Exclusion in Smart Cities

Assessment and Strategy for Strengthening Resilience

Izabela Jonek-Kowalska and
Radosław Wolniak

First published 2025

ISBN: 978-1-032-81460-5 (hbk)
ISBN: 978-1-032-81465-0 (pbk)
ISBN: 978-1-003-49999-2 (ebk)

Chapter 1

The concept of a Smart City in modern economies

DOI: 10.4324/9781003499992-2

The funder for this chapter is Silesian University of Technology.

Routledge
Taylor & Francis Group
LONDON AND NEW YORK

1 The concept of a Smart City in modern economies

1.1 Creation and assumptions of the Smart City concept

The genesis of the Smart City concept goes deep to the roots of dynamic technological development and the increase in urbanization in the second half of the 20th century. Growing challenges related to the rapid growth of urban population, growing infrastructure needs and environmental pollution have prompted communities and decision-makers to look for innovative solutions. The Smart City concept has emerged as a response to these challenges, integrating modern information, telecommunications, energy and transport technologies to create more efficient, sustainable and citizen-friendly environments.

The Smart City concept is a response to global demographic changes and ongoing urbanization processes. It is the result of the development of an innovation ecosystem and the pursuit of sustainable progress. The first step in the development of a Smart City is to define challenges and priorities aimed at effectively solving these problems, which leads to the creation of the so-called Smart Cities. This term is usually associated with cities that have adopted a development strategy based on technology, creativity, openness to innovation and flexibility, understood as the ability to quickly adapt to changing external and internal conditions (Khavarian-Garmsir and Sharifi, 2022). In this context, various communication channels are used, such as e-governance or e-democracy (Makieła et al., 2022).

Arun was the scientist who first defined the Smart City concept in 1999. According to him, the foundation of this idea was information

DOI: 10.4324/9781003499992-2

technology, and an integral part of it was the commitment to improve the quality of life of an ordinary citizen (Arun, 1999). The creation of this definition coincided with the intensive development of the Smart City idea in the following years.

In the initial stage of development of the Smart City concept, the main focus was on the use of information technologies in managing urban infrastructure, improving access to public services and increasing energy efficiency. Monitoring systems, automation of urban processes, and the development of smart energy and transportation networks were key elements of this approach (Lyu and Hao, 2020).

Over time, the Smart City concept has evolved to take into account an increasingly wider range of elements, such as social participation, social innovation and even cultural aspects. The development of IoT and data analysis have become key elements, allowing monitoring and optimization of various aspects of urban life in real time.

Today's understanding of the Smart City concept also includes a strong emphasis on sustainable development, effective use of natural resources and the creation of resident-friendly places, both in terms of comfort and safety. The idea of Smart Cities is constantly being developed by technological progress, the growing needs of society and the desire to create better living conditions in cities, which makes it a dynamic area of research and implementation (Toli and Murtagh, 2020).

The history of Smart City development is a testimony to the evolution of society, technology and urbanization over the last few decades (Madhee, 2024). As already mentioned, the origins of this concept date back to the second half of the 20th century, when the dynamic growth of the urban population and the related challenges required innovative approaches to city management. In the 1960s and 1970s, cities began to move towards the use of computerization in administrative processes. The first IT systems were aimed at improving the efficiency of urban infrastructure management, such as transport and waste management. However, it was in the 1980s and 1990s that the real breakthrough occurred when information technology began to integrate with other fields, such as telecommunications, energy and transport (Vasudavan et al., 2019).

With the development of the Internet, the Smart City concept began to include the ideas of intelligent monitoring systems that enabled data collection in real time. This, in turn, allowed for a better understanding and optimization of the functioning of cities. In the 1990s, the first pilot projects were developed, where various solutions were tested in practice.

With the advent of the 21st century, the IoT has become a key element of the Smart City concept. It acted as the core, allowing communication and collaboration between various city devices. This combination of information, telecommunications and sensor technologies has enabled a more comprehensive approach to city management (Picioroaga et al., 2018).

The modern concept of a Smart City is not only technology, but also a complex ecosystem covering a wide range of fields (Ffitra et al., 2023). Developments in data analysis, AI and predictive algorithms are enabling more advanced forecasting and planning of urban development. In addition, the concept of a Smart City has also evolved to include sustainability, public participation and the creation of citizen-friendly places.

Given modern challenges, such as climate change, growing urban populations and the need for efficient resource management, the Smart City concept is becoming not only an innovative approach, but also an indispensable tool for creating better living conditions in cities. Its development is dynamic, driven by continuous progress (Mkrtychev et al., 2018).

Table 1.1 shows the key stages in the development of the Smart City concept and the characteristics of each of them. From the early days, when IT began to be introduced into urban management, through the integration of technology in the 1980s and 1990s, to the contemporary approach based on data analysis, AI and sustainability. The last 2 phases also underscore the growing importance of active public participation and the creation of places that respond to residents' needs.

The Smart City concept revolves around the 4T potentials: Tolerance, Trust, Technology and Talent. The city's progress in these areas dictates its level of intelligence, entrepreneurship and innovation, as highlighted by Makieła et al. (2022). Active engagement with the 4T factors plays a crucial role in the effective management of a Smart City, influencing the quality of life for residents and enhancing competitiveness within a larger entity, such as a metropolis. Beyond technology as a developmental support, there are other highly significant factors in promoting sustainable development. The description of all 4 factors is in Table 1.2.

The modern concept of a Smart City development is divided into 5 periods – from Smart City 1.0 to Smart City 5.0 (Figure 1.1). Each

Table 1.1 Characteristics of the early stages of Smart City development

Stage	*Characteristics*
Introduction of information technology in urban management	The use of computers in the 1960s and 1970s to improve the efficiency of administrative processes and infrastructure management
Integration of information technology in the 1980s and 1990s	Dynamic development of information technology, its integration into the telecommunications, energy and transportation sectors. Use of the first monitoring systems
Pilot projects in the 1990s	Beginning of practical experiments with various Smart City solutions in selected areas. Testing the capabilities and effectiveness of new technologies
The era of the IoT in the 21st century	Use of IoT in the development of a Smart City, enabling communication and cooperation between urban devices. Dynamic development of sensor systems
Advanced data analysis and AI	Introduction to the Smart City: advanced data analysis, use of AI and predictive algorithms for more efficient city management
Sustainability and public participation	Expanding the Smart City concept to include aspects of sustainability, active public participation and the creation of citizen-friendly places

Source: Authors' own study based on Sharifi and Alizadeh (2023); Khavarian-Garmsir and Sharifi (2022); Lyu and Hao (2020); Vasudavan et al. (2019); Picioroaga et al. (2018); Mkrtychev et al. (2018).

Table 1.2 Four T's of a Smart City

T type	*Characteristics*
Tolerance	The area of tolerance and diversity management is a captivating domain within management science. Tolerance involves embracing an uncritical understanding of individuals and appreciating their unique traits and features. These traits include age, origin, race and sexual orientation (Embarak, 2022). The evolution of diversity management initially focused on ensuring equal opportunities for ethnic and social minorities. Subsequent phases extended to equal

(*Continued*)

Table 1.2 (Continued)

T type	*Characteristics*
	treatment in employment and expanded to encompass interactions with customers, service recipients and various social groups. A city that fosters openness and tolerance stands a better chance of developing and achieving a higher level of social inclusion than one lacking these features.
Trust	The level of risk in cities and regions is on a rapid ascent, particularly in developing countries, where urban development may lack orderliness. Consequently, new technologies present an opportunity to enhance urban safety. Many cities have adopted ICT-based systems to bolster citizen security, where video surveillance is a primary system. Cities are shifting their urban innovation systems from traditional to innovative models like 'green', 'smart' and 'open', striving for environmental and social sustainability.
Technology	The integration of cutting-edge technologies, such as the IoT, AI, cloud computing, and data analytics empowers cities to efficiently manage resources, optimize infrastructure and provide innovative services. Smart Cities leverage technology to create intelligent networks that facilitate real-time communication and data exchange between various components, from smart traffic management systems to energy-efficient utilities and advanced public services. This interconnected ecosystem allows cities to make informed decisions, respond promptly to challenges and enhance sustainability.
Talent	Knowledge management forms the foundation of contemporary organizational management. Whether it involves examining market outcomes for globally or locally influential organizations, their strategies, developmental directions, market offerings and marketing approaches, they all underscore knowledge as a key determinant of modern thinking. Drawing from Kinelski's research on enterprises (Kinelski 2022), it is evident that the 'suppliers' of intellectual capital are creative residents, who are identified and managed through specialized programmes and methods rooted in the concept of human capital applied to the city as an organization. Based on their objectives and personnel programmes, these individuals are classified as talented artists, creative leaders, dedicated volunteers and more. Continuous, comprehensive development of innovation and creativity, along with the integration of key residents into the city, assumes paramount importance.

Source: Authors' own work based on Kinelski (2022).

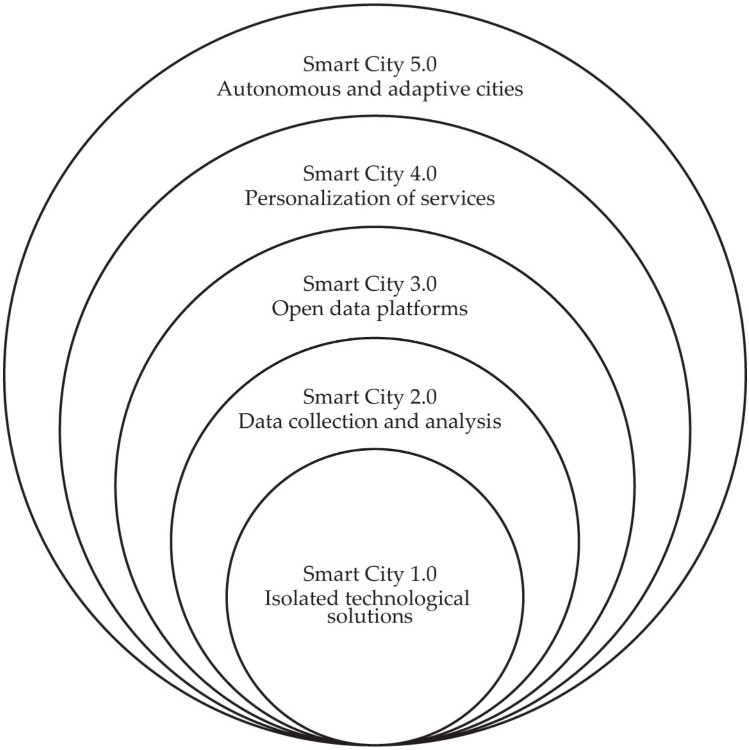

Figure 1.1 Five generations of Smart Cities.

Source: Authors' own study.

period brings the development of the Smart City concept with further important aspects. **Smart City 1.0** is the initial stage of Smart City development, where the implementation of modern technologies was initiated mainly by ICT companies. These companies introduce a variety of solutions, regardless of the actual needs of cities. An example of this approach is Songdo in South Korea, which is currently in the construction phase of a ubiquitous city. It is the largest private development project in the world, with the assumption that it will become a business centre comparable to such metropolises as Shanghai, Hong Kong, Kuala Lumpur and Singapore (Hussain et al., 2021). The initial period of Smart Cities was focused on individual, siloed solutions. Sensor-based traffic management, smart lighting and public WiFi were first to be adopted, introduced by companies keen to showcase their innovations. While efficiency gains were achieved, these isolated implementations lacked a centralized vision and often overlooked citizen needs.

Smart City 2.0 represents a stage in the development of Smart Cities, where public administration plays a key role (Trencher, 2019). In this case, it is the local government that initiates the use of modern technologies, and the introduction of innovative solutions is aimed at improving the quality of life of residents. In this period, data centres and centralized dashboards allowed for coordinated management of various systems, leading to improved traffic flow, waste management and energy consumption. However, concerns about data privacy and citizen involvement began to surface (Etezadzadeh, 2015). Examples of such cities include Seoul and San Francisco, which have been highlighted as examples of Smart City implementation (Lee et al., 2014). Today, most of the cities implementing Smart City projects are within Generation 2.0 (Azkuna, 2012).

Smart City 3.0 means that many influential modern cities are actively involving their residents in shaping further development. In this phase, local governments are focusing on creating spaces and opportunities to tap the diverse potential of residents as co-producers of public services. The focus shifted from technology-centric to citizen-centric (McKenna, 2016). Open data platforms empowered citizens to access information and engage in decision-making. Participatory budgeting and interactive platforms fostered dialog between residents and city authorities (Yun and Lee, 2020). However, challenges remained in ensuring equitable access to technology and addressing digital divides.

Although Smart City 3.0 remains focused on the use of modern technology to improve the quality of life in cities, its scope of interest also includes social, equality, educational and environmental issues, going beyond the projects characteristic of the second generation. Smart City 3.0 fits into the growing sharing economy (Nugraha, 2020). This often implies the need for courage on the part of city governments, which must confront the growing role of residents, for example by introducing participatory budgeting. Nevertheless, it is important not only to change the mentality (authorities-citizens), but especially the sphere of communication. At this stage, tools based on AI are beginning to be used more and more in the Smart City.

At the stage of **Smart City 4.0**, with the rise of AI and advanced analytics, cities are gaining access to deeper insights from their data. Predictive maintenance, AI-powered traffic management and personalized citizen services are becoming a reality. However, ethical considerations regarding AI usage and potential job displacement require careful navigation (Alexopulos et al., 2022). At this stage, customization and personalization of the city's services is being pursued.

In the development of a Smart City 4.0, it is essential to consider the intricate web of connections that yield tangible advantages. Employing blockchain technology for data encryption and distribution becomes crucial, as certain existing Smart City systems already leverage such technological advancements (Makieła et al., 2022). Building a Smart City 4.0 is closely tied to previous industrial revolutions characterized by robotics, AI, nanotechnology, the IoT and self-driving vehicles (Smart City 4.0, 2023). This transformative technological shift carries substantial social and economic implications for urban areas and the environment, integral to the pursuit of sustainable development, thereby establishing elevated expectations for citizens. Table 1.3 provides a description of differences between Smart City 3.0 and Smart City 4.0.

Table 1.3 Differences between Smart City 3.0 and Smart City 4.0

Feature	*Smart City 3.0*	*Smart City 4.0*
Focus	Citizen-centric	Data-driven and AI-powered
Key technologies	Open data platforms, participatory budgeting, digital twins	AI, predictive analytics, blockchains
Data usage	Used for transmitting informing decisions and personalized services	Used for deeper insights, prediction and automation
Citizen engagement	Active participation and feedback encouraged	Extensive analysis of needs and expectations
Partnership	Collaboration with some external partners	Extensive collaboration with various stakeholders
Challenges	Equitable access to technology, digital divide	Ethical considerations of AI, potential job displacement
Sustainability	Considered, but not the main focus	A core principle, integrated with solutions
Examples	Seoul, San Francisco	Cities investing heavily in AI and advanced analytics

Source: Alexopulos et al. (2022); Nugraha et al. (2020); Makieła et al. (2022), Garau et al. (2023).

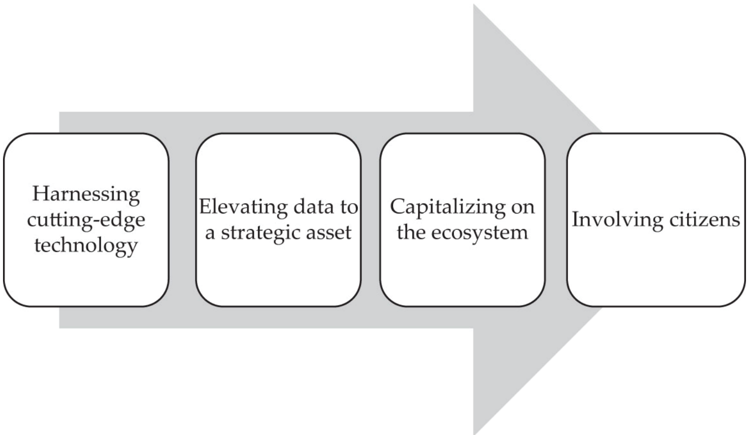

Figure 1.2 Steps towards Smart City 4.0.

Source: Authors' own study.

To reach Smart City 4.0, the following steps must be taken (Figure 1.2; Smart City 4.0, 2022):

- Harnessing cutting-edge technology. Smart City 4.0 has invested significantly in fundamental technologies, like cloud computing, mobile applications, IoT and Robotic Process Automation (RPA). Additionally, they have adopted specialized solutions, such as biometrics, blockchains, AI and telematics. These cities utilize smart technologies and applications to promote the achievement of Sustainable Development Goals (SDGs).
- Elevating data to a strategic asset. Smart City 4.0 leverages a diverse range of data types, with a particular emphasis on actively utilizing data from IoT, citizen engagement, biometrics, geospatial sources, peer-based interactions, business operations and real-time information.
- Capitalizing on the ecosystem. Smart City 4.0 collaborates extensively with external partners beyond local government entities. These partnerships include academic institutions, community organizations, industry associations, city networks, businesses and financial institutions.

- Involving citizens. More than half of Smart City 4.0 analyses the needs and expectations of citizens, actively seeking their feedback. Additionally, over 6 out of 10 cities closely collaborate with their employees to understand their requirements.

Smart City 5.0 represents an advanced stage in the evolution of cities, acknowledging their intricate and complex nature as urban systems (Svitek and Kozhevnikov, 2023). As cities continue to grow, they face challenges, such as traffic congestion, pollution, immigration, overcrowding and insufficient services. To address these issues, a new concept is proposed, viewing each city as a dynamic and continually evolving complex adaptive system (Rastogi et al., 2023).

Smart City 5.0 addresses the limitations of previous Smart City research, shifting from a provider-centric perspective (focusing on how technologies improve city objectives) to a citizen-centric viewpoint. It emphasizes how technologies can overcome constraints for citizens, such as the implementation of suburban working hubs to eliminate the need to navigate congested city centres (Becker et al., 2023). In essence, Smart City 5.0 aspires to create a 'liveable' city that goes beyond tangible benefits, connecting to the broader idea of a 'happy city' (Brdulak and Brdulak, 2017).

Smart City 5.0 represents a paradigm envisioning Smart Cities with a strong emphasis on human-centric design and addressing challenges faced by citizens (Svitek et al., 2020). This approach is akin to Industry 5.0, highlighting a human-centric philosophy that prioritizes core human needs and interests in city management (Svitek et al., 2023). Rather than solely exploring the possibilities of new technologies, Smart City 5.0 focuses on what the city can do for its residents, aiming to remove constraints that impact their perception of liveability.

Aligned with the European Commission's concept of Industry 5.0 (Breque et al., 2021), Smart City 5.0 aims to establish a living environment devoid of constraints by integrating human-centric principles into city solutions (Rastogi et al., 2022). The ultimate objective is to enhance well-being, as defined by the Organization for Economic Cooperation and Development (OECD), encompassing local material conditions, quality of life and sustainability (OECD, 2020). Smart City 5.0 strives to achieve well-being through initiatives that improve health, education, social services, citizen participation, environmental impact, vulnerability reduction and enhanced security (Becker et al., 2023).

Table 1.4 provides a characterization of the discussed Smart City 1.0–5.0 concepts, summarizing the current discussion.

At present, successive models of economic helixes clarify the concept and principles of cooperation between local participants in innovation processes in the face of the challenges of the global economy and the expectations of society. They are closely correlated with the development of smart urban structures described earlier. In retrospect, the following generations of helixes can be distinguished (Carayannis and Campbell, 2009; Carayannis et al., 2012):

- First Helix – Academia, universities, higher education system;
- Second Helix – Industry firms, economic system;
- Third Helix – State government, political system;
- Fourth Helix – Media-based and culture-based public;
- Fifth Helix – Natural environment, sustainability.

The innovation model, known as the Triple Helix, involves a series of interactions among the academia (represented by the university), industry and government. Its purpose is to promote economic and social development in alignment with concepts like the knowledge economy and knowledge society. In the theoretical framework of the innovation helix, each sector is depicted as a circle, or helix, with overlapping regions indicating interactions (Lopes and Luciano, 2023).

