipped

with warning systems to prevent the harmful impact of environmental factors on citizen's health and well-being (Marsal-Llacuna 2016; Anthony, 2020; Polese et al., 2021; Kaluarachchi 2021).

- Smart living- when public services and facilities are well managed through the use of new technologies and data-driven solutions, it becomes possible to create a secure, accessible, and healthy lifestyle, thus realizing the concept of smart living. Smart systems can enhance call centers, assist first responders at emergency scenes, and improve field operations during emergency responses. Response time plays a crucial role in emergency situations, so these services need to be integrated with traffic system controls, vehicle recognition applications, and speed management. Smart living also aims to promote better health and provide improved long-term medical treatments and applications that assist in preventing, treating, and monitoring various conditions (Geekiyanage et al., 2020).
- Smart people - data-driven smart applications that result in inclusive communities, provide educational opportunities, promote digital literacy, and grant access to digital platforms all contribute to the development of smart cities. This includes neighborhoods with free Wi-Fi, utility services powered by renewable energy, and new housing equipped with intelligent systems. However, the concept of smart cities also raises questions about equity and the need to ensure that all citizens have online access and are digitally literate, as many data-driven applications require smartphones or smart devices. Aging populations can particularly benefit from these types of applications, as they can be remotely monitored to detect and treat health issues early on and prevent hospitalizations, allowing seniors to live independently. When implementing the criteria for smart cities, it is important to consider the specific requirements of each neighborhood and community in order to promote digital culture and foster participation (Rathore et al., 2016).

The data-driven city is a city that implements datafication for enhancing and optimizing its operations, functions, services, strategies, and policies. Broadly, datafication refers to the collective tools, processes, methods, techniques, and technologies used to transform a city to a data-driven enterprise (Crawford and Schultz, 2014; Osman, Elragal and Ståhlbröst, 2022). The intensification of datafication is manifested in the radical expansion in the volume, range, variety, and granularity of the data generated about urban environments and citizens, with the aim to quantify the different aspects of urbanity in the modern city. In a modern data-oriented urban landscape, a city's performance is measured, assessed, and enhanced based on the ability of having control over the storage, management, processing, and analysis of the urban data, as well as on the knowledge extracted from these data in the form of applied urban intelligence. Tackling the challenges of sustainability and mitigating the negative effects of urbanization are among the key concerns of the datafication of the modern city (Bibri et al., 2020; Wu et al., 2022).

Smart cities include sensor networks and the connection of intelligent appliances to the internet, which is essential to remotely monitor their treatment such as power usage monitoring to improve the electricity usage, lighting, and air conditioning management. To achieve this aim, sensors can be extended at various locations to gather and analyze data for utilization improvements (Talari et al., 2017). Sensor services can be employed in projects regarding the monitoring of cyclists, vehicles, and parking lots. This data can feed into service applications that utilize an IoT substructure to simplify operations in air, noise pollution control, the movement of cars, as well as surveillance and supervision systems. A city with robust communication networks can rapidly and safely transmit the data collected by smart devices and other sensors. Open data platforms are another aspect of the data driven technology base and create large volumes of data that can become useful when built into smart applications. In most of these applications, data and connectivity are key in achieving efficient operations (Botta et al., 2016; Bokolo, 2022).

As cities are routinely embedded with all kinds of ICT forms, including infrastructure, platforms, systems, devices, sensors and actuators, and networks, the volume of data generated about them is growing exponentially and diversifying, providing rich, various streams of information about urban environments and citizens (Wang and Zhou, 2023). This data enables the real-time analysis of different urban systems and interconnects data across different urban domains to provide detailed views of the relationships between different forms of data that can be utilized for advancing the various aspects of smart city management.

3. Research Methodology

The research methodology used in this study is qualitative, and data and information were obtained from secondary sources. A case-study approach was employed to examine the role of data-driven smart city solutions in managing urban development. Many publications attempt to conceptualize and define the

elements and application domains that make up smart cities, often through case studies or comparative case study analysis. However, it is argued that there is a need for research on effective strategies for cities to become smarter. The purpose of this paper is to investigate the general conditions necessary for implementing advanced data-driven technologies for smart city management, based on insights gained from literature analysis and case studies. To accomplish this, a small sample of data-driven solutions implemented in various smart cities was selected, in order to study their impact on urban development and smart city indicators.

Data and information about data-driven smart city initiatives have been collected from secondary sources. The presented case studies were explored through desk research using online resources, such as the web pages of smart city initiatives. Scientific articles and studies that formed the basis for the literature analysis were searched for in relevant databases like Web of Science and Scopus. The strategy for finding relevant articles involved searching for articles based on selected keywords (smart city, data-driven applications, smart city management, datafication) and removing duplicate articles.

Smart Cities were selected based on their rankings in the Digital Cities Index 2022, the Smart City Index 2022, and the IESE Cities in Motion Index 2022. The table below (Table 1) presents the top results from these rankings.

Table 1: Leaders of Ranking Smart Cities according to world indices (Smart City Index 2022 Ranking, IESE Cities in Motion Index 2022, Digital Cities Index 2022)

Ranking	Index		
	Digital Cities Index 2022	**Smart City Index 2022**	**IESE Cities in Motion Index 2022**
1	Copenhagen	Amsterdam	London
2	Amsterdam	Barcelona	New York
3	Beijing	Berlin	Paris
4	London	Brisbane	Tokyo
5	Seoul	Brussels	Berlin
6	New York	Busan	Washington
7	Sydney	Chicago	Singapore

The Smart City Index, Digital Cities Index and the IESE Index were selected on the basis of temporal and thematic relevance, as they reflect the current results in several indicators, which are the priority indicators of city's technological development.

Descriptive case study research here involves describing, analyzing, and interpreting the current nature, composition, and processes of data-driven smart cities. The focus is on the current conditions and how these cities behave in terms of what has been achieved, specifically in the form of data-driven smart city solutions.

4. Results and Discussion

This section presents data obtained through secondary analysis of best practice strategies from selected smart cities, including comparison and key findings. A sample of 17 case studies that use data-driven applications deployed in real-world settings were identified from secondary sources and evaluated based on smart city indicators and related data-driven applications. The results are presented in Table 2.

Table 2: Data-Driven Smart City Applications Categorized According to the Smart City Indicators

City	Data Driven Applications	Smart city indicators
Copenhagen	Citizen participation, fast broadband and mobile connections, smart energy incubators and energy labs, smart transport systems, and open data platforms	Smart governance Smart environment Smart mobility Smart economy Smart people Smart living

City	Data Driven Applications	Smart city indicators
Amsterdam	Citizen participation, smart lighting controls for energy efficiency and saving, improved safety, traffic reduction, digital platforms for citizens, open databases, opportunities for smart entrepreneurs	Smart governance Smart environment Smart mobility Smart people Smart living
London	Citizen participation, green and smart technology application in transport and parking, pollution and congestion control, innovation in entrepreneurship, digital platforms for citizens, and open databases	Smart governance Smart environment Smart mobility Smart economy Smart people Smart living
Barcelona	Combined information, communication and green technologies, smart water efficiency, smart public transportation, participatory democracy, open databases, and opportunities for smart entrepreneurs.	Smart governance Smart environment Smart mobility Smart economy Smart people Smart living
New York	Digital tools to share information to overcome crime, innovation in entrepreneurship opportunities, open Wi-Fi, infrastructure management system, online transportation control system, and open data initiative: "Making city data open"	Smart environment Smart mobility Smart economy Smart people Smart living
Beijing	Intelligent urban infrastructure, sharing data and public services for healthcare and education among cities, and digital platforms	Smart mobility Smart people Smart living
Berlin	Mobile remote health monitoring, smart metering, smart transport systems, services to assist and support entrepreneurship, and open data platforms	Smart environment Smart mobility Smart economy Smart people Smart living
Paris	Smart applications for lighting, road circulation, waste management, and environment monitoring, extensive public Wi-Fi network, online transportation control system, and open databases	Smart environment Smart mobility Smart people Smart living
Brisbane	Smart infrastructure, economic growth and environment sustainability, community involvement in urban city decisions, and services to assist and support entrepreneurship	Smart governance Smart environment Smart mobility Smart economy Smart people Smart living
Tokyo	Energy efficiency, digital connectedness, waste	Smart environment

City	Data Driven Applications	Smart city indicators
	management, fully automated buildings, smart street lighting and meters, intelligent urban infrastructure, digital platforms, and smart mobility management	Smart mobility Smart people Smart living
Seoul	Energy efficiency, business productivity, healthcare and public sector services, services to assist and support entrepreneurship, intelligent transport systems	Smart environment Smart mobility Smart economy Smart people Smart living
Brussels	Energy efficiency through smart sensors, smart mobility systems, real-time transportation information, waste management, and environmental monitoring.	Smart environment Smart mobility
Busan	Cloud infrastructure connecting shared applications, geographic information and intelligent transportation, digital platforms, and open data systems	Smart mobility Smart economy Smart people Smart living
Washington	Citizen participation, open data and open government, IT cloud, equitable justice delivery system, online communities, smart grid, and digital evidence management	Smart governance Smart environment Smart mobility Smart economy Smart people Smart living
Sydney	Smart lighting system that utilizes sensors, smart waste management system that uses data analytics, open data platform, intelligent transportation system, and public services for healthcare and education	Smart environment Smart mobility Smart people Smart living
Chicago	Digital government portal with language support, open data and open government, IT cloud, online communities, smart grid, and digital evidence management	Smart governance Smart environment Smart mobility Smart economy Smart people Smart living
Singapore	Energy efficiency, intelligent transportation system, healthcare and public sector services, environment monitoring system, services to assist and support entrepreneurship and business productivity	Smart environment Smart mobility Smart economy Smart people Smart living

The results illustrate that the majority of smart cities use data-driven applications in all categories to improve operations and achieve efficiency. Smart mobility, smart living, smart environments, and smart economy criteria are implemented quite commonly, while smart governance criteria are relatively new to be implemented.

Smart mobility and transport concepts have been implemented in cities for some time and cover a wide range of criteria. Data-driven applications systems that provide smart transportation systems management were employed in all surveyed cities. A variety of data-driven traffic control systems have been implemented for

the efficient performance of city services and include interactive notifications of parking availability and distribution, bike and car sharing, digital public transit payment, predictive maintenance of transportation infrastructure, real-time public transit information, and road navigation. These applications support agent-based simulations of transport systems and many encounters they can face so that complex systems that incorporate and respond to a multitude of entities, including the shortest routes, minimal waiting times, and diversions aware from traffic congestions, can provide the optimum traffic solutions.

Smart economies support entrepreneurship and a culture of innovation, and 11 cities in the sample were implementing data-driven smart economic concepts embracing an open approach to support innovation and providing opportunities for entrepreneurs. An emerging trend is also to initiate innovation hubs. Smart economy examples present in the sample are public-private partnerships that bring together municipal agencies, educational institutions, non-profit agencies, private-sector companies, and start-ups that put people at the center and use technology to unite the city.

In data driven smart cities, Big Data and analytics help utilities providers to gain operational efficiencies in smart environments. Organizations and citizens consider how to maximize the use of resources while preserving them, and 15 case study examples were utilizing smart environment techniques.

Data-driven application systems that provide digital platforms and promote digital literacy in citizens to engage in digital services come under smart people city services, and 16 examples were identified in the case study sample. Many government departments and authorities have added new digital infrastructure, new roles, and personnel to support digital services to promote people using smart networks. Establishing data science teams and analytic units distributed in all sections of the government to support these services are essential in this effort.

City governance can be influenced by technology and by changing the relationship between the local authorities and citizens. In the case study examples, 7 cities were using smart governance systems. With the aid of data-driven digital platforms, citizens can engage in dialogue with local authority officials and agencies via interactive mobile apps and social media platforms.

