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Infrastructural Development of Smart Cities as the Background of Digital Transformation of Territorial Units

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Abstract

The Interoperability, continuous data and technology flow are core requirements of a proper smart city. Smart cities take on the characteristics of innovative, competitive and attractive megalopolises, which is strategically important for residents and investors. The aim of the article was to identify the current state and current issues of the Smart City concept implementation in Ukraine in the context of the experience of developed countries. The main methodological tools included the observation, statistical and comparative analysis. The study found that the effective development of digital transformation of territorial units in Ukraine requires focusing on certain factors during the implementation of the Smart City concept. Such factors conditionally include: technology-based infrastructure; environmental comments; constructive level of public transport; progressive city plans; opportunities for citizens to use appropriate resources. It was found reasonable to introduce infrastructural development of smart cities in Ukraine as a foundation of digital transformation of territorial units. Smart

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Cities were substantiated as an important tool for effective prevention and control of the pandemic without the introduction of restriction policies. A comparative analysis of the practice of Ukraine and developed countries in the implementation of infrastructural development of Smart Cities is a promising area of further research.

Keywords: cybersecurity; digitalization; innovative technologies; internet of Things; smart city.

El Desarrollo Infraestructural de las Ciudades Inteligentes como Contexto de la Transformación Digital de las Unidades Territoriales

Resumen

Las ciudades inteligentes asumen las características de megalópolis innovadoras, competitivas y atractivas, lo cual es estratégicamente importante para residentes e inversores. El objetivo del artículo fue identificar el estado actual y los problemas de la implementación del concepto Smart City en Ucrania en el contexto de la experiencia de los países desarrollados. Las principales herramientas metodológicas incluyeron la observación, el análisis estadístico y comparativo. El estudio encontró que el desarrollo efectivo de la transformación digital de las unidades territoriales requiere centrarse en ciertos factores durante la implementación del concepto de Ciudad Inteligente. Dichos factores incluyen condicionalmente: infraestructura basada en tecnología; comentarios ambientales; nivel constructivo del transporte público; planes urbanos progresistas, y; oportunidades para que los ciudadanos utilicen los recursos apropiados. Se consideró razonable introducir el desarrollo de infraestructura de ciudades inteligentes como base de la transformación digital de las unidades territoriales. Se concluye que las Ciudades Inteligentes se fundamentaron como una herramienta importante para la prevención y el control efectivos de la pandemia sin la introducción de políticas de restricción. Un análisis comparativo de la práctica de Ucrania y los países desarrollados en la implementación del desarrollo de infraestructura de *Smart Cities* es un área prometedora de investigación adicional.

Palabras clave: seguridad cibernética; digitalización; tecnologías innovadoras; internet de las cosas; ciudad inteligente.

Introduction

The COVID-19 pandemic has made the global population realize how technology can improve current realities by keeping citizens healthy and transforming the economy. COVID-19 urged digitalization and urban innovation. The development of a regulatory framework, organizational structure, approaches to citizen involvement and general ethical considerations are currently required for taking relevant actions in cities (Amankwah-Amoaha *et al*., 2021).

According to 2018 scientific data, more than 50% of the world population lived in cities, and this figure is expected to exceed 70% by 2050 (Ritchie and Roser, 2018). Covering about 1% of the land area, cities consume 75% of energy, 85% of resources and produce about 80% of the world's greenhouse gas emissions (Huang *et al.,* 2021). The structural changes in the world were driven by the fourth industrial revolution. Technological changes, innovation and human capital were recognized by industrial enterprises and small firms as the driving force of modern economic and social transformations (Chung, 2021). Continuous urbanization of cities can, however, lead to more serious environmental pressure, as well as inconsistencies between supply and demand of resources (Fox and Goodfellow, 2021). Digital transformation is conductive for many cities on their way of becoming "smarter", providing them with the opportunity to improve digital processes, pursue climate-friendly goals, or raise the standards of living of their citizens (Elberzhager *et al*., 2021).

Smart City theory and practice emerged in developed countries, where the urban infrastructure was superior and which launched urbanization earlier. Smart Cities evolved from the smart growth concept being part of the New Urbanism movement in the United States in the 1980's, and were created through information technology (Hollands, 2020). They have begun to use this technology in order to offer innovative solutions to urbanization with the aim of sustainable development, as well as the protection of life and the environment.

Smart City is currently defined as the favourable integration of information technology (IT), social, human systems and business infrastructures to generate a collective mind with the proper use of all available interconnected information (Antwi-Afari *et al*., 2021). Optimization of urban functions is the main goal of the Smart City. Smart Cities can be argued to bring technology closer to people, integrate them into a new spatial system of many-sided, multi-actor and multi-level local government (Echebarria *et al*., 2021). The level of relations between the public and private sectors measures the performance of Smart City. Besides, the role of data analytics being part of the Smart City structures remains very important in finding errors and ways to eliminate them.

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There is no doubt that Smart Cities, like every innovation, have certain drawbacks. These technologies can also boost the territorial digital gap, posing risks of disintegration of communities in some small remote settlements. Besides, there is a threat that the economy and the population will become even more vulnerable to cyber-attacks. In Ukraine, the digitalization process is slow, Smart Cities projects are point-like (mostly in megalopolises), smart ideas are still largely defined as populist (Chernova, 2021). The chosen subject matter of the article in Ukraine and the post-Soviet space is still highly controversial. Therefore, the experience of the states that have become leaders in this aspect requires additional comparative analysis to substantiate the appropriateness of transformations (Gryshchenko *et al*., 2021).

In view of the above, the aim of the article was to identify the current state and current issues of the Smart Cities concept implementation in Ukraine in the context of the experience of other countries. The aim provided for the following objectives:

1) identify the current state and main problems of the infrastructural development of Smart Cities in Ukraine;

2) identify the current state of digital transformation of territorial units in a number of countries and find out the possible implementation of relevant achievements in order to develop the Smart Cities concept in Ukraine.

1. Literature Review

The representatives of theory and practice currently pay considerable attention to the study of the concept of Smart City in different jurisdictions. The collective work of Huang *et al*. (2021) deals with the basic problems and risks of the Smart City concept. The scholars successfully substantiated the prospects of digitalization in the global aspect, as well as in the EU and China in terms of the introduction of Smart Cities.

Hollands (2020) studies the structural components of the Smart City, in which the author defines the nature and content of the popularized Smart City concept. Fox and Goodfellow (2021) cover management competencies promoting the creation and development of Smart Cities. Scholars also emphasize the complex implications of "late urbanization" and their impact on the environment. Giuffrida (2021) considered the Smart Cities concept from the sustainable development perspective. The scholar's findings allowed considering the development of Smart Cities in terms of the UN Global Goals.

A comprehensive work by Muraev (2021) entitled Organizational and Informational Support for the Development of the Strategy of Smart Cities of Ukraine in the Digital Economy had a significant impact on the author's opinion in the article.

The value and significance of the findings obtained by these researchers is unconditional, but it should be noted that the theoretical, organizational and methodological issues relating not only to the implementation of Smart Cities but also its information support remain unresolved in the current context of digitalization.

2. Methods

The outlined range of issues were covered in the article through a step-by-step scientific research with effective testing of methodological tools. The results of each stage are reflected in the appropriate parts of research and the author's substantiated conclusions. Moreover, the scientific novelty of the study was previously outlined by the doctrine representatives only in part, which indicates that modern scientific analysis in this area is topical. Figure 1 presents the research procedure.
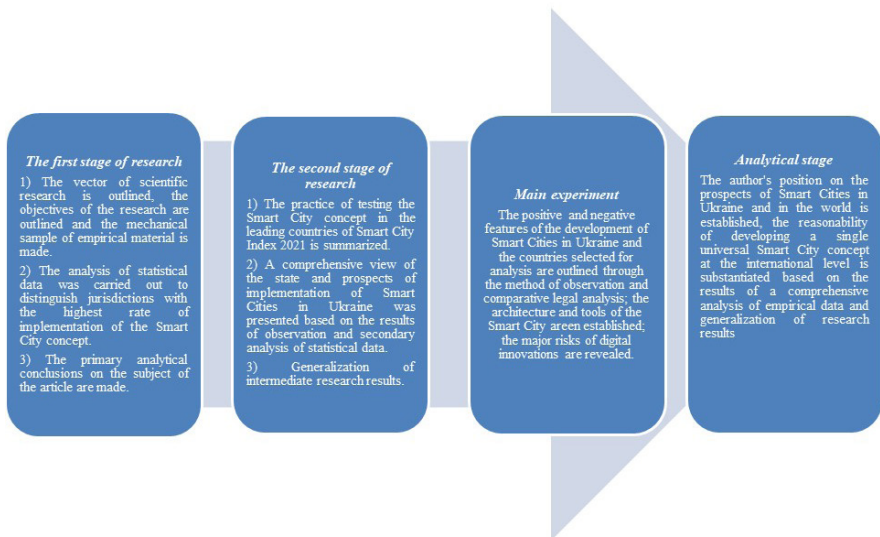
The first stage of research

1) The vector of scientific research is outlined, the objectives of the research are outlined and the mechanical sample of empirical material is made.

2) The analysis of statistical data was carried out to distinguish jurisdictions with the highest rate of implementation of the Smart City concept.

3) The primary analytical conclusions on the subject of the article are made.

The second stage of research

1) The practice of testing the Smart City concept in the leading countries of Smart City Index 2021 is summarized.

2) A comprehensive view of the state and prospects of implementation of Smart Cities in Ukraine was presented based on the results of observation and secondary analysis of statistical data.

3) Generalization of intermediate research results.

Main experiment

The positive and negative features of the development of Smart Cities in Ukraine and the countries selected for analysis are outlined through the method of observation and comparative legal analysis; the architecture and tools of the Smart City areen established; the major risks of digital innovations are revealed.

Analytical stage

The author's position on the prospects of Smart Cities in Ukraine and in the world is established, the reasonability of developing a single universal Smart City concept at the international level is substantiated based on the results of a comprehensive analysis of empirical data and generalization of research results

Figure 1: Research procedure.

Source: Authors.

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The theoretical background of the study is based on a systemic and operational approach, the information society concept. The systemic approach was used to reveal the features of digitalization of public relations and management system, to identify the aim, as well as the actors implementing these innovations, their functions and relationships with participants. The Smart City concept implementation is also considered from the perspective of a systematic approach — as an integrated direction of responsible and involved actors to achieve a common goal — improving the quality of life of urban residents and achieving sustainable functioning of the cities. The activity approach was applied to identify the peculiarities of the efforts of the subjects of the digitalization process and the implementation of the Smart City project, the regulatory, personnel, organizational and financial support for such activities.

The objectives set in the article were fulfilled on the basis of such research methods as analysis of theoretical and legal documents, methods of observation, statistical and comparative analysis. A study was conducted with the involvement of secondary data analysis and document analysis. The architecture and tools of Smart Cities in different countries were revealed through the observation and comparative analysis. Besides, these methodological tools were useful in outlining the leading risks and prospects of digital innovation in the context of intensifying urbanization and globalization in Ukraine. The method of statistical analysis was of particular importance for the author's scientific research. This method was used both in sampling of leading countries with a positive practice of implementing the Smart City concept and in the analysis of the effectiveness of relevant innovations.

The information background of the study includes statistical data, analytical reports and open data on the results of the implementation of urbanization projects of the Smart City urban environment by public authorities of different levels and jurisdictions, as well as legal documents of different states and comprehensive research of scholars in this area. A total of 41 sources were reviewed and taken into account in the work.

3. Results

In 2015, the United Nations adopted the Sustainable Development Goals, also known as the Global Goals, as a general call for action to eradicate poverty, protect the planet and ensure well-being of people by 2030 (United Nations Development Programme, 2015). In this context, sustainable urban development is provided through creating career and business opportunities, safe and affordable housing, and building up sustainable societies and economies. According to statistical forecasts, the

cost of technological innovation under the Smart Cities Initiative in the world will more than double between 2018 and 2023, increasing from $ 81 milliard in 2018 to $ 189.5 milliard in 2023 (Statista, 2020).

The improvement of Smart Cities is supported by the state political support as an important external driving force. The implementation of the Smart City concepts currently involves a number of stages. First, it is necessary to establish a smart physical infrastructure by grouping the available specific technological solutions: smart home, smart transport, smart energy, smart housing management system, smart waste management, smart education, smart health care system and others. This shall be followed by the establishment of the primary digital infrastructure, which includes common standards and protocols that can provide device compatibility. The next step is the creation of digital platforms by merging smart physical and digital infrastructure. The final stage is the combination of the data from individual vertical digital platforms into a horizontal integrated digital platform — the Digital City Twin (Figure 2).
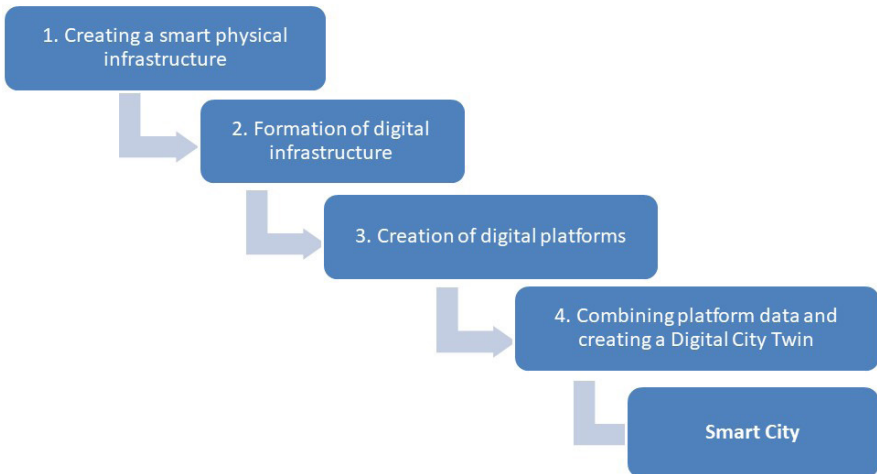

1. Creating a smart physical infrastructure

2. Formation of digital infrastructure

3. Creation of digital platforms

4. Combining platform data and creating a Digital City Twin

Smart City

Figure 2: Gradual cycle of processes of implementation of the Smart City concepts

Source: Authors.

Technology is the main driving force of municipal development. Smart Cities provide connected solutions to the public through a variety of software, user interfaces, and communication networks, as well as the Internet of Things (IoT). IoT is the most important of the listed tools, which is a network of connected devices for communication and data sharing. In

addition to the IoT solutions, Smart Cities also involve such technologies as: application programming interfaces (APIs); artificial intelligence (II); cloud computing services; monitoring panels; machine learning; machine-to-machine communication (M2M); 3D printing; mesh networks. Cities obtain valuable information from large data sets collected from various sources through Big Data. Smart Cities perform a series of consistent actions in order to improve the quality of life and promote economic growth through a network of connected IoT devices and other technologies.

In 2021, the European Parliament and the Council of Europe launched the Digital Europe Programme as part of the 2021-2027 Multiannual Financial Framework (MFF) in order to promote digitalization in the EU (European Parliament and Council of Europe, 2021). The programme intends to eliminate the gap between research in the field of digital technologies and their introduction to the market, the introduction of digital solutions for cities. For example, Germany has been implementing the industry 4.0 Initiative (European Commission, 2017) designed for the research and initiatives related to IoT technologies and the Smart Manufacturing concept. The annual Smart City Index is calculated by the Institute for Management Development (IMD, 2021) in Lausanne, Switzerland, and the Singapore University of Technology and Design (SUTD). The report ranks 118 cities around the world based on citizens' perceptions of how technology can improve their lives, as well as economic and social data from the UN Human Development Index (HDI).

The IMD-SUTD Smart City Index (SCI) measures residents' perceptions of the structures and technological software solutions available in their community in the context of its infrastructure. In SCI, Smart City describes the urban environment where technologies are used to increase the benefits and reduce the negative aspects of urbanization. The perception of 120 people in each city is randomly selected when evaluating the cities of the world. SCI is based on more than 12,000 surveys, there are 40 questions in each survey. The main part (36 questions) is equally divided between two factors: structures that include existing urban infrastructure, and technologies that describe the technological conditions and services available to residents. There are also three other questions to evaluate attitudes towards the use of personal data, identity recognition and general confidence in the city authorities.

The overall ranking of the city corresponds to the above breakdown and is related to the overall score of the city. The results of the 2021 Smart City Index (IMD, 2021) showed that citizens' perceptions of how technology helps solve urban problems have been strongly influenced by the pandemic and the accelerating digital transformation. According to the report, affordable housing is a major problem in cities around the world. Environmental problems are more acute in richer cities, while access to

better quality air and health services has also become a priority around the world in the context of the Covid-19 pandemic.

It is also noted in the report that the pandemic revealed the innovative potential of Smart Cities to address issues such as the distribution of protective equipment, the use of health facilities and vaccination campaigns, contact tracking compared to central governments. Singapore tops the list of cities in the world that most actively use the technology, as well as in terms of environmental, medical and social issues. Table 1 demonstrates the top ten cities in the Smart Cities Index. These are all cities that, have effectively coped with the Covid-19 crisis and will be able to become resilient quickly according to their residents.

Table 1. 2021 Smart City Index leaders

Item No.	City name	"Technologies" factor	"Structures" factor
1.	Singapore	*AAA*	*AAA*
2.	Zurich (Switzerland)	*A*	*AAA*
3.	Oslo (Norway)	*A*	*AAA*
4.	Taipei (Taiwan)	*A*	*A*
5.	Lausanne (Switzerland)	*A*	*AAA*
6.	Helsinki (Finland)	*A*	*AA*
7.	Copenhagen (Denmark)	*A*	*AA*
8.	Geneva (Switzerland)	*A*	*AA*
9.	New Zealand	*A*	*A*
10.	Bilbao (Spain)	*BBB*	*A*

Source: IMD (2021).

Since the launch of the Smart Nation initiative in 2014, Singapore has introduced a wide range of smart technologies in both the public and private sectors. Furthermore, Singapore announced its plans to create a new eco-smart city, completely devoid of vehicles (Holland, 2021).

The street lighting project became important for Zurich. The city presented a series of streetlights that adapted to the traffic level with sensors to increase or decrease the brightness. The project saved up to 70% of electricity (Von Hunnius, 2019).

Helsinki has set the goal of achieving zero carbon emissions by 2035. The city managed to reduce emissions by 27% back in 2017 compared to 1990 (Sustain Europe, 2019). Another goal of Helsinki is to reduce road emissions by 69% by 2035 through such measures as converting the entire city bus fleet to electricity and expanding the metro network and charging networks for electric vehicles (Lai, 2021).

Launched in June 2019, the G20 Global Smart Cities Alliance on Technology Governance brings together municipal, regional and national governments, private sector partners and urban residents around a common set of principles for the responsible and ethical use of Smart Cities technologies (World Economic Forum, 2019). In 2020, the World Economic Forum selected thirty-six cities in twenty-two countries and six continents to develop a new global policy roadmap for Smart Cities (World Economic Forum, 2020). This Global Smart Cities Alliance, which was established at the Forum, commits member cities to adopting privacy policies, improving broadband coverage, ensuring accountability for cybersecurity, enhancing the openness of urban data and improving access to digital urban services for people with disabilities and elderly people.

Policy experts and government officials were interviewed in 2021 to evaluate the implementation of a set of five key policies identified by the G20 in 2020 (World Economic Forum, 2020). Almost all of the cities surveyed have serious policy gaps related to Smart City technology management.

Compared to 2020, Kyiv has improved its performance in the Smart City Index 2021 (IMD, 2021) and moved from 98th to 82nd place. Some components of "smart" infrastructure are also being implemented in Vinnytsia, Dnipro, Drohobych, Zhytomyr, Lviv, Mariupol, Kharkiv and other cities. For example, the Kyiv Smart City Forum 2020 recognized Kharkiv as the Best Digital City (Kharkiv City Council, 2020) due to the introduction and active use of digital technologies. In particular, the online platforms Portal of Electronic Services and Portal of Kharkiv, mobile application My Kharkiv are currently operational (see Figure 3).

In turn, Ukraine has introduced regulations that can define and lay the foundation for the development of Smart Cities: The Law of Ukraine "On the National Informatization Programme" (Verkhovna Rada of Ukraine, 1998); "On Personal Data Protection" (Verkhovna Rada of Ukraine, 2010); 2021–2027 State Regional Development Strategy (Cabinet of Ministers of Ukraine, 2020); Kyiv Smart City 2020 concept (Kyiv City Council, 2017) and others. Ukraine, like other UN member states, has joined the global sustainable development process (President of Ukraine, 2019). At the same time, a number of problems that hinder the implementation of smart infrastructure initiatives in Ukraine have been proved.
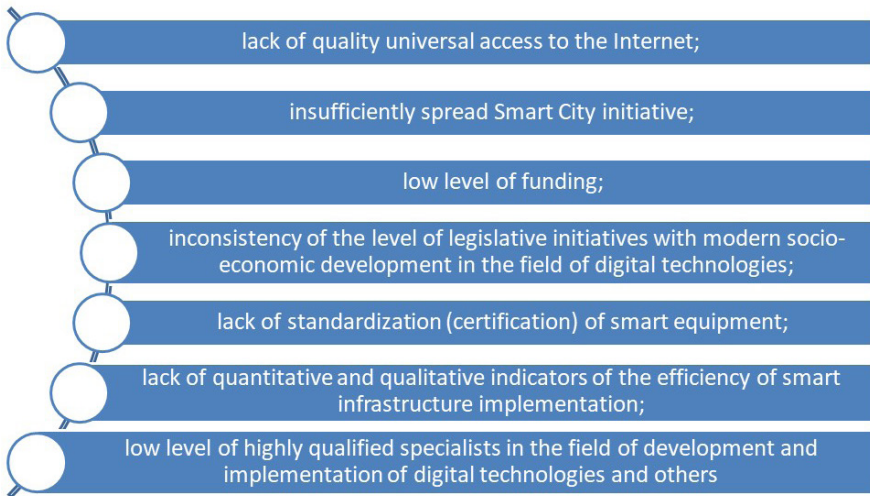
**Figure 3: Major problems in the implementation
of Smart Cities in Ukraine**

Source: Chernova (2021).

The Ministry for Communities and Territories Development of Ukraine is currently working on the creation of innovation infrastructure in the regions to overcome a number of relevant problems. The 2021–2027 State Regional Development Strategy (Cabinet of Ministers of Ukraine, 2020) provides for the introduction of innovative technologies into urban development management systems based on the Smart City concept as one of the objectives of regional policy. The digital transformation of regions must be implemented through the tools of smart urban planning, spatial planning and building innovative ecosystems. the Ministry for Communities and Territories Development of Ukraine and the non-profit British organization World Smart Cities Forum (WSCF) signed the Memorandum of Cooperation on April 27, 2021 (Lviv Polytechnic National University, 2021). The parties will jointly develop a strategic plan for Smart Cities in Ukraine. Moreover, the Sustainable Cities Programme funded by the International Finance Corporation's (2021) in Ukraine provides financial and advisory support to the country's growing cities.

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4. Discussion

It is apparent that building Smart Cities ultimately serves the needs of the people, so it is reasonable to develop a comprehensive concept oriented to the residents of settlements. Attention should be paid to the relationship between cities and the environment in view of the need of cities for sustainable development (Obringer and Nateghi, 2021). At the same time, development should combine the available resources and sectoral characteristics with regard to the real situation in the region in view of urbanization, maintaining the same priority for the economy and security, as well as taking into account local features of building Smart City (Huang *et al.,* 2021).

Researchers underline that technology- and enterprise-oriented Smart Cities have many drawbacks because of the lack of social and cultural inclusion (Huang *et al.*, 2021). Public distrust of technologies that may track and provoke the loss of privacy is inextricably linked to transparency, which is the key in democratic systems. Achieving greater resilience requires a serious consideration of the level of relevant risks (Giuffrida, 2021). Therefore, other researchers support the author's conclusion about the high degree of risk of innovation.

The integration of technology and society is especially important for public recognition. They currently fail to pay adequate attention to people-centred services and innovation-based sustainable development. This is directly reflected in the "emphasis on building infrastructure and neglecting the use of services" (Han and Hawken, 2018). Real Smart Cities must start with the city and its social problems, while technology-oriented needs must meet people's desires. So, there shall be a balance between technology, innovation, people, society, culture and the environment (Xu and Geng, 2019).

The services, innovative platforms and systems are provided to citizens through infrastructure and interoperability technologies, many of them are accessible via mobile devices. This situation may entail deprivation of voting rights of key population segments (Hryshchenko and Lavshchenko, 2020). Designers and planners of Smart Cities must take into account that innovations as blockchain-based systems and the wider use of IT are becoming an integral part of the system architecture (Ismagilova *et al*., 2020).

Technology expanded opportunities to overcome difficulties and recover during the COVID-19 pandemic by expanding participation and social ties, improving physical and mental health, and supporting the educational and economic systems. With regard to the abovementioned, policymakers and researchers need to rethink the role of Smart City projects in future health emergencies such as COVID-19 (Cavada, 2022). Relevant research and

discussions need to be expanded on the role of Smart City projects in health emergencies (Yang and Chong, 2021). The introduction of technology can, however, have adverse consequences, such as social exclusion, digital gap, privacy and confidentiality, political bias and disinformation, and inefficient teleworking and distance study (Hassankhani *et al.*, 2021).

Ukrainian cities have just begun to develop the Smart City concept, and the main problem they face is the lack of funding, because the state should be the main initiator of the Smart Cities development. Scholars support the author's position and emphasize that it is up to the authorities to realize the potential of cities to implement "smart" technologies (Muraev, 2021).

It is necessary to pay more attention to improving not only digital literacy but also digital security in a rapidly changing both technological and social reality, which should be the basis for sustainable development of smart cities (Vershinina and Volkova, 2020). The risk rates and the difficulties in their management changes over time due to the development of technologies and processes. Therefore, it is important to continuously monitor and assess the risks of each aspect of the Smart City and this concept as a system (Sharif and Pokhare, 2022).

Conclusions

The idea of smart cities is attracting attention as a new driver of growth and development strategy in many cities around the world in view of the development of artificial intelligence and the Internet of Things. Smart City implies such a structure of municipal government, which is able to interact with a large proportion of the city's residents and respond quickly to the population's requests. Technology-based infrastructure; environmental proposals; functional level of public transport; advanced plans of settlements; the ability of residents to use these resources are the features of the effective development of the Smart City.

Adherence to basic systemic process underlies building a smart city. This process includes selecting a competent team, in-depth diagnostics of particular urban technologies, human resources and institutional capabilities, financial assets, constraints and challenges, as well as establishing a coherent system of cooperation and interaction between all stakeholders. Besides, the sustainable development of the Smart City faces a variety of challenges, where the relevant risks must be properly realized and mitigated, otherwise they may create privacy and security concerns.

Reviewed examples of the implementation of the Smart Cities concept in some developed countries indicate that these cities make full use of the competencies and infrastructure required to generate, transmit, process

and analyse large data sets to obtain useful knowledge for more effective decision-making and a deeper understanding of the urban environment, operational functioning, sustainability management and planning. Smart City technologies can help identify and mitigate health care crises, as evidenced by the experience of combating the COVID-19 pandemic in developed cities.

When implementing the Smart City concept in Ukraine, it is necessary to clearly define the priorities, develop a consistent implementation programme and take into account an integrated approach in its implementation. Relevant achievements of developed countries can be used as a positive example for testing in Ukraine. Therefore, it is urgent to develop a unified conceptual approach to the implementation of the Smart City components in Ukraine in the short and long run.

A further research will be aimed at updating the results of Ukraine's implementation of the Smart Cities concept as a background for digital transformation. Besides, the synergy of the Internet of Things (IoT) and Big Data technologies can lead to promising horizons for the Smart City development. In this sense, security combined with confidentiality is an important topic for further research in the field of Smart Cities.

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