The initial model has evolved from 2 dimensions to illustrate more intricate interactions, particularly over time. The concept was originally formulated by Henry Etzkowitz and Loet Leydesdorff in the 1990s, with the release of 'The Triple Helix, University-Industry-Government Relations: A Laboratory for Knowledge-Based Economic Development' (Etzkowitz and Leydesdorff, 1995). The interactions between universities, industries and governments have led to the emergence of new intermediary institutions, such as technology transfer offices and science parks. Etzkowitz and Leydesdorff proposed a theoretical framework to explain the relationship between these 3 sectors and the formation of these innovative hybrid organizations. The adoption of the Triple Helix innovation framework has been widespread, and its application by policy-makers has played a role in transforming each sector.

Table 1.4 Evolution of Smart City from 1.0 to 5.0

Stage	*Time frame*	*Focus*	*Key features*	*Description*
1.0	1990s–2000s	Basic automation and efficiency	Traffic light control, automated waste collection	Isolated technology solutions; focus on improving operational efficiency; limited citizen engagement
2.0	2010s	Data collection and analysis	Sensors, IoT devices, integrated platforms, citizen engagement	Centralized platforms for data collection and management; improved resource allocation; early stages of citizen involvement
3.0	2020s	Human-centric	Personalized services, advanced technologies (blockchains, digital twins), ethical considerations, data privacy	Personalized citizen services; integration of advanced technologies like blockchains and digital twins; emphasis on ethical AI and data privacy
4.0	2025s	The usage of AI in a Smart City	Predictive analytics, sustainability, resilience, public–private partnerships	Open data platforms; AI-powered insights for decision-making; focus on sustainability and resilience; increased citizen participation
5.0	2030s+	Autonomous and adaptive cities	Seamless physical and digital integration, advanced AI and robotics, long-term sustainability, social equity	Self-healing infrastructure; autonomous mobility solutions; seamless integration of physical and digital worlds; focus on long-term sustainability and social equity

Source: Authors' own study.

The Triple Helix model states that the 'innovation ecosystems' within cities evolve through the collaboration of 3 distinct agents (Pique, 2019):

- Universities, acting as magnets to foster scientific and technological knowledge.
- The industrial sector, playing a crucial role in driving economic growth.
- Government entities at various levels (local, regional, national and international), actively involved in initiatives, governance and the formulation of land use policies.

The quadruple and quintuple innovation helix framework delineates interactions between universities, industries, government, public and environment within the context of a knowledge economy. Elias G. Carayannis and David F. J. Campbell (Carayannis and Campbell, 2009) co-developed the quadruple and quintuple innovation helix framework, with the Quadruple Helix model introduced in 2009 and the Quintuple Helix in 2010 (Carayannis and Campbell, 2010). The concept of extending the Triple Helix model to a Quadruple Helix was explored by various authors during the same period. The Carayannis and Campbell Quadruple Helix model integrates the public through the concept of a 'media-based democracy', highlighting the importance of effective communication of innovation policy by the government to the public and civil society through the media to garner support.

For industries engaged in research and development (R&D), the framework underscores the need for companies' public relations strategies to navigate media-driven 'reality construction'. The Quadruple and Quintuple Helix frameworks can be explained in terms of the knowledge models they utilize and the 5 subsystems (helixes) they encompass (Kuzior and Kuzior, 2020). In a Quintuple Helix model, knowledge and know-how are generated, transformed and circulated, influencing the natural environment (Suzic et al., 2020). Socio-ecological interactions facilitated by the Quadruple and Quintuple Helixes can be leveraged to identify opportunities for the knowledge society and knowledge economy, particularly in addressing sustainable development, including challenges like climate change.

The Quadruple Helix model emphasizes the inclusion of the cultural pillar and underscores the significance of constructing and communicating 'public awareness', asserting its impact across all dimensions of the system (Schütz et al., 2019). Nordberg (2015) characterizes the fourth helix as a more 'cultural' dimension and a backdrop crucial to the innovation roadmap. Ivanova (2014), approaching the subject from a systemic perspective with a focus on services, argues that the Quadruple Helix model not only engages consumers, but also addresses communication and media aspects (Yazici, 2023).

On a contrasting note, Höglund and Linton (2018) contend that the fourth helix is not a separate additional component, but an integral part of society, serving to respond to citizens' needs (Gasco-Hernandez et al., 2022). Despite the unquestionable contribution of the Quadruple Helix model, there exists a methodological challenge in how citizens introduce their public perspective, and how various actors define their functional role within society as a fourth pillar, collaborating with innovative processes (Taratori et al., 2021).

Carayiannis et al. (2012) describe the Quintuple Helix model as simultaneously interdisciplinary and transdisciplinary, highlighting the fifth helix's role in providing a more analytical perspective for the dynamic involvement of all stakeholders. This evolved model places a significant emphasis on an active and more 'human-oriented' approach, particularly emphasizing the circular process of knowledge production between subsystems, such as society and the economy (Crumpton et al., 2021). The Quintuple Helix model underscores the importance of collective efforts and exchange across education, the economy, the environment, society and political systems (Carayannis and Campbell, 2010).

The innovation processes within the Quintuple Helix model incorporate a fifth dimension, focusing on the nature and social ecology. However, a lingering question within this model is the challenge of connecting the 5 helixes in an innovation process. Markard et al. (2012) propose a response centred around 'ecology', which encompasses interdisciplinary relations between living organisms (social) or between them and their environments (natural), forming an integrated 'ecosystem'. The various concepts within the Quintuple Helix model converge in the society–nature transition (Van Den Berg and Verster, 2023). Consequently, the Quintuple Helix places particular emphasis on translating environmental and ecological issues, identifying them as crucial 'drivers' for future knowledge and innovation (Taratori et al., 2021).

The concept of successive Smart Cities from 3.0 to 5.0 is closely linked to successive helixes of economic development. The three-layered structure of economic development (Triple Helix) involves business, city and science and is gradually joined by the local community (Quadruple Helix) and environmental and cultural organizations (Quintuple Helix). This configuration of cooperation should ensure the achievement of the intended goals of all stakeholders and promote sustainable and dynamic economic development in the local and regional area.

Currently, 3 models of socio-economic cooperation – Triple Helix, Quadruple Helix and Quintuple Helix – are an important part of the evolution of the Smart City concept from version 3.0 to 5.0. In the context of Smart City 3.0, where AI and machine learning are beginning to play a key role, the Triple Helix model points to the integration of business, the city and science. Collaboration between these 3 sectors is becoming crucial for the effective use of modern technology to improve the quality of life of residents.

The transition to Smart City 4.0, which emphasizes human-centred design, personalization of services and ethical aspects, involves an expansion of the collaboration model. Quadruple Helix is including the local community, reflecting the growing role of citizens in decision-making. Together with business, the city and science, the local community is becoming an active participant in shaping dynamic and sustainable solutions for cities.

As we reach the Smart City 5.0 stage, where cities are becoming autonomous and adaptive, the Quintuple Helix model is becoming a key element. It includes not only business, city, science and community, but also environmental organizations. This expanded cooperation takes into account not only technological and social aspects, but also issues of sustainability and social equality. The efforts of these 5 areas of cooperation are aimed at creating autonomous and sustainable cities, integrating the physical and digital worlds and nurturing long-term social equality.

1.2 Areas of Smart City development and evaluation

The literature identifies 6 so-called pillars of Smart City (Table 1.5). Those pillars were first described by McKinsey Group in 2018 (McKinsey Global Institute, 2018). Smart governance plays a crucial role in leveraging digital technologies to streamline administrative

Table 1.5 Six pillars of Smart City

Pillar	*Description*	*Examples*
Smart Governance	Utilizes advanced information and communication technologies to streamline administrative processes, enhance transparency and improve decision-making within municipal authorities	Electronic voting systems, online citizen engagement platforms, digital services
Smart Economy	Fosters economic growth by integrating digital innovations, supporting entrepreneurship, encouraging innovation and implementing sustainable business practices	Innovation hubs, digital payment systems, technology incubators
Smart Mobility	Revolutionizes urban transportation through intelligent solutions, including efficient public transit, smart traffic management and promotion of sustainable transport modes	Intelligent traffic lights, real-time public transportation tracking, bike-sharing systems
Smart Environment	Monitors and manages environmental resources by optimizing waste management, conserving energy and ensuring sustainable water usage to minimize ecological impact	Smart waste bins, energy-efficient street lighting, water usage monitoring systems
Smart Living	Improves the quality of life for residents by deploying smart infrastructure, such as intelligent buildings, healthcare systems and educational institutions	Smart homes with automation, telemedicine services, smart classrooms
Smart People	Empowers citizens through digital literacy, access to information and community engagement, fostering a sense of inclusion and participation in shaping the city's future	Digital education initiatives, community engagement platforms, citizen forums

Source: Embarak (2021); Khan et al. (2020); Wolniak and Jonek-Kowalska (2023).

processes, enhance transparency and improve decision-making within municipal authorities (Embarak, 2021). This pillar focuses on using data-driven insights and communication technologies to create a more responsive and efficient government. The smart economy pillar is centred on fostering economic growth through the integration of digital innovations. This involves supporting entrepreneurship, encouraging innovation and implementing sustainable business practices (Izbash et al., 2023). By leveraging technology, Smart Cities aim to create a resilient and dynamic economic environment (Belaid et al., 2024).

Smart mobility is a key pillar that focuses on revolutionizing urban transportation. This involves the integration of intelligent transportation systems, efficient public transit options and the promotion of sustainable modes of transport (Wolniak, 2023). The goal is to reduce traffic congestion, enhance connectivity and minimize the environmental impact of transportation. In the case of the smart environment, cities strive to monitor and manage their environmental resources effectively. This includes deploying technologies to optimize waste management, conserve energy and ensure sustainable water usage. The emphasis is on creating urban spaces that minimize ecological impact and promote environmental sustainability (Xu, 2023).

Smart living is another important pillar that seeks to improve the quality of life for city residents. This involves the deployment of smart infrastructure, such as intelligent buildings, healthcare systems and educational institutions (De Matos and Ramos, 2023). These initiatives aim to create safer, more comfortable and accessible living environments for citizens. Lastly, the smart people pillar focuses on empowering citizens through digital literacy, access to information and community engagement (Khan et al., 2020). By fostering a sense of inclusion and participation, Smart Cities aim to create a more informed and actively involved citizenry, encouraging collaboration in shaping the city's future.

Implementing a Smart City is a complex process that is closely linked to the development of technical infrastructure. A key aspect is the development of advanced communications systems, including broadband Internet networks and cellular technologies. Telecommunications infrastructure plays a key role in enabling high-speed data transfer between different elements of a Smart City (Sharifi and Alizadeh, 2023).

Today's Smart Cities are complex ecosystems that use a range of advanced technologies to improve the quality of life of residents, increase the efficiency of urban services and contribute to sustainable development. One of the key elements of this concept is the development of the IoT, enabling various urban devices to connect and collaborate (Streitz et al., 2023).

Sensors and monitoring systems are an important component of the Smart City, enabling real-time data collection. With them, cities can monitor traffic, air quality, energy consumption or waste volumes, allowing them to react quickly to changes and optimize different areas of urban life. Data analysis and AI technologies also play a key role. Advanced algorithms allow processing vast amounts of information, identifying patterns and forecasting events. This enables more effective planning for urban development, optimized traffic management, or even faster response to emergencies (Tamas and Dora, 2023).

Smart transportation systems are another important area of technology in the Smart City. The development of public transportation, car-sharing systems, traffic management platforms or the development of autonomous vehicles are improving transportation accessibility, reducing traffic jams and emissions (Wolniak, 2023; Kowalska and Wolniak, 2023).

Energy is a key area, where modern technologies are being used. Smart Grids, or smart energy networks, allow efficient management of energy supply, increase the share of renewable sources and minimize losses (Gajdzik et al., 2024). Energy infrastructure must be upgraded to integrate new technologies, such as smart grids. These enable optimal management of energy consumption, monitoring of the grid and introduction of renewables.

Smart Cities prioritize involving and empowering citizens in the management of energy. They encourage active participation in energy conservation, promote informed decision-making regarding energy usage and foster contributions to a sustainable future. Innovative strategies in electric systems provide citizens with tools, platform and real-time data access to monitor and control their energy consumption, enabling them to actively play a role in creating a more efficient and sustainable electric system. In the context of Smart Cities, energy systems encompass an integrated network of infrastructure, technologies and policies designed to facilitate efficient energy generation, distribution and consumption within urban environments. These systems aim to optimize energy usage, mitigate carbon emissions and enhance overall sustainability.

Adoption of a new approach to electric systems in Smart Cities becomes imperative to meet the increasing energy demands, address environmental concerns, bolster grid resilience, accommodate decentralized energy generation, leverage technological advancements and empower citizens. Through the integration of renewable energy sources, smart grids, energy storage solutions, as well as advanced monitoring and management systems, Smart Cities can establish electric systems that are more efficient, sustainable and resilient, tailored to the evolving needs of urban environments (Gajdzik et al., 2024).

Seven primary elements constitute the energy systems in Smart Cities: renewable energy generation, smart grids, energy storage, demand response and energy efficiency, electric mobility, energy management systems and citizen engagement. Table 1.6 provides detailed

Table 1.6 Main components of energy systems used in Smart Cities

Component	*Characteristics*
Renewable energy generation	Smart Cities prioritize utilizing renewable energy sources, such as solar, wind, geothermal and biomass. They integrate various renewable systems like solar panels, wind turbines and geothermal heating/cooling.
Smart grids	Advanced electrical grids in Smart Cities incorporate digital technologies, sensors and automation to optimize electricity distribution. Smart grids enable real-time monitoring, efficient load balancing and integration of decentralized energy sources. They also facilitate two-way communication between utilities and consumers, supporting demand response programmes and energy conservation.
Energy storage	Crucial for Smart Cities, energy storage technologies efficiently capture and store surplus energy from renewables during peak production. Solutions like batteries, pumped hydro storage and compressed air energy storage balance electricity supply and demand, ensure grid stability and provide backup power during outages.
Demand response and energy efficiency	Smart Cities implement demand response programmes to encourage consumers to adjust energy usage during peak demand. Real-time data and communication networks provide incentives for reducing or shifting energy consumption. Additionally, energy-efficient technologies and practices, including smart appliances, LED lighting, intelligent HVAC systems and building automation, are promoted.

Table 1.6 (Continued)

Component	*Characteristics*
Electric mobility	Smart Cities promote electric vehicle (EV) adoption through comprehensive charging infrastructure, strategically placed in residential areas, parking lots and public spaces. Integration with renewable sources and smart grids manages increased energy demand, promoting sustainable transportation options.
Energy management systems	These systems use data analytics and AI algorithms to monitor and optimize energy consumption across various sectors. They collect and analyse data from sensors and devices to identify inefficiencies, recommend energy-saving measures and enable predictive maintenance. Energy management systems allow real-time monitoring, analysis and control of energy usage at the city-wide level.
Citizen engagement	Smart Cities actively engage citizens in energy conservation. They provide real-time energy consumption data, user-friendly interfaces and personalized recommendations. Awareness campaigns, educational programmes and interactive platforms empower individuals and communities to make informed choices for a sustainable energy future.

Source: Gajdzik et al., (2024); Sarjana (2023); Darmawan et al. (2023).

characteristics of each of these components. The goal of integrating these elements and encouraging collaboration among stakeholders is to optimize energy utilization, decrease carbon emissions, improve grid resilience and cultivate a sustainable and enjoyable urban environment.

Smart City communication relies on telecommunication technologies, creating smart networks that enable the rapid exchange of information between devices, as well as between residents and city authorities. It is also worth highlighting the development of blockchain technologies, which can find application in the area of data security, transparency of transactions or even in urban identification systems (Kalenyuk et al., 2023). The implementation of Smart City also requires the modernization of building infrastructure to enable the integration of smart solutions into existing urban infrastructure.

Notably, the most important technologies in a Smart City are not just single solutions, but a comprehensive system, in which diverse technologies work together to create smart, integrated urban environments. It is the interaction of various innovations – from sensors to AI – that contribute to efficient and sustainable urban development. Table 1.7 provides an overview of selected technologies used in Smart Cities.

Table 1.7 Characteristics of selected technologies used in Smart Cities

Technology	*Characteristics*
IoT	The IoT enables the integration of various devices, sensors and systems to form a smart network. This allows data on the environment, transportation, energy and other areas to be collected and then analysed for effective city management. IoT can include smart street lights, environmental sensors, smart energy meters, etc.
Sensors and monitoring	Using advanced sensors to continuously monitor various parameters of the urban environment. Sensors can measure pollution levels, humidity, temperature, noise levels, as well as monitor traffic and waste volumes. This data is then analysed to make informed urban planning decisions.
Big Data Analytics	Big Data Analytics is a technology that makes it possible to analyse huge amounts of data, from various sources, to identify patterns and trends. In the context of the Smart City, data analytics allows for a better understanding of residents' behaviour, urban infrastructure needs and optimization of public service delivery.
Traffic management systems	Advanced traffic management systems include smart traffic signals, traffic monitoring cameras, dynamic traffic guidance systems and parking monitoring. These technologies help minimize traffic jams, improve road safety and optimize the use of urban space.
E-mobility	E-mobility focuses on the introduction of electric modes of transportation, such as electric cars, electric bicycles and scooters. Infrastructure supporting e-mobility includes charging stations and traffic management systems for electric vehicles. The goal is to reduce greenhouse gases emissions and improve air quality.
Smart grid	Smart Grid integrates communications technology into the power grid. This allows monitoring, control and optimization of electricity distribution in real time. Smart Grid helps increase energy efficiency and integrate renewable energy sources.

Table 1.7 (Continued)

Technology	*Characteristics*
Waste management systems	Waste management systems use technology to monitor the capacity and condition of trash containers, optimize trash collection routes and promote waste segregation. Smart garbage cans can report when they are full, enabling efficient waste management and minimizing environmental impact.
Digital participatory platforms	Participatory technologies include online platforms, mobile apps and social media tools that enable residents to actively participate in decision-making processes. This can include public consultations, online voting, participation in community projects and tracking government activities.
Smart lighting	Smart lighting systems use motion, time and weather sensors to adjust light intensity. This saves energy by turning the light on only when needed, contributing to a sustainable city.
Blockchains in government	Blockchain technology used in government can secure data, facilitate transactions, eliminate bureaucracy and increase transparency. With its decentralized structure, blockchains can improve data security and facilitate administrative processes, such as citizen data management and property registration.
AI	AI in Smart Cities can be used to analyse data, forecast trends, optimize traffic, personalize public services and improve energy efficiency. Machine learning algorithms can help respond more quickly to changes and adapt to residents' needs.
5G and mobile networks	The deployment of 5G technology and the development of high-speed cellular networks enable fast and stable data transmission, which is crucial for the efficient operation of many Smart City applications. This supports communication between IoT devices, enabling seamless city management and improving access to online services.
Biometrics and identification	Biometric technologies, such as facial recognition, fingerprint readers and iris scanners, can be used to secure access to buildings, monitor public safety and authorize transactions, helping to improve overall security in the city.
Drones and unmanned aerial vehicles	The use of drones in the Smart City includes monitoring traffic, patrolling urban areas, delivering packages and inspecting infrastructure. This acts as an additional tool for rapid response to emergencies, monitoring hard-to-reach areas and enhancing public safety.

(*Continued*)

Table 1.7 (Continued)

Technology	*Characteristics*
Augmented reality	Augmented reality (AR) technology can be used to provide information about the surrounding environment, urban navigation, education and to create interactive cultural experiences. AR can improve residents' interaction with the urban environment and enhance education and tourism processes.
Green technologies	They include innovative solutions for sustainable urban development, such as energy-efficient buildings, green roofs, photovoltaic panels and rainwater recycling. These technologies contribute to reducing emissions, protecting the environment and improving the quality of life for residents.
Epidemic tracking systems	Using technologies, such as GPS tracking, AI and data analytics, to monitor, predict and manage potential epidemics, which is crucial in the context of public health.
Smart health	Integration of technology in the health sector includes telemedicine, population health monitoring, medical data management systems and access to electronic patient records. Smart health supports efficient healthcare delivery, disease prevention and improved quality of life for residents.
Geolocation and GIS	Geographic information systems (GIS) and geolocation technologies help in effective urban planning, management of urban infrastructure data, analysis of areas at risk and creation of interactive maps for residents. These are tools that support sustainable development and urban planning.
Urban robotics	Urban robotics includes the use of robots for a variety of tasks, such as maintenance, deliveries, infrastructure inspections and construction work. Robots can operate autonomously or be remotely controlled, helping to improve efficiency and safety in the city.

Source: Authors' own work based on Wolniak (2023); Streitz et al. (2023); Kalenyuk et al. (2023); Sarjana (2023); Tamas and Dora (2023); Duan et al. (2022); Zhou (20220; Al Nuaimi et al. (2015); Wolniak and Grebski (2023); Kvalvik et al. (2023); Vlahkis et al. (2023); Dadwal et al. (2023); Barrera-Camara et al. (2023); Ruiz-Vanoye (2023); Pellatt and Palfreman (2023); Kondratenko et al. (2023); Caputo et al. (2015); Raj and Shetty (2024); Ali et al. (2023); Ddeja et al. (2023); Kramarz et al. (2022); Jonek-Kowalska (2022); Jonek-Kowalska (2023); Wolniak (2023); Stecuła et al. (2023).

Smart City and Industry 4.0 are interdependent areas that support each other, leading to more integrated and efficient societies. Industry 4.0, also known as the fourth industrial revolution, focuses on the intelligent use of digital technologies in manufacturing, while Smart City focuses on using these technologies to improve the quality of life in urban areas.

In the context of Industry 4.0, automation, cyber-physical systems, the IoT and data analytics are key. These same technologies are also key to Smart City. The automation of manufacturing processes in Industry 4.0 aims to increase efficiency, reduce costs and optimize resources. In Smart City, these technologies are used to monitor and manage various aspects of urban life, such as transportation, energy, waste management and public services (Kurshudov, 2024).

Industry 4.0 is bringing innovation to manufacturing, introducing smart factories, where machines communicate with each other and make autonomous decisions. Within the Smart City, the same principles can be applied to urban infrastructure management. For example, smart traffic management systems can use sensor data and data analysis algorithms to optimize traffic, reduce congestion and improve safety (Wolniak, 2023).

The IoT plays a key role in both Industry 4.0 and Smart City. In the context of Industry 4.0, devices in manufacturing plants communicate with each other, enabling monitoring, analysis and optimization of processes (Manfreda and Mijač, 2024). In Smart City, IoT enables the connection of various elements of urban infrastructure, such as smart streetlights, environmental sensors and Smart City platforms, to collect data, monitor and manage resources efficiently.

The collaboration between Industry 4.0 and Smart City is helping to create more sustainable, efficient and resident-friendly cities. Smart technologies not only streamline production processes, but also enable dynamic and adaptive management of urban infrastructure, resulting in improved quality of life for residents and optimal use of urban resources. As a result, this synergy between Industry 4.0 and Smart City is a key development direction for modern societies.

Table 1.8 presents a comparison between Smart City and Industry 4.0.

Implementation of the Smart City concept has the potential to affect public policy in the city. Using advanced digital infrastructure and data-driven solutions, the implementation of Smart City solutions can help improve security (Teng et al., 2024). One key aspect in

Table 1.8 Comparison between the Smart City concept and Industry 4.0

Aspect	*Smart City*	*Industry 4.0*
Scope	Encompasses a wide range of urban services and infrastructure, including transportation, energy, healthcare and governance.	Primarily focuses on the transformation of manufacturing and industrial processes, optimizing production through digital technologies.
Key technologies	IoT, Big Data, AI, sensors, smart grids and communication technologies are integral for managing city services efficiently.	IoT, Industrial IoT (IIoT), cloud computing, machine learning and robotics play crucial roles in creating smart and interconnected industrial systems.
Objectives	Enhancing quality of life, sustainability and efficiency in urban areas. Improving public services, infrastructure and citizen well-being.	Enhancing manufacturing processes, increasing efficiency, reducing downtime and enabling more flexible and agile production. Improving productivity and product quality.
Focus on data	Relies heavily on data analytics for optimizing city operations, predicting trends and improving decision-making in areas like traffic management and waste disposal.	Emphasizes data-driven decision-making in industrial settings to optimize production, predict maintenance needs and enhance overall operational efficiency.
Integration of systems	Aims to integrate various urban systems, such as transportation, energy and public services, to create a holistic and interconnected urban environment.	Focuses on integrating digital technologies into the entire manufacturing process, from design and production to supply chain and customer service.
User involvement	Involves citizen participation through platforms for feedback, engagement and collaboration to address the needs and preferences of residents.	Involves collaboration between machines, systems and human operators, emphasizing human-machine interaction and cooperation in the manufacturing environment.

Table 1.8 (Continued)

Aspect	*Smart City*	*Industry 4.0*
Cyber-physical systems	Emphasizes the deployment of sensors and devices in the physical environment to collect and transmit data for improved decision-making and automation.	Utilizes cyber-physical systems in manufacturing equipment and processes to enable real-time monitoring, control and optimization of industrial operations.
Challenges	Privacy concerns, security issues and the need for extensive infrastructure investment are common challenges.	Implementation costs, workforce adaptation and potential job displacement due to automation are challenges faced in the adoption of Industry 4.0.
Global adoption	Smart City initiatives are being implemented globally on various scales, with cities around the world investing in technology to become smarter and more sustainable.	Industry 4.0 is a global phenomenon transforming manufacturing industries, with countries and industries adapting to stay competitive in the digital age.

Source: Authors' own work based on Wolniak et al. (2023).

this regard is improving public safety through advanced monitoring systems. Smart City initiatives often include the deployment of intelligent video analytics, sensors and IoT devices to detect and respond to incidents in real time. This approach can help prevent crime, optimize emergency response and generally maintain public order (Li et al., 2024).

Traffic management is another important area, where Smart City implementation can have a significant impact. Smart transportation systems use data analysis to optimize traffic flow, reduce traffic jams and improve overall mobility. This not only leads to more orderly and efficient transportation, but also reduces the potential for traffic-related disruptions and conflicts (Elhofy et al., 2023).

When it comes to public management, Smart City systems use data analysis and digital platforms to streamline administrative processes. This can result in improved delivery of public services, faster responses to citizens' concerns and increased overall communication between authorities and residents.

The implementation of smart infrastructure in the city contributes to sustainable development, which indirectly affects public policy. Initiatives such as efficient waste management, energy conservation and pollution monitoring can contribute to a cleaner and healthier urban space. A clean and healthy environment can positively affect the well-being of residents and contribute to the quality of urban life (Rele and Patil, 2023).

In terms of public policy in Smart Cities, it is important to address potential challenges related to privacy, data security and equal access to these technologies to ensure that the benefits of Smart City implementation are felt by all residents. Furthermore, public awareness and involvement are key to the successful adoption of these technologies, as informed and engaged citizens are more likely to support and actively participate in Smart City development. Table 1.9 reviews selected Smart City solutions that impact security.

Table 1.9 Solutions used in Smart Cities that affect security

Area	*Description*
City monitoring	The use of advanced surveillance systems, smart cameras and sensors to continuously monitor the urban area. This allows for rapid detection of incidents, including crimes, accidents or dangerous situations.
Smart video analysis	The use of video analysis technology to identify unusual behaviour, facial recognition or vehicle registration. This allows rapid response to potential threats and tracking of suspects.
Alarm systems	Implementation of smart alarm systems that can be activated automatically in response to identified threats. This allows for instant notification of emergency services and minimizes response time.
IoT sensor networks	Expand the infrastructure of IoT sensors to monitor various parameters, such as air pollution levels, noise or water quality. This data is analysed in real time to maintain a safe environment.
Smart street lighting	The use of street lighting systems that adapt to environmental conditions. Smart streetlights can respond to movement by changing the intensity of the light, increasing safety and saving energy.

Table 1.9 (Continued)

Area	*Description*
Emergency management systems	Creating integrated emergency management platforms that result in a coordinated response to emergencies. This includes monitoring, communicating and coordinating emergency services and informing communities of risks.
Safe transportation infrastructure	Implementation of traffic monitoring systems that identify and manage road hazards. Smart traffic signals, cameras and warning systems help ensure safe mobility in the urban area.
Public safety mobile apps	Developing mobile apps to quickly report incidents, access safety information and receive alerts. This increases community involvement in maintaining safety through active participation in the monitoring and reporting process.
Analysing data to predict threats	Using advanced data analysis technologies to predict potential threats. Algorithms can analyse data from a variety of sources, identifying patterns and correlated events, making it possible to prevent incidents before they occur.
Education and public awareness	Organizing educational campaigns and activities to raise community awareness of the benefits and security associated with Smart City technology. Informing residents about measures taken to increase safety and promoting active participation.

Source: Li et al. (2024); Konstantopoulou et al. (2024); Erces et al. (2023); Osipova and Hornecker (2023); Elhofy et al. (2023); Qian (2023); Role and Patil (2023); Tomitsch et al. (2023); Vătăşoiu et al. (2023).

Smart City technologies have a significant impact on public participation, enabling more active involvement of residents in public life. Thanks to mobile applications, online platforms and other innovative solutions, the community has easier access to information and the opportunity for direct dialog with local authorities (Arora et al., 2024). Information technologies enable rapid communication of information about local issues, events or planned projects. Residents can raise issues, provide feedback and actively participate in the decision-making process through public consultations or online voting. Participatory platforms integrate different social groups, allowing them to exchange ideas and work together on local initiatives. With this, the community becomes more organized and able to effectively express its needs and expectations.

In addition, smart transportation or waste management solutions allow residents to actively participate in caring for the environment and make more informed decisions about the use of urban resources. As a result, Smart City technologies support the development of civil society, foster transparency in the actions of local authorities and allow for more democratic participation of residents in shaping their environment (Domingo et al., 2021). This makes public participation more dynamic, effective and accessible to a wider spectrum of the local community.

As part of the Smart City, mobile applications are being used in a variety of areas, aiming to improve the city's daily operations. An important application of these is to facilitate public transportation through apps that allow for route planning, online ticketing, monitoring delays or informing about schedule changes (Maddel et al., 2023). Therefore, residents can move around the city more efficiently and the traffic management becomes smoother. Mobile applications are also being used to monitor and manage urban infrastructure, such as street lighting, water supply systems and waste management (Neofotistos et al., 2023). Smart sensors and remote control allow efficient management of resources, minimizing energy consumption and increasing environmental performance.

In the area of public safety, mobile apps support city monitoring systems, allowing residents to report incidents and receive warnings or emergency information (Alam et al., 2022). This increases cooperation between the community and security authorities. In addition, mobile apps are being used to improve access to public services, such as healthcare, education and administration. Electronic appointment scheduling, remote medical consultations or educational platforms are just a few examples of how mobile apps support the operation of these sectors (Stahl and Reiterer, 2022).

From a Smart City perspective, mobile apps are an integrative tool that connects different aspects of urban life, fostering efficiency, sustainability and better alignment of the city with the needs of its residents. Table 1.10 reviews examples of mobile apps that influence social participation in Smart City.

An important issue related to Smart City development is its environmental impact. Smart Cities often promote sustainable transportation, favouring public transportation, electric bicycles or electric cars.

Table 1.10 Example of applications used in the Smart City context

Application	*Characteristics*
mObywatel	This national app allows users to access various public services electronically, including reporting problems, registering vehicles, purchasing public transport tickets and voting in local elections. It fosters participation by simplifying interactions with government and empowering citizens to engage in civic activities.
Locate Me	This app empowers people with disabilities by facilitating navigation and access to public services and facilities. It allows users to report accessibility issues and suggest improvements, promoting inclusive infrastructure and social participation.
DecydujMy	This platform enables citizens to participate in decision-making processes by engaging in public consultations, proposing ideas and voting on initiatives. It encourages open dialog and collaboration between residents and local authorities.
FIXiT	This app allows users to report problems in their city, ranging from potholes to vandalism. It enables citizens to contribute to improving their environment and fosters a sense of community responsibility.
Kulturalna Warszawa	This app provides information about cultural events in Warsaw, allowing users to discover activities, purchase tickets and share their experiences. It promotes cultural engagement and encourages social interaction.
Nextbike	This bike-sharing app facilitates sustainable transportation and allows users to find available bikes for rent. It promotes healthy lifestyles and active participation in urban life.
Lokal	This app provides real-time information about public transport schedules and delays. It improves mobility and accessibility, enabling citizens to plan their journeys and participate more actively in city life.
EcoMap	This app displays air quality data and encourages users to report and discuss environmental issues. It promotes environmental awareness and empowers citizens to advocate for sustainable practices.

Source: Authors' own work based on mObywatel (2024); Locate Me (2024); DecydujMy (2024); FIXiT (2024); Kulturalna Warszawa (2024); Nextbike (2024); Lokal (2024); SoS Alarm (2024).

This approach reduces emissions, improving air quality and reducing atmospheric pollution, which has a positive impact on residents' health and the environment.

In addition, Smart City waste management systems enable more efficient trash management. Monitoring waste levels and segregation automatically lead to a reduction in the amount of waste going to landfills, which reduces the negative impact on soil and water. The previously discussed smart technologies also support sustainable urban design, promoting urban greening, parks and the general availability of recreational areas. This contributes to improving the quality of life for residents and preserving biodiversity in the urban area.

However, it is worth noting that the introduction of the Smart City requires strict control and monitoring to avoid potential negative effects, which will be discussed in detail in Chapter 2, such as excessive consumption of resources for the production of modern technology or the generation of additional electronic waste. Ultimately, the development of Smart City can contribute to reducing the negative impact of cities on the environment, provided the systems are properly designed, implemented and maintained.

The economic development of a Smart City depends on a number of factors that combine to create innovative and sustainable communities (Jonek-Kowalska and Wolniak, 2021). The first key element, discussed in detail earlier, is the technological infrastructure, including broadband Internet connections, sensor networks and data management systems. This allows for the efficient use of information, which is key to improving various aspects of city life.

Another important factor is community involvement and cooperation between the public sector, private sector and civil society. The Smart City concept involves the active participation of residents in decision-making processes and the use of their knowledge in creating innovative solutions. Education and skills development are also a key element in supporting Smart City economic development. Investments in digital education and training related to modern technologies enable residents to use new tools and foster the creation of new jobs.

Sustainability is another aspect that affects the economic progress of a Smart City. This happens through efficient management of resources, reduction of CO_2 emissions, development of public transportation based on green technologies and promotion of renewable energy.

Private and public investments in the new technology sector and start-ups that create innovative solutions have a significant impact on the economic development of the Smart City (Jonek-Kowalska and Wolniak, 2021). Creating a favourable business environment that supports the development of new technologies attracts entrepreneurs and investors.

The economic importance in Smart City development can be observed following the research by Jonek-Kowalska and Wolniak (2021). They observed that the progress of Smart City initiatives in Poland faces challenges due to the inadequate economic well-being of residents and the challenging financial circumstances of cities, limiting their capacity to undertake Smart City projects. Polish cities show a preference for the Triple Helix model, concentrating on fostering business collaborations and establishing favourable conditions for commercial entrepreneurship, rather than engaging higher-order helixes that involve communities or ecological organizations. This inclination might contribute to urban challenges, such as unsustainability and socio-economic exclusion. The evaluated Polish cities are considered average in terms of financial stability, wealth, investment, administrative efficiency and citizen participation. The weakest aspect pertains to the wealth and quality of life of residents, including gross remuneration levels. The economic stability of the city and its indebtedness strongly impact investment parameters, subsequently influencing the city's ability to advance Smart City initiatives.

The underdevelopment of Polish Smart Cities is also evidenced by the predominant utilization of conventional financing methods, relying primarily on budgetary funds and sponsorships, rather than embracing more innovative approaches like public–private partnerships or participatory budgets. To enhance the progression of Smart Cities in Poland, it is imperative to provide support to less developed cities, alleviate local budgets from non-stimulative expenditures, address the fundamental needs of urban communities, improve demographic trends and establish transparent and accessible standards for private–public partnerships.

Bibliography

Al Nuaimi, E., Al Neyadi, H., Mohamed, N., Al-Jaroodi, J. (2015). Applications of big data to smart cities. *Journal of Internet Services and Applications*, 6(1), 1–15.

Alam, T., Hadi, A. A., Najam, R. Q. S. (2022). Designing and implementing the people tracking system in the crowded environment using mobile application for smart cities. *International Journal of System Assurance Engineering and Management*, 13(1), 11–33.

Alexopoulos, C., Keramidis, P., Pereira, G. V., Charalabidis, Y. (2022). Towards Smart Cities 4.0: Digital participation in smart cities solutions and the use of disruptive technologies. *Lecture Notes in Business Information Processing*, 437, 258–273.

Ali, S. A., Elsaid, S. A., Ateya, A. A., ElAffendi, M., El-Latif, A. A. A. (2023). Enabling technologies for next-generation smart cities: A comprehensive review and research directions. *Future Internet*, 15(12), 398.

Arora, A., Jain, A., Yadav, D., Chamola, V., Sikdar, B. (2024). Next generation of multi-agent driven smart city applications and research paradigms. *IEEE Open Journal of the Communications Society*, 4, 2104–2121.

Arun, M. (1999). Smart cities: The Singapore case. *Cities*, 16(1), 16–22.

Azkuna, I. (Ed.) (2012). Smart cities study: International study on the situation of ICT, *innovation and knowledge in cities*. Bilbao: The Committee of Digital and Knowledge-Based Cities of UCLG.

Barrera-Cámara, R. A., Fuentes-Penna, A., Bernabe-Loranca, M. B. (2023). Tools and technologies for smart education in sustainable smart cities. *Management, Technology, and Economic Growth in Smart and Sustainable Cities*, 156–173.

Becker, J., Chasin, F., Rosemann, M. (2023). City 5.0: Citizen involvement in the design of future cities. *Electron Markets*, 33, 10. https://doi.org/10.1007/s12525-023-00621-y

Belaid, F., Amine, R., Massie, C. (2024). Smart cities initiatives and perspectives in the MENA region and Saudi Arabia. In *Smart cities*. Studies in Energy, Resource and Environmental Economics, Berlin: Springer, 295–313.

Brdulak, A., Brdulak, H. (2017). *Happy city: How to plan and create the best livable area for the people.* Berlin: Springer. https://doi.org/10.1007/978-3-319-49899-7.

Breque, M., De Nul, L., Petridis, A. (2021). *Industry 5.0: Towards a sustainable, human-centric and resilient European industry*. Luxembourg: European Commission, Directorate-General for Research and Innovation. https://ec.europa.eu/info/publications/ (accessed 16.02.2024).

Caputo, F., Magliocca, P., Canestrino, R., Rescigno, E. (2015). Rethinking the role of technology for citizens' engagement and sustainable development in smart cities. *Sustainability*, 15(13), 10400.

Carayannis, E. G., Barth, T. D., Campbell, D. F. J. (2012). The Quintuple Helix innovation model: Global warming as a challenge and driver for innovation. *Journal of Innovation and Entrepreneurship*, 1, 2.

Carayannis, E. G., Campbell, D. F. J. (2009). 'Mode 3' and 'Quadruple Helix': Toward a 21st century fractal innovation ecosystem. *International Journal of Technology Management*, 46(3/4), 201–234.

Carayannis, E. G., Campbell, D. F. J. (2010). Triple Helix, Quadruple Helix and Quintuple Helix and how do knowledge, innovation and the environment relate to each other: A proposed framework for a trans-disciplinary analysis of sustainable development and social ecology. *International Journal of Social Ecology and Sustainable Development*, 1(1), 41–69.

Crumpton, C. D., Wongthanavasu, S., Kamnuansilpa, P., Draper, J., Bialobrzeski, E. (2021). Assessing the ASEAN Smart Cities Network (ASCN) via the Quintuple Helix Innovation Framework, with special regard to smart city discourse, civil participation, and environmental performance. *International Journal of Urban Sustainable Development*, 13(1), 97–116.

Dadwal, S. S., Jahankhani, H., Bowen, G., Nawaz, I. Y. (2023). *Technology and talent strategies for sustainable smart cities: Digital futures*. London: Emerald.

Darmawan, A. K., Muhsi, M., Anekawati, A., Umam, B. A., Jalil, D. K. A. (2023). An interpretive structural model approach to strategic management modelling for sustainable smart village development in Indonesia. In *10th International Conference on ICT for Smart Society*, 6–7 Sept. 2023, Bandung, Indonesia.

DecydujMy Razem – Gliwicka Platforma Partycypacyjna. (2024). https://decydujmyrazem.gliwice.pl/ (accessed 16.02.2024).

Deja, A., Ślączka, W., Dzhuguryan, L., Dzhuguryan, T., Ulewicz, R. (2023). Green technologies in smart city multifloor manufacturing clusters: A framework for additive manufacturing management. *Production Engineering Archives*, 29(4), 428–443.

deMatos, N., Ramos, C. M. Q. (2023). Smart cities: Operational concepts for an elusive framework. In *Handbook of research on network-enabled IoT applications for smart city services*, Hershey, PA: IGI Global, 323–338.

Domingo, J., Cabello, K. A., Rufino, G. A., Villanueva-Jerez, M. J., Sarmiento, C. J. (2021). A framework in developing a citizen-centered smart city mobile application as a platform for digital participation in iloilo city. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 46(4/W6-2021), 153–160.

Duan, Y., Xu, C., Hu, W., Zhao, W. (2022). Research on the regulation of artificial intelligence on the orderly development of China's intelligent economy. In *2022 Asia-Pacific Computer Technologies Conference*, Wuhan, China, January 7–9, 2022, 11–15.

Elhofy, M., Abdelaziz, M., Omran, I., Abdelwahab, M. (2023). Effects of independent wheels steering system on vehicle cornering performance and road safety of the smart cities. *Ain Shams Engineering Journal*, 14(6), 102097.

Embarak, O. (2021). Smart city transition pillars with layered applications architecture. *Procedia Computer Science*, 191, 57–64.

Embarak, O. (2022). Smart cities new paradigm applications and challenges. In *EAI/Springer Innovations in communication and computing*, Berlin: Springer, 147–177.

Érces, G., Rácz, S., Vass, G., Varga, F. (2023). Fire safety in smart cities in Hungary with regard to urban planning. *Journal of Integrated Disaster Risk Management*, 13(2), 104–128.

Etezadzadeh, C. (2015). *Smart city – Future city? Smart City 2.0 as a livable city and future market.* Berlin: Springer.

Etzkowitz, H., Leydesdorff, L. (1995). The Triple Helix: University-industry-government relations – A laboratory for knowledge based economic development. *Glycoconjugate Journal*, 14(1), 14–19.

Fitria, I., Rosa, H. U., Firmansyah, M., Lembang, G. R., Mardianto, M. F. F. (2023). Analysis of factors influencing public perceptions of smart city concept of Indonesia's new capital city. *AIP Conference Proceedings*, 2975(1), 080016.

FIXiT. (2024). https://play.google.com/store/apps/details?id=nz.co.android.touchtech&hl=pl (accessed 16.02.2024).

Gajdzik, B., Wolniak, R., Grebski W., Grebski, M., Danel, R. (2024). *Smart cities with smart energy systems. Key development directions*. Gliwice: Silesian University of Technology Publishing House.

Garau, C., Desogus, G., Annunziata, A., Mighela, F. (2023). Mobility and health in the Smart City 3.0: Trends and innovations in Italian context. In *Smart cities and digital transformation: Empowering communities, limitless innovation, s*ustainable *d*evelopment and the *n*ext *g*eneration, London: Emerald, 105–127.

Gasco-Hernandez, M., Yerden, X., Burke, G. B., Gil-Garcia, J. R. (2022). The potential role of public libraries in a Quadruple Helix model of 'Smart City' development: Lessons from Chattanooga. *Sustainability*, 16, 1750.

Höglund, L., Linton, G. (2018). Smart specialization in regional innovation systems: A quadruple helix perspective. *R&D Management*, 48, 60–72.

Hussain, H. I., Haseeb, M., Kamarudin, F., Dacko-Pikiewicz, Z., Szczepańska-Woszczyna, K. (2021). The role of globalization, economic growth and natural resources on the ecological footprint in Thailand: Evidence from nonlinear causal estimations. *Processes*, 9(7), 1103.

Ivanova, I. (2014). Quadruple Helix systems and symmetry: A step towards helix innovation system classification. *Journal of Knowledge Economy*, 5, 357–369.

Izbash, A., Fomenko, O., Danylov, S. (2023). Innovative tools for implementing the smart city concept in architectural urbanism. *IP Conference Proceedings*, 2490(1), 030009.

Jonek-Kowalska, I. (2022). Municipal waste management in Polish cities: Is it really smart? *Smart Cities*, 5(4), 1635–1654.

Jonek-Kowalska, I. (2023). Assessing the effectiveness of air quality improvements in Polish cities aspiring to be sustainably smart. *Smart Cities*, 6(1), 510–530.

Jonek-Kowalska, I., Wolniak, R. (2023). *Smart cities in Poland: Towards sustainability and a better quality of life?* London: Routledge.

Jonek-Kowalska, I., Wolniak, R. (2021). Economic opportunities for creating smart cities in Poland: Does wealth matter? *Cities*, 114, 103222.

Jonek-Kowalska, I., Wolniak, R. (2021). The influence of local economic conditions on start-ups and local open innovation system. *Journal of Open Innovation: Technology, Market, and Complexity*, 7(2), 110.

Kalenyuk, I., Lukyanenko, L., Tsymbal, L., Stankevics, A., Uninets, I. (2023). The smart manufacturing: Imperatives and trends. *Financial and Credit Activity: Problems of Theory and Practice*, 5(52), 327–340.

Khan, T. S., Khan, N. U., Juneio, H. F. (2020). Smart city paradigm: Importance, characteristics, and implications. In *Advances in Science and Engineering Technology International Conferences*, 4 February–9 April 2020, Dubai, United Arab Emirates, 9118352.

Khavarian-Garmsir, A. R., Sharifi, A. (2022). Smart cities: Key definitions and new directions. In *Urban climate adaptation and mitigation*, London: Elsevier, 49–67.

Khurshudov, A. (2024). The smart city conundrum: Technology, privacy, and the quest for convenience. *Smart and Sustainable Built Environment*,. https://doi.org/10.1108/SASBE-12-2023-0377

Kinelski, G. (2022). Ewolucja koncepcji Smart City w aktywności zasobów miejskich – studium przypadku Górnośląsko-Zagłębiowskiej metropolii. *Przegląd Organizacji*, 2, 36–44.

Kinelski, G. (2022). Smart City 4.0 as a set of social synergies. *Polish Journal of Management Studies*, 26(1), 92–106.

Kondratenko, I., Mironov, D., Kulikova, E. (2023). Analysis of smart city energy efficiency technologies. *AIP Conference Proceedings*, 2812(1), 020079.

Konstantopoulou, E., Sklavos, N., Ognjanovic, I. (2024). Securing public safety mission-critical 5G communications of smart cities. *Signals and Communication Technology*, F1293, 61–74.

Kowalska, I. J., Wolniak, R. (2023). Sharing economies' initiatives in municipal authorities' perspective: Research evidence from Poland in the context of smart cities' development. *Sustainability*, 14(4), 2064.

Kramarz, M., Przybylska, E., Dohn, K., Jonek-Kowalska, I. (2022). *Urban logistics in a digital world: Smart cities and innovation.* London: Palgrave, 1–173.

Kulturalna Warszawa. (2024). https://polskieapps.pl/iphone-ipad/rozrywka/kulturalna-warszawa-aqaqmc.html (accessed 16.02.2024).

Kuzior, A., Kuzior, P. (2020). The quadruple helix model as a smart city design principle. *Virtual Economics*, 3(1), 39–57.

Kvalvik, P., Sánchez-Gordón, M., Colomo-Palacios, R. (2023). Beyond technology in smart cities: A multivocal literature review on data governance. *Aslib Journal of Information Management*, 75(6), 1235–1252.

Lee, J. H., Hancock, M. G., Hu, M. C. (2014). Towards an effective framework for building smart cities: Lessons from Seoul and San Francisco. *Technological Forecasting and Social Change*, 89, 80–90.

Li, D., Shang, X., Huang, G., Zhang, M., Feng, H. (2024). Can smart city construction enhance citizens' perception of safety? A case study of Nanjing, China. *Social Indicators Research*, 171, 937–965.

Locate Me. (2024). https://play.google.com/store/apps/details?id=com.anuraag.locateme&hl=pl&gl=US&pli=1 (accessed 16.02.2024).

Lokal. (2024). https://play.google.com/store/apps/details?id=com.mtdata.LokalWaterloo&hl=pl&gl=US (accessed 16.02.2024).

Lopes, C. T., Luciano, E. M. (2023). The role of the private sector on developing smart cities under a quadruple helix approach. *ACM International Conference Proceeding Series*, 470–472.

Lyu, K., Hao, M. (2020). Definition and history of smart cities: The development of cities and application of artificial intelligence technology in smart cities. In *AI-based services for smart cities and urban infrastructure*. Hershey, PA: IGI Global, 1–22.

Maddel, M., Gite, P., Sudhakar, K. N., Bakhare, R., Mittal, V. (2023). Development of specific mobile applications supporting the smart city trend. In *2nd International Conference on Edge Computing and Applications*, 19–21 July 2023, Namakkal, India, 195–202.

Madhee, K. H. (2024). Future of urban architectural design based on the concept of smart city. *Journal of Autonomous Intelligence*, 7(1), 1–10.

Makieła, Z. J., Stuss, M. M., Mucha-Ku´s, K., Kinelski, G., Budziński, M., Michałek, J. (2022). Smart City 4.0: Sustainable urban development in the metropolis GZM. *Sustainability*, 14, 3516.

Manfreda, A., Mijač, T. (2024). Smart city as a mix of technology, sustainability and well-being: A myth or reality? *IFIP Advances in Information and Communication Technology*, 699, 46–57.

Markard, J., Raven, R., Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy*, 41, 955–967.

McKenna, H. P. (2016). Is it all about awareness? People, Smart Cities 3.0, and evolving spaces for IT. In *2016 ACM SIGMIS Conference on Computers and People Research*, June 2–4, Virginia, USA, 47–56.

McKinsey Global Institute. (2018). Smart cities: Digital solutions for a more livable future. www.mckinsey.com/~/media/McKinsey/Industries/Public%20and%20Social%20Sector/Our%20Insights/Smart%20cities%20Digital%20solutions%20for%20a%20more%20livable%20future/MGI-Smart-Cities-Executive-summary.pdf (accessed 29-01-2024).

Mkrtychev, O., Starchyk, Y., Yusupova, S., Zaytceva, O. (2018). Analysis of various definitions for smart city concept. *IOP Conference Series: Materials Science and Engineering*, 365(2), 022065.

mObywatel. (2024). www.gov.pl/web/mobywatel (accessed 16.02.2024).

Neofotistos, M., Hanioti, N., Kefalonitou, E., Perouli, A. Z., Vorgias, K. E. (2023). A real-world scenario of citizens' motivation and engagement in urban waste management through a mobile application and smart city technology. *Circular Economy and Sustainability*, 3(1), 221–239.

Nextbike. (2024). https://nextbike.pl/dla-ciebie/ (accessed 16.02.2024).

Nordberg, K. (2015). Enabling regional growth in peripheral non-university regions: The impact of a Quadruple Helix intermediate organisation. *Journal of Knowledge Economy*, 6, 334–356.

Nugraha, Y. (2020). Building a smart city 4.0 ecosystem platform: An overview and case study. In *7th International Conference on ICT for Smart Society: AIoT for Smart Society*, 19–20 November 2020, Bandung, Indonesia, 930753.

Organisation for Economic Co-operation and Development. (2020). Better life initiative: Measuring well-being and progress. www.oecd.org/wise/better-life-initiative.htm (accessed 16.02.2024).

Osipova, M., Hornecker, E. (2023). Exploring the potential for smart city technology for women's safety. *ACM International Conference Proceeding Series*, 245–250.

Paskaleva, K., Evans, J., Watson, K. (2021). Co-producing smart cities: A Quadruple Helix approach to assessment. *European Urban and Regional Studies*, 28(4), 395–412.

Pellatt, J., Palfreman, J. (2023). Smart technology solution for a cleaner city: A case study of Dar es Salaam, Tanzania. *GeoJournal*, 88(5), 5221–5245.

Picioroaga, I.-I., Eremia, M., Sanduleac, M. (2018). Smart city: Definition and evaluation of key performance indicators. In *10th International Conference and Expositions on Electrical and Power Engineering*, 18–19 Oct. 2018, Iasi Romania, 8559763.

Piqué Huerta, J. M. (2019). *Understanding the urban development and the evolution of the ecosystems of innovation*. PhD thesis, Universidad Ramon Llull, Barcelona.

Qian, X. (2023). Evaluation on sustainable development of fire safety management policies in smart cities based on big data. *Mathematical Biosciences and Engineering*, 20(9), 17003–17017.

Raj, A., Shetty, S. D. (2024). Smart parking systems technologies, tools, and challenges for implementing in a smart city environment: A survey based on IoT & ML perspective. *International Journal of Machine Learning and Cybernetics*, 15(7), 1–22.

Rastog, R., Bhardwaj, M., Sharma, A. (2022). Crop and yield prediction through machine learning techniques to maximize production: 21st century sustainable approach for Smart Cities 5.0. In *4th International Conference on Advances in Computing, Communication Control and Networking*, 16–17 Dec. 2022, Greater Noida,·India, 1286–1291.

Rastogi, R., Arora, P., Dhamija, L., Shrivastava, R. (2023). Intelligent online voting system for twenty-first century and Smart Cities 5.0: An empirical approach through blockchain with ML techniques. *Lecture Notes in Electrical Engineering*, 1056, 151–156.

Rele, M., Patil, D. (2023). Enhancing safety and security in renewable energy systems within smart cities. In *12th IEEE International Conference on Renewable Energy Research and Applications*, 105–114.

Ruiz-Vanoye, J. A. (2023). *Management, technology, and economic growth in smart and sustainable cities„* 29 August–1 September 2023, Oshawa, Canada. https://doi.org/10.4018/979-8-3693-0373-3.

Sarjana, S. (2023). Smart city in supporting sustainable cities. In 2023 10th International Conference on Information Technology, Computer, and Electrical Engineering, 31 Aug.–1 Sep. 2023, Semarang, Indonesia, 365–370.

Schütz, F., Heidingsfelder, M., Schraudner, M. (2019). Co-shaping the future in Quadruple Helix innovation systems: Uncovering public preferences toward participatory research and innovation. *Journal of Design, Economics, and Innovation*, 5, 128–146.

Sharifi, A., Alizadeh, H. (2023). Societal smart city: Definition and principles for post-pandemic urban policy and practice. *Cities*, 134, 104207.

Smart City 4.0. (2022). www.skills4cities.eu/blog--news/smart-city-40 (accessed 16.02.2024).

Smart City 4.0. (2023). www.linkedin.com/pulse/smart-city-40-thinkco-pl/ (accessed 16.02.2024).

SOS Alarm. (2024). https://play.google.com/store/apps/details?id=se.sos.soslive&hl=pl&gl=US, (accessed 16.02.2024).

Stahl, B., Reiterer, A. (2022). Mobile mapping platform with integrated end-to-end data processing chain for smart city applications. *Proceedings of SPIE – The International Society for Optical Engineering*, 12269, 1226902.

Stecuła, K., Wolniak, R., Grebski, W. W. (2023). AI-driven urban energy solutions: From individuals to society: A review. *Energies*, 16(24), 7988.

Streitz, N. A., Riedmann-Streitz, C., Quintal, L. (2023). From 'smart-only' island towards lighthouse of research and innovation. *Lecture Notes in Computer Science*, 13325, 105–126.

Suzic, B., Ulmer, A., Schumacher, J. (2020). Complementarities and synergies of quadruple helix innovation design in smart city development. *2020 Smart Cities Symposium*, Prague, 25 June 2020, 9133961.

Svitek, M., Kozhevnikov, S. (2023). Smart City 5.0 as digital ecosystem of smart services: Basic concepts. In Smart *cities* and *digital transformation*: Empowering *communities, limitless innovation, sustainable development and the next generation*, Bingley: Emerald, 35–57.

Svitek, M., Kozhevnikov, S., Tencar, J., Bhattacharjee, S., Benes, V. (2023). Smart City 5.0 as the digital ecosystem of smart services: Practical applications. In *Smart cities and digital transformation: Empowering communities, limitless innovation,* sustainable development and the next generation, Bingley: Emerald, 327–356.

Svítek, M., Skobelev, P., Kozhevnikov, S. (2020). Smart City 5.0 as an urban ecosystem of smart services. *Studies in Computational Intelligence*, 853, 426–438.

Tamás, S. T., Dóra, S. (2023). Measuring the economic and environmental sustainability of cities with county rank, 2020–2021. *Teruleti Statisztika*, 63(1), 89–124.

Taratori, R., Rodriguez-Fiscal, P., Pacho, M. A., Koutra, S., Pareja-Eastaway, M., Thomas, D. (2021). Unveiling the evolution of innovation ecosystems: An analysis of triple, quadruple, and quintuple helix model innovation systems in European case studies. *Sustainability*, 13(14), 7582.

Teng, L. M., Yusoff, K. H., Mohammed, M. N., Sapari, N. M., Alfiras, M. (2024). Toward sustainable smart cities: Smart water quality monitoring system based on IoT technology. Studies in Systems, Decision and Control, 487, 577–593.

Toli, A. M., Murtagh, N. (2020). The concept of sustainability in smart city definitions. *Frontiers in Built Environment*, 6, 77.

Tomitsch, M., Ellison, A. (2023). A human-centred technology approach to pedestrian safety in smart cities. *Advances in Science, Technology and Innovation*, 19–32.

Trencher, G. (2019). Towards the Smart City 2.0: Empirical evidence of using smartness as a tool for tackling social challenges. *Technological Forecasting and Social Change*, 142, 117–128.

Van Den Berg, C., Verster, B. (2023). Advancing sustainable-smart innovations through a transdisciplinary learning intervention: Insights from the quintuple helix model. *European Conference on Innovation and Entrepreneurship*, 2, 883–890.

Vasudavan, H., Gunasekaran, S. S., Balakrishnan, S. (2019). Smart city: The state of the art, definitions, characteristics and dimensions. *Journal of Computational and Theoretical Nanoscience*, 16(8), 3525–3531.

Vătăşoiu, R.-I., Brătulescu, R.-A., Mitroi, S.-A., Mari-Anais S., Tudor, A.-M., Vintilă, A.-G. (2023). The importance of security and safety in a smart city. Smart Innovation, Systems and Technologies, 321, 11–23.

Vlahakis, V., Protopsaltis, A., Sarigiannidis, P. (2023). Smart city traffic monitoring using digital twin technology. *AIP Conference Proceedings*, 2909(1), 120014.

Wolniak, R. (2023). Smart mobility in smart city: Copenhagen and Barcelona comparison. *Scientific Papers of Silesian University of Technology*, 172, 679–697.

Wolniak, R., Grebski, W. (2023). Energy efficiency management in smart city: Smartphone applications aspects. *Scientific Papers of Silesian University of Technology*, 185, 605–615.

Wolniak, R. (2023). European Union smart mobility: Aspects connected with bike road system's extension and dissemination. *Smart Cities*, 6(2), 1009–1042.

Wolniak, R. (2023). Analysis of the bicycle roads system as an element of a smart mobility on the example of Poland provinces. *Smart Cities*, 6(1), 368–391.

Wolniak, R., Jonek-Kowalska, I. (2023). The creative services sector in Polish cities. *Journal of Open Innovation: Technology, Market, and Complexity*, 8(1), 17.

Wolniak, R., Gajdzik, B., Grebski, W. (2023). The implementation of Industry 4.0 concept in smart city. *Scientific Papers of Silesian University of Technology*, 178, 753–770.

Xu, H. (2023). Intelligent automobile auxiliary propagation system based on speech recognition and AI driven feature extraction techniques. *International Journal of Speech Technology*, 25(4), 893–905.

Yazici, A. M. (2023). The quintuple helix, industrial 5.0, and society 5.0. In Digitalization, sustainable development, and Industry 5.0: An organizational model for twin transitions, Bingley: Emerald, 317–336.

Yun, Y., Lee, M. (2020). Smart City 4.0 from the perspective of open innovation. *Journal of Open Innovation: Technology, Market, and Complexity*, 5(4), 92.

Zhou, Y. (2022). The application trend of digital finance and technological innovation in the development of green economy. *Journal of Environmental and Public Health*, 2022, 1064558.