From the surveyed cities, 16 cities were implementing criteria listed under smart living. While improving security and health, data-driven technologies can improve the quality of life by facilitating engagement in culture and arts and include online information sharing, ticketing, and reservations. In the sample, smart security measures implemented include real-time crime mapping that utilizes data and statistical analysis to highlight potential conflict areas and patterns and predictive policing that could anticipate crime to prevent incidents before they occur. Other measures present included promoting culture and leisure activities and health and security monitoring by smart systems.

The study results illustrate that smart people, smart living, and smart governance criteria are integrated and play an important role as smart mobility, smart environments, and smart economy. Smart mobility is the most widely implemented technological, whilst smart governance, a relatively new phenomenon. This demonstrates that even though some cities have not received highly technical infrastructures, they are still opening to new, transparent, and participatory governance approaches where citizens play a key role.

The study results suggest difference in the smart city indicators with regards to their implementation. The development of smart people, smart living, and smart governance concepts illustrate that the current new wave of smart cities is realizing the importance of human and social capital in future cities. These shifting paradigms give insights to policy makers, urban planners, and designers in prioritizing resources and implementing future city strategies. Access to real-time data can result in digital literacy and digital culture that improve public participation, online deliberation systems, and societies of urban futures. Data-driven smart cities are also places where entrepreneurs can innovate, and technology can contribute to improve the quality of life, security, protection of nature, and the way forward for future cities.

Access to real-time data and information can provide effective services that improve productivity, resulting in environmental, social, and economic benefits. It also assists in the decision-making process and provides opportunities for community engagement and participation by improving digital literacy and culture.

5. Conclusion

Cities today generate and act as huge repositories of information and real-time data. When collected and systematically organized, this data can be stored, shared, and applied to provide new ways of services and applications that can influence lifestyles. This capability of cities to collect data via sensors and other smart

devices are resulting in large data bases that are difficult to manage and use. Real-time data can be utilized to improve connectivity, information sharing, and performance, resulting in data driven cities and societies. There is a global movement to open up public data and make it more accessible to application innovation, to create novel mobile apps and services, and promote the transparency of governments.

Current trends in smart cities include intelligent, data-driven technology and its applications that can facilitate citizen participation and support decision making and policy formulation. Hence, novel ways of governing that engage stakeholders are emerging and are capable of collecting ideas, anticipating trends, as well as planning and evaluating policy, all in collaboration with citizens.

There has been significant progress in the utilization of data-driven applications to perform and oversee various urban functions in recent years. These smart applications, driven by data, enable improved governance and operational implementation by enhancing public participation. They can facilitate innovation, promote information sharing, and engage communities to enhance the city's overall performance. In order to fully leverage the potential of data-driven applications, cities need to integrate them into their existing data strategies, while also addressing new challenges and continuously refining their processes. By embracing data-driven applications, future cities can benefit greatly in terms of achieving performance efficiencies, mitigating the impact of climate change, and enhancing the quality of life for their citizens.

Big Data can promote innovations and create new paradigms. The importance of being digitally literal, being connected to online services, and having access to real-time data has been further exacerbated where many essential activities are carried out remotely via digital online methods.

However, it is clear that the selection of several case studies is a limitation of this research. It is therefore important to explore the potential of data-driven smart city solutions in urban development and city management in more detail by considering more cases. Nonetheless, the analysis of best practices in selected case studies the smart city model for the city can provide useful insights and practical guidelines.

The study was based only on a qualitative approach, so the results are restricted to understanding, explaining, and demonstrating of how the selected smart city dimensions can be integrated into the effective knowledge-based urban development management.

At the same time, the paper launches the opportunity for future research on the smart city concept more targeted on issues related to smart governance and active involvement of citizens in smart initiatives.

Moreover, as this study has demonstrated that applied technological solutions already exist across the selected cities, it would be extremely useful to conduct a wider and more varied comparison involving more other cities with a view to revealing more general trends in data-driven smart city management.

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