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SMART INFRASTRUCTURE IN THE CITIES OF THE FORMER YUGOSLAVIA

Abstract:

Modern cities face traffic congestion, inefficient use of resources, and pollution, challenges that are intensified by urbanization. The smart city concept, based on the application of the Internet of Things (IoT), enables more efficient management of urban infrastructure and improvement of the quality of life. This paper examines the application of affordable IoT solutions in the areas of waste management, traffic management, and air quality monitoring. An analysis of examples from cities such as Zurich, Oslo, Geneva, as well as Novi Sad and Zagreb, reveals that IoT contributes to cost reduction, improved resource utilization, and environmental protection, while underscoring the need for a clear legal and ethical framework and a sustainable development strategy.

Keywords: smart city, Internet of Things, sustainable development, Smart City Index

ПАМЕТНА ИНФРАСТРУКТУРА У ГРАДОВИМА БИВШЕ ЈУГОСЛАВИЈЕ

Апстракт:

Савремени градови се суочавају са саобраћајним гужвама, неефикасним коришћењем ресурса и загађењем, што су све посљедице појачане урбанизације посљедњих деценија. Концепт паметног града, заснован на примјени интернета ствари (IoT), омогућава ефикасније управљање урбаном инфраструктуром и унапрјеђење квалитета живота. Рад разматра примјену приступачних IoT рјешења у областима управљања отпадом, саобраћаја и праћења квалитета ваздуха. Анализа примјера градова као што су Цирих, Осло, Женева, као и Нови Сад и Загреб, показује да IoT доприноси смањењу трошкова, бољем коришћењу ресурса и очувању животне средине, уз неопходност постојања јасног правног и етичког оквира и стратегије одрживог развоја.

Кључне ријечи: паметни град, интернет ствари, одрживи развој, Smart City Index

1. INTRODUCTION

Modern cities represent key economic, social, and cultural centers, but they simultaneously face numerous challenges that negatively impact the quality of life of their residents. The most prominent problems relate to traffic congestion, inefficient waste management, excessive energy consumption, air pollution, and increased noise levels. These challenges are primarily consequences of accelerated and excessive urbanization, population growth, and outdated urban infrastructure. The global process of urbanization further intensifies the aforementioned problems. According to United Nations data, more than half of the world's population lives in cities, and this proportion is expected to continue growing [1]. The increased pressure on resources and infrastructure necessitates new models of city management that are more efficient, sustainable, and adapted to the modern needs of society. In this context, the concept of the smart city has emerged over the last twenty years as a response to the limitations of traditional management systems.

A smart city is not just a city full of technology. It is an urban area that uses digital technologies and data to improve quality of life, increase sustainability, and make urban services more efficient and accessible for all citizens [2]. The Internet of Things (IoT) plays a key role in this concept, enabling the connection of sensors, devices, and infrastructure into a unified system for real-time data collection and analysis, and the management of specific activities within the urban domain.

The aim of this paper is to analyze how the application of simple and relatively inexpensive IoT sensors and digital platforms contributes to the more efficient management of key segments of urban infrastructure, with a special focus on waste management, traffic regulation, and air quality monitoring. Particular emphasis is placed on examples from the region of the former Yugoslavia, along with a comparative overview of practices from developed smart cities in Europe, to examine the real possibilities and challenges of applying these solutions in the local context.

2. SMART INFRASTRUCTURE AND IOT TECHNOLOGIES

2.1. LEVEL OF FUNCTIONING OF SMART TECHNOLOGIES AND TYPES OF SENSORS

In the modern urban context, smart infrastructure is based on the ability to represent the physical world we live in with data that is continuously collected, transmitted, stored, and analyzed. This ability is enabled by the development and application of smart technologies, especially IoT [3], which form the basis of smart cities.

IoT sensors represent the “senses” of the smart city. These are small devices equipped with specific detectors that continuously collect data about the physical environment. Parking sensors are embedded into the road structure or directly next to parking spaces and detect the presence of vehicles. They enable real-time monitoring of free parking spaces, driver guidance through applications, and dynamic price management. Air pollution sensors measure the concentration levels of harmful particles ($PM_{2.5}$, PM_{10}) or gases (NO_2, CO). This data is crucial for creating “pollution maps”, assessing health risks, and implementing measures such as traffic restrictions in specific zones or warning residents about potential problems. A critical aspect of their design is energy efficiency and power supply. Due to hard-to-access locations, IoT sensors must be energy-efficient and autonomous, often using solar cells or low-consumption batteries [4].

2.2. DATA TRANSMISSION AND NETWORK SECURITY

After collecting data from sensors is transmitted to the computer cloud or central servers, which represents one of the most critical segments of the smart city system. Although individual sensors send small amounts of data, the simultaneous operation of thousands of devices creates a large network load and requires efficient infrastructure and advanced data analytics.

Due to the different locations and operating conditions of sensors, various communication protocols are used. Wi-Fi and mobile networks (4G/5G) are applied for devices with higher energy consumption and larger data volumes, while LPWAN (Low Power Wide Area Network) networks are intended for sensors that send small data packets over long distances with minimal battery consumption. The data transmission phase is the most sensitive from a security aspect. Unencrypted communication allows eavesdropping or data manipulation, which can lead to incorrect decisions and serious disruptions in the city's functioning. An additional problem is the fact that many sensors are inexpensive and poorly protected, so they can serve as an entry point for cyber-attacks on critical city systems. These risks have been confirmed in practice, as shown by the cyber-attack on the city of Saint Paul in July 2025, which led to disruptions in city networks (internal IT networks of the city

administration, server and communication networks, public Wi-Fi systems, and online digital services) and the declaration of a state of emergency [5]. Therefore, the application of comprehensive protection measures is necessary, including communication encryption, regular system updates, network monitoring, and access segmentation.

2.3. USER INTERFACES AND APPLICATION IN URBAN SYSTEMS

The success of IoT application in urban systems depends not only on technical implementation but also on how different groups of citizens accept and use technology [3]. Older populations often face the digital divide and need adapted, intuitively designed user experiences, while younger generations generally accept applications and networked services, although they are sensitive to privacy and data commercialization. The acceptance of IoT also depends on socio-economic factors, as low incomes and perceived risks can limit access to and use of smart services.

Table 1. Categories of state roads in Serbia according to administrative classification [9]

Category	Road type	Main characteristics
Ia	motorways and expressways	fully controlled access, high capacity, intensive national and international traffic
Ib	main (trunk) roads	connection of major administrative, economic, and regional centers, partially controlled access
IIa	regional roads	connection of regional centers, formation of the primary regional network
IIb	district roads	provision of local and district connections, integration into higher-level networks

3. EXAMPLES OF SMART CITIES

The IMD Smart City Index is an annual index that assesses the extent to which residents perceive their city as “smart”, i.e., how urban infrastructure and digital solutions affect the quality of daily life [8]. The index is developed by International Institute for Management Development (IMD) from Lausanne, in collaboration with the Singapore University of Technology and Design, with the aim of evaluating the smart city concept through actual benefit to citizens, and not exclusively through technological advancement [9].

Cities are divided into four groups based on the Human Development Index (HDI). Within each group, cities are assigned a rating scale from AAA to D, based on the perception of that city compared to other cities in the same group. The ranking is shown through the overall rank, as well as through scores in individual pillars and the overall score (Table 2).

Table 2. Overview of the top ten ranked cities and scoring by established categories [10]

City	Smart City Rank 2025	Smart City Ranking 2025	Structure 2025	Technology 2025	Smart City Rank 2024
Zurich	1	AAA	AAA	AAA	1
Oslo	2	AAA	AAA	AAA	2
Geneva	3	AAA	AAA	AAA	4
Dubai	4	A	A	A	12
Abu Dhabi	5	A	A	A	10
London	6	AA	AAA	AAA	8
Copenhagen	7	AAA	AAA	AA	6
Canberra	8	AAA	AAA	A	3
Singapore	9	AAA	AAA	AAA	5
Laussane	10	AAA	AA	AA	7

The index covers 146 cities worldwide and is based on a survey of residents’ perceptions, where results from the previous three years are combined with greater weight given to newer data. The evaluation is conducted through two main pillars: “Structure”, which refers to the quality of existing urban infrastructure, and “Technology”, which measures the availability and application of digital and IoT solutions in the areas of mobility, management, and environmental protection [8]. The particular value of the IMD Smart City Index lies in its human-oriented approach, as it views

technology in the context of the real needs of citizens and infrastructure capacities. Therefore, the index represents a relevant tool for analyzing good practices and assessing the potential for the development of smart cities, enabling a more objective comparison of cities at a global level [9].

Based on IMD Smart City Index data, cities that consistently apply smart technologies and show a high level of integration of infrastructure and digital services into the daily lives of citizens can be identified. Such cities represent examples of good practice, showing how connecting sensors, IoT platforms, and resource management systems contributes to improving quality of life, the efficiency of public services, and the sustainability of urban environments. In 2025, the top three positions on the global IMD Smart City Index list are held by Zurich, Oslo, and Geneva, making them the highest-rated cities in the application of smart solutions. On the other hand, Table 3 shows some of the lowest-ranked cities according to this index.

Table 3. Overview of some of the lowest-ranked cities and scoring by established categories [10]

City	Smart City Rank 2025	Smart City Ranking 2025	Structure 2025	Technology 2025	Smart City Rank 2024
Cape Town	124	C	C	C	129
Manila	125	C	C	C	121
San José	126	CC	C	C	125
Amman	127	C	C	C	128
Algiers	128	C	C	C	124
Athens	129	CCC	CCC	CCC	120
Brasilia	130	C	C	C	130
Buenos Aries	121	C	C	C	123
Abuja	133	C	C	D	135

3.1. ZURICH

Zurich has been the top-ranked city by Smart City Index value for the last five years and in 2025 received the highest rating (AAA) in both dimensions ("Structure" and "Technology"). This shows that the smart infrastructure of this city and the application of digital technologies are not the result of one-time projects, but of consistent and comprehensive planning. This consistency makes it an extremely relevant example of good practice for analyzing the impact of simple IoT platforms on more efficient and intelligent urban infrastructure management.

In Zurich, waste management represents one of the priority segments within the smart city strategy. The city has signed the Circular Cities Declaration, reflecting a focus on a circular economy, emission reduction, and more efficient use of resources, including waste [11]. Accordingly, Zurich develops and applies IoT-based solutions for digital waste management, e.g., waste bins and containers equipped with sensors that measure fill levels, and this data is sent via wireless networks to the centralized platforms.

This approach ensures that container emptying is based on actual need, not a fixed schedule, thereby reducing unnecessary vehicle trips, saving fuel, reducing emissions, and optimizing the resources of the local utility service. The collected data enables the local administration to plan container distribution and emptying routes based on the actual dynamics of waste, which significantly improves system efficiency.

Zurich also applies the concept of smart mobility through integrated systems that enable traffic regulation, smart parking, and maximum efficiency of urban transport. In many city zones, a system of "smart" lampposts (Figure 1) has been installed, which measure traffic flow, detect free parking spaces, and can also serve as public Wi-Fi and charging points for electric vehicles [12].

The results of academic studies [14] have shown the effective application of sensor networks in traffic. This 2021 research on traffic condition assessment in urban environments using the example of Zurich uses data from thermal cameras, video recordings, and Google Distance Matrix to assess current traffic load, which enables travel time modeling, management of public transport supply, and adaptation of traffic policies.

Zurich implements strategies that include air quality monitoring, as part of broader sustainability, pollution prevention, and citizen health policies. Within modern smart-city solutions, networks of air quality sensors have been deployed, measuring particles, gases, and other pollutants, and enabling real-time data collection. This approach, also known as crowdsensing, shows that it is possible to monitor pollution efficiently, without the need for expensive and static stations [15].

Research has shown that when smart traffic systems and air monitoring are integrated, i.e., when traffic lights, traffic flows, and transport are adapted based on air quality data, a significant reduction in emissions and improvement in urban health can be achieved. This confirms that IoT sensors and digital platforms are not just a technical option, but a key tool for the real improvement of air quality.

Figure 1. A representation of one type of smart poles [12]

3.2. OSLO

Oslo represents one of the most advanced European smart cities, basing its development on long-term digital transformation, green policies, and integrated management of urban systems. In the IMD Smart City Index for 2025, the city received an AAA rating in both dimensions ("Structure" and "Technology") and remained ranked in second place, confirming the high level of development of its urban infrastructure [16].

In the area of waste management, the Norwegian company Sensorita has launched a smart waste management solution aimed at companies that maintain and collect waste containers. The "Sensor1" system uses IoT technology and machine learning based on research from the Norwegian University of Life Sciences to estimate the fill level and content of large waste containers (Figure 2). This data is then processed on the Sensorita Cloud platform to assist in the management and collection of these containers [17].

Figure 2. Waste containers equipped with fill-level monitoring sensors [18]

Oslo also uses technological solutions at the final stage of waste sorting, to adapt the waste management system to existing logistics and citizen engagement. Citizens sort household waste into several fractions (paper and cardboard, glass and metal, plastic packaging, and organic waste). Organic waste is converted into biogas for 150 buses and bio-fertilizer for about 100 farms, while the remaining waste is used for energy recovery, showing significant efficiency and citizen involvement in the waste management system. Both cases show how IoT and automation can be used (from container monitoring to waste separation) to increase recycling, reduce costs, and encourage citizens towards better habits [18].

In Oslo, parking and traffic management include digital tools that make the system more modern and user-friendly. Citizens can pay for parking in public traffic zones via the Bil and Oslo applications, simplifying the procedure and reducing the need for physical parking cards. Furthermore, as part of the public lighting modernization program, the city has introduced smart LED streetlights, controlled via IoT modules, which allow the lighting to be adapted to conditions

(congestion, weather conditions, traffic activity), as well as remote management and infrastructure monitoring [20].

Oslo is one of the European leaders in digital air quality monitoring. A network of sensors deployed on city roads, schools, and public spaces measures $PM_{2.5}$, PM_{10}, NO_2, and other pollutants. The collected data is published in real-time on the city portal Luftkvalitet-Norge, while in some municipalities, a crowdsensing approach via mobile devices and bicycle sensors is also being tested [21]. This model has proven to enable more efficient pollution mapping and support policies for traffic restrictions in critical zones. Scientific studies [22] show that the integration of smart traffic systems and air monitoring can significantly reduce emissions and improve population health.

3.3. GENEVA

Geneva was ranked third on the global IMD Smart City Index list in 2025, showing that citizens perceive it as an urban example that applies digital technologies and integrated services.

One example of waste management digitization in Geneva is the "Smart Bin" project for the municipality of Thônex in the canton of Geneva. Within this project, bins are equipped with sensors (NB-IoT network) that measure fill levels, and the data is sent to a central system. This enables dynamic planning of vehicle routes for emptying and reduces unnecessary trips, leading to more efficient and environmentally acceptable waste management [23].

In August 2025, during a sudden increase in ozone and high concentrations of air pollution, authorities in Geneva introduced temporarily free public transport: buses, trams, ferries, and trains were free of charge, to reduce the number of individual vehicles on the roads and lower traffic emissions. Also, between 6 AM and 10 PM, only vehicles with lower emissions were allowed in the city center, and the speed on the bypass was reduced to 80 km/h [24]. Such measures in an emergency show that IoT and digital platforms are not just a technical option, but a key part of the sustainable management of urban systems. By combining smart traffic regulation systems and sensor networks for air quality monitoring, Geneva establishes an integrated approach that allows traffic flows to be adapted to ecological conditions in real time.

4. EXAMPLES OF GOOD PRACTICE IN THE REGION

In the countries of the former Yugoslavia, various projects in the domain of smart cities have begun to develop in recent years, using digital technologies to improve public services, transport infrastructure, energy efficiency, and the management of urban resources. Initiatives vary in scope and level of development, some cities are implementing pilot projects and experimental platforms, while others are already establishing integrated systems for real-time data monitoring and management. The development of these systems is also supported by national strategies, such as, for example, in Serbia, the National Strategy of Smart Specialization [24], which sets the framework for stimulating digitalization, innovation, and the application of technologies in various sectors.

According to the IMD Smart City Index, most cities of the former Yugoslavia are not ranked on the global list, except for Ljubljana, which holds 16th place, and Zagreb, which is in 85th position [8]. Although data is lacking for other major cities in the region, these examples primarily point to differences in approach and development. Capital cities, such as Zagreb and Ljubljana, usually initiate most innovations and represent central hubs for the application of smart technologies.

Although the concept of smart cities in our region is still not fully established nor has it reached the level of integration present in leading European metropolises, numerous cities are slowly introducing technological innovations that represent important steps towards the smart city model. In the following, specific examples of good practice in the region will be presented, with a focus on cities that show the greatest potential for progress in the application of smart technologies. Although these processes are most often in their initial phase, certain cities in the region, such as Novi Sad, Ljubljana, and Zagreb, are already implementing concrete projects that show that smart technologies can be efficiently integrated into urban management in our region as well. For specific examples of good practice in the region, Zagreb and Novi Sad have been selected. Although Novi Sad is not ranked, it was chosen as an example of good practice because it stands out for its significant initiatives in the field of smart urban solutions.

4.1. NOVI SAD

The City Administration in the official document "Development plan of the city of Novi Sad 2023-2030" has defined the smart city concept as one of its priority goals, which signifies a public commitment to improve infrastructure, public services, waste management, energy, the environment, and transport with the help of digital technologies [27].

Within the broader smart city concept, the city's energy sector has been modernized: through a smart grid project. The applied system provides better possibilities for monitoring and managing the electric power system, better insight and control over energy flows, and a reduction in the average annual time consumers spend without electricity supply [28].

The city, with the support of the European Bank for Reconstruction and Development (EBRD), financed the purchase of 10 electric buses and charging infrastructure. This is part of the program for renewing public city transport services, with the aim of reducing emissions and air pollution [29]. Within the TRIBUTE project, a pilot system has been applied on some lines where monitors have been installed at stations showing bus arrivals in real time, and application users can see transport options (bus, bicycle, walking), which is a step towards smart mobility and more efficient traffic management [30].

4.2. ZAGREB

Zagreb, as the capital of Croatia, is gradually introducing smart solutions to improve urban infrastructure, the quality of life of its residents, and sustainability. Although the process of digital transformation is still ongoing, there are concrete projects indicating progress towards the smart city concept [31].

The city has launched a mobility project that includes the development of integrated multimodal transport solutions. One of the key elements is the ZET Info platform [32], an application that provides real-time information on the departure of public transport vehicles, routes, and transfer possibilities. Also, in partnership with private companies, Zagreb has introduced a system for sharing electric scooters and bicycles, supported by applications for reservation and payment.

In a pilot phase, smart waste bins equipped with sensors that monitor fill levels have been installed in some parts of the city (e.g., the center) [33]. The data is sent to a central system, enabling optimization of waste collection routes and reducing unnecessary trips by utility vehicles.

Zagreb has a network of air quality monitoring sensors deployed at key locations throughout the city. Data on particle concentrations ($PM_{2.5}$, PM_{10}) and gases (NO_2) are available to citizens via the city portal and the Zagreb Air application [34], which enables transparency and promotes ecological awareness.

Although Zagreb has several initiatives, challenges include incomplete integration of individual systems, budget limitations, and the need to strengthen the digital skills of the population. The city continues to develop its strategy, which aims to improve all segments of urban infrastructure through greater use of IoT, data analytics, and the inclusion of citizens in the decision-making process.

5. REGIONAL PROBLEMS AND POTENTIALS

Despite the growing interest in the concept of the smart city and digital technologies in urban management, cities in the former Yugoslavia still face a multitude of systemic obstacles that hinder their full transformation. Although individual pilot projects, such as smart waste bins in Zagreb or electric buses in Novi Sad, indicate a desire for change, these initiatives often remain isolated and fragmented, lacking a broader strategy and mutual interconnectedness. The fundamental problem lies in the lack of a comprehensive vision and a clear legal framework that would guide development, ensure financial sustainability, and guarantee the ethical use of technology. Without this, the smart city risks remaining an expensive technological experiment rather than a tool for the real improvement of the quality of life for all citizens. The key to overcoming these challenges lies in a systematic and coordinated approach, inspired by the experiences of leaders such as Zurich and Oslo, but adapted to local limitations and opportunities.

It is necessary, first and foremost, to formulate a regional or national smart city strategy that will define priorities, standards, and success indicators, transcending the narrow frameworks of individual municipalities. Such a strategy must be supported by strengthening the legal framework, especially in sensitive areas of data privacy protection, IoT device security, and conditions for the use of open public data. Adopting principles like the EU General Data Protection Regulation (GDPR) should not be a formal obligation, but a foundation for building citizens' trust and attracting responsible investors.

It is equally important to ensure that technology does not deepen the social divide. The design of smart services must be intuitive and accessible, accompanied by digital literacy programs aimed at the older population and less privileged groups. A truly smart city is one that serves everyone.

Cities should actively publish data in real-time on air pollution, traffic flows, energy consumption, and encourage society and the academic community to use it to create solutions of public interest. In this way, technology ceases to be merely a management tool and becomes a platform for civic participation and collective decision-making. The path to a smart city in this region is not in blindly copying foreign models, but in carefully building its own sustainable system guided by the principles of transparency, inclusion, and a strategic vision that puts technology at the service of people and their community.

6. CONCLUSION

Smart infrastructure, based on IoT and digital platforms, represents a crucial step towards sustainable, efficient, and adaptable cities of the future. Through a systematic review and analysis of good practice examples, this paper has shown that the application of simple and relatively inexpensive sensors can significantly impact the management of key segments of urban infrastructure: waste, traffic, energy, and air quality. The research confirms that cities such as Zurich, Oslo, and Geneva have not achieved their high level of development solely through technological advancement, but also through long-term planning, system integration, and a focus on citizen needs. On the other hand, cities in the region (Novi Sad, Zagreb) show that even initial steps, such as the introduction of smart grids, electric buses, or mobility platforms, can serve as a foundation for further development.

However, successful transformation requires more than technology. It is necessary to strengthen legal frameworks (inspired by the GDPR) that will protect privacy and ensure the ethical use of data, as well as invest in digital inclusion so that all citizens, regardless of age or socio-economic status, can use smart services. Furthermore, open data and intercity cooperation should become standard to accelerate the adoption of good practices and reduce implementation costs. Ultimately, a smart city is not an end in itself, but a means to achieve a sustainable, healthy, and inclusive urban space. Future development should be guided by principles of environmental responsibility, social justice, and technology that serve humanity, so that cities remain livable for future generations.

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