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The Importance of the Internet of Things for Smart Cities

Anna Reklewska

Wroclaw University of Economics and Business, Komandorska 118/120,
53-345 Wroclaw, Poland

anna.reklewska@gmail.com

Abstract. The concepts of Smart City and the Internet of Things have become a frequent topic of discussion in recent years. Due to the changes that take place in cities and the challenges cities face, modern solutions are sought to improve their functioning and enable their development. The aim of this paper was to demonstrate whether the Internet of Things is an essential element of a smart city. In the first part of the paper, the author focused on an introductory presentation of the basic problems of modern cities and defining the concept of Smart City. In the second part, the author focused on the Internet of Things and the description of selected technologies, with particular emphasis on their usefulness in the city. The last part of the paper showed how many elements of modern cities are closely related to the Internet of Things. The author presented real solutions implemented in smart cities, indicating that solutions based on the Internet of Things can be useful in every area of a smart city.

Keywords: Smart City, Internet of Things, Artificial Intelligence

Introduction

Modern cities are facing many challenges. There is mention of significant natural resource use and environmental protection, an aging population, management of urban services, and many others. Those cities that successfully manage to meet at least some of these needs are often called smart cities. However, it is important to consider what makes a city smart. Apart from the enormous influence of city dwellers and authorities, their creativity, skills and knowledge, the second factor is definitely technology. The main aim of this paper is to demonstrate how important the Internet of Things is for smart cities. The author of this paper decided to combine two concepts: Internet of Things and Smart City to verify whether a smart city could exist without solutions based on the Internet of Things and to present the potential benefits of their use in modern cities. In the first part of the paper, the author focused on the smart city concept, explaining its definitions. In the next section, the author presented the concept of the Internet of Things focusing in particular on the technologies used in cities. In the last part of the paper, the author focused on both concepts, showing the benefits of their combination and examples of already functioning solutions. The

summary includes the issues on which the author of the paper would like to concentrate in the future.

1 Why do we need smart cities?

1.1 The needs of modern cities

Modern cities face many challenges. The constant migration of people into cities causes not only development but also numerous problems. “The future of cities” report released in 2019 by the European Commission points to the most important of these [1]:

1) Affordable housing

The first challenge is the financialisation of housing and concerns affordability, responsibility and living conditions. For example, table number one shows how long a qualified city dweller has to work to be able to afford to buy a 60 square metre flat. These data show how many times the typical sales price is higher than the median annual income of the household.

Table 1. Years a skilled worker needs to work to be able to buy a 60 m2 near the city center.

City	Number of years
Hong Kong	Between 20 to 25
London	Between 13 to 17
Paris	Between 12 to 17
Singapore	Between 11 to 14
Tokyo	Between 10 to 14
New York	Between 10 to 13
Amsterdam	Between 8 to 11
Vancouver	Between 7 to 10
Sydney	Between 7 to 9
Munich	Between 7 to 9

As the table above shows, real estate markets in many large cities are difficult to access or completely inaccessible. Another report prepared by Deloitte in 2018 shows that the average annual increase in property prices in the European Union was 5% over three years [2]. The authors of the report indicate that the problem is the effects of the debt crisis or the weak and slow administration of state-building authorities.

2) Mobility

The mobility of people and goods is one of the fundamental determinants of urban development. In recent years, cities have been dominated by car transport, which has had a negative impact on the environment or health and has made it more difficult to

move around the city through traffic jams lasting several kilometers. In order to prevent these negative effects, cities are trying to implement initiatives such as the creation of parking zones around cities or charging for entry into the city center, which should, however, be combined with investment in the development of public transport. According to the authors of the report "The future of cities", mobility is one of the sectors that will change the most as a result of technological innovation and behavioral changes.

3) Provision of services

The nature of services in cities is constantly changing. These are mainly influenced by the widespread use of modern technology and the Internet. Nowadays, having specialised services focused on city dwellers and visitors is becoming an essential element of a city. It is expected that these changes will be even more noticeable in the future.

4) Ageing

According to "The future of cities" report, life expectancy will rise to over 88 years by 2070, while the ratio of older to younger people will double. Population ageing is a global trend, but it is a particular problem in places where the population is declining. This means that rising health care costs or pension payments will have to be covered by an ever-narrower workforce.

Table 2. Increase in a share of the population aged 65 years and over between 2009 and 2019 in selected countries [3].

Country	Increase in percentage points
Finland	5.1
Lichtenstein	5.0
Czech Republic	4.7
Malta	4.5
Netherlands	4.2
Poland	3.8
Portugal	3.8
Albania	3.7
Denmark	3.7
France	3.6
Slovenia	3.4
Serbia	3.3

Cities will have to learn to respond to these changes by also adapting their services such as health, mobility or social policies. Age-friendly cities can be characterised by age-appropriate elements such as transport, outdoor space and housing, communication and information.

5) Urban Health

Living in a city can be linked to health in many ways. On the one hand, interconnected networks of people make it easier for diseases to spread; on the other, the fast lifestyle typical of city dwellers or environmental pollution contributes to the development of diseases of civilizations.

6) Environmental footprint

The use of natural resources puts enormous pressure on the environment and leads to irreversible consequences such as water stress, biodiversity loss or climate change. In addition, providing city dwellers with access to water, energy and food requires the use of the natural environment beyond urban borders. Most city dwellers live far from agricultural and production systems so may not be aware of the impact they have on the environment.

7) Climate action

Cities are a major factor in climate change. It is estimated that they are responsible for 75% of global carbon dioxide emissions. At the same time, rising global temperatures are causing rising sea levels, increasing weather events such as floods, droughts and storms. All these events have a costly impact on basic urban services, infrastructure, housing and human health. Only coordinated action at the global and local level can bring about positive change. Cities are beginning to see the need to innovate to protect the environment, so they are using renewable energy sources, reducing urban transport and much more.

The needs of cities identified above are not all that exists. This short description is only a starting point for further development of the topic. However, they show how many different challenges the city authorities are facing. In response, cities began to look for different solutions. The first smart cities also began to appear.

1.2 Smart city definition

The Smart City concept is becoming more popular every year. Cities are outdoing themselves with ideas for improvements and innovations that will make their functioning even more efficient. There is actually no one proper definition of a smart city but they are often described as "high-tech", "innovative" or "green". In general, a smart city is a city that uses technology to provide services and solve urban problems, but in research and scientific sources, we can find more detailed description. One of the definitions is that "a smart city is (...) a city which invests in ICT enhanced governance and participatory processes to define appropriate public service and transportation investments that can ensure sustainable socio-economic

development, enhanced quality-of-life, and intelligent management of natural resources” [4]. Another definition is “The smart city concept describes the ability for utilizing the capacity of a city/community to create and adopt solutions for overcoming challenges and seizing opportunities that help transform cities/municipalities to more prosperous and livable places for all stakeholders. The ecosystem of implemented solutions is what defines how smart a city or community is” [5]. What these and many other definitions have in common is the use of modern technology in cities and ensuring sustainability.

Some areas of the city are particularly often highlighted when talking about the smart city. The table below shows the factors of smart city with their description and examples.

Table 3. Factors of smart cities

Defined area	Description and Examples
	All actions that aim to strengthen the economy.
Smart Economy	<ul style="list-style-type: none"> - Improving the attractiveness of the city, - Looking for new companies and investors, - Investing in qualified talents, - Flexibility of the labour market, - Using Information and Communication Technologies (ICT) for business.
	Improving the efficiency and quality of transport services and new mobility solutions.
Smart Mobility	<ul style="list-style-type: none"> - Sustainable and safe transport systems, - Innovative logistics systems, - Combining private and public transport - New forms of transportation (electric cars, bike sharing)
	Managing the environment to improve its quality and to ensure the well-being of cities' dwellers.
Smart Environment	<ul style="list-style-type: none"> - Environmental protection, - Sustainable resource management, - Water management, - Managing pollution, - Reduction of waste production.
	Involvement of city dwellers in its functioning and development.
Smart People	<ul style="list-style-type: none"> - Level of qualification,

	<ul style="list-style-type: none"> - Creativity, - Participation in public life - Labor market opportunities, - Smart ways of education, - Lifelong learning.
	Increasing quality of life for city dwellers and visitors.
Smart Living	<ul style="list-style-type: none"> - Health conditions, - Cultural facilities, - Quality of education, - Smart homes, - Smart workplaces, - Social platforms, - Safety.
Smart Governance	<p>Intelligent management of public administration, connection between government and all stakeholders - city dwellers, business etc.</p> <ul style="list-style-type: none"> - Transparent governance, - Political strategies, - Crowdsourcing, - Active participation in city management.

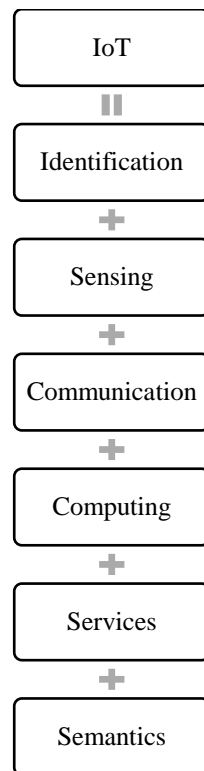
As shown in the table above, the concept of a smart city can relate to many elements. It can be discussed about smart city solutions in many contexts, having in mind **the human factor** (city dwellers and visitors), **the technological factor** (smart technologies) and **the institutional factor** (governance and policy) [6].

2 Internet of Things

2.1 Internet of things characteristics

The term "Internet of Things" (IoT) was first used in 1999 during a presentation by Kevin Ashton at Procter&Gamble company, but the concept only began to gain popularity around 2010 [7]. Since that year, the term has increasingly featured in scientific publications and business campaigns. However, it is in vain to look for its unique, valid definition. As in the case of the 'smart city', we can find many descriptions and characteristics of the Internet of Things, but in general, it can be said that IoT is "An open and comprehensive network of intelligent objects that have the capacity to auto-organize, share information, data and resources, reacting and acting in face of situations and changes in the environment" [8]. Internet of Things can be understood as a world where almost anything can be connected and communicate in an intelligent way. Figure 1 below shows components of the Internet of Things.

Fig.1 Internet of Things components



Source: A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, M. Ayyash, *Internet of things: A survey on enabling technologies, protocols, and applications*, "IEEE Communications Surveys&Tutorials" 2015

We can identify six key elements [9]:

1) Identification

Identification is needed to match services with their demand. We can use multiple identification methods, such as electronic product codes (EPCs) and ubiquitous codes (uCodes). Additionally, addressing IoT objects is important to differentiate between the object identifier and its address. Identification methods are used to deliver a unique identity for each object on the network.

2) Sensing

Sensing in the context of the Internet of things means collecting data from various objects on the network and sending it to a data warehouse, database or the cloud. The collected data is then processed and analyzed to take operations based on the requested services.

3) Communication

IoT communication technologies connect objects together to provide specific services. IoT communication protocols are communication modes that provide optimal security for data exchanged between devices. Examples of communication protocols could be WiFi, Bluetooth, IEEE or RFID. More information on specific IoT technologies can be found in subsection 2.2.

4) Computing

This refers to the computing units and software applications that constitute the computing capability of IoT. Over the years, various hardware platforms have been developed to run IoT applications. In addition, many software platforms are used to provide IoT functionality.

5) Services

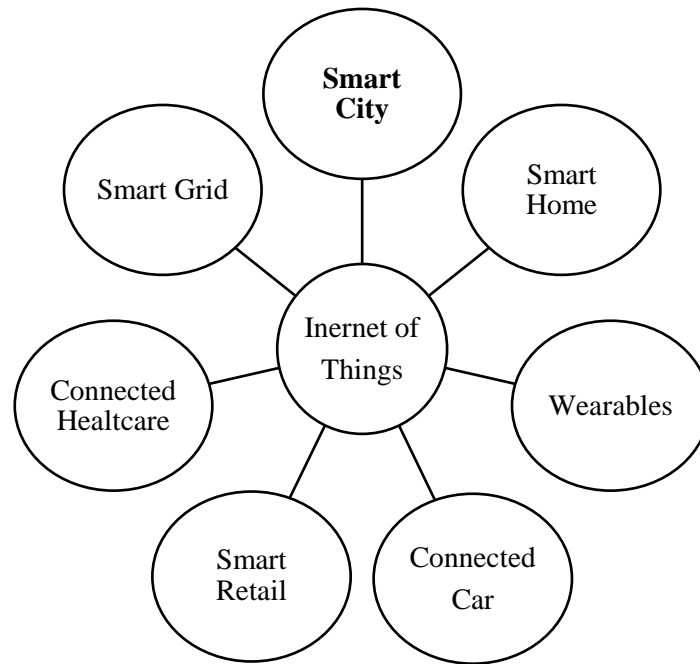
The authors of the discussed classification propose to divide IoT services into four types: Identity-related Services, Information Aggregation Services, Collaborative-Aware Services and Ubiquitous Services. Identity-related Services are the most basic but also the most important because any application that wants to bring objects into the virtual world must identify them. Information Aggregation Services collect sensory measurements that need to be communicated to IoT applications. Collaborative-Aware Services use the data obtained to make decisions and react appropriately. Ubiquitous services aim to deliver collaboration-aware services at any time to anyone anywhere who needs them.

6) Semantics

In the context of the Internet of Things, semantics refers to the ability of machines to intelligently mine knowledge to provide required services. Knowledge mining includes resource discovery and exploitation and information modelling. Semantic includes analyzing data in order to make the appropriate decisions.

The Internet of Things is an evolving concept thanks to technological developments, so more and more applications can be identified. Figure 2 shows examples of its most common applications.

Fig.2 Internet of Things applications



As shown in figure 2 above, one of the applications of the Internet of Things could be smart cities, so in the following part of the paper, we will focus more on this application.

2.2 IoT technologies for smart cities

The Internet of Things is a network that uses standard communication protocols, and the Internet is their convergence point. A growing number of Internet-enabled devices that can connect and communicate with each other and, as a result of the information they collect, are able to sense various situations in the environment, form their own network connections and generate entirely new information, becoming an integral part of the Internet. The selected technologies related to the Internet of Things are presented below [10].

1) Radio-Frequency Identification (RFID)

RFID enables the communication between a powered reader and an unpowered tag, a type of electronic label with a unique identification number. The range of RFID communication significantly depends on the parameters of the reader and the size and type of tag. RFID provides applications such as smart grids, including object tracking and location, healthcare applications or parking management.

2) Near Field-Communication (NFC)

NFC is used for two-way communication over a short distance - usually a few centimeters. Because it works two-way, it can be used to exchange data between devices. In a city, NFC can have many applications such as smartphone payments or smart energy metering.

3) ZigBee

ZigBee is a standard for self-configuring short-range radio networks, designed for use in telemetry systems, for communication between various types of sensors, monitoring devices, as well as for wireless reading of measurement results from energy meters or heat meters.

4) Wireless Sensor Networks (WSNs)

WSN is a wireless network consisting of spatially distributed devices that use sensors to monitor conditions such as temperature, sound, pressure or pollution. It consists of thousands of sensors that communicate with each other and transmit data.

5) 3G, Long Term Evolution (LTE)

3G and LTE are standards for wireless communication. 3G and LTE are common in most countries of the world. This technology was designed for wideband communications.

6) 5G

The latest mobile network standard is 5G. 5G enables a new kind of network to connect virtually all machines, objects and devices. Additionally, 5G is expected to deliver higher data rates of many Gbps, low latency, massive network capacity and increased availability. It is predicted that the 5G network could greatly influence the development of smart cities.

3 Internet of Things in a concept of Smart City

3.1 IoT Applications for Smart Cities

The number of Internet of Things applications for smart cities is increasing successively. In general, it can be said that Smart Cities are powered by millions of connected devices. Cities are deploying sensors and devices in their areas, monitoring city activity and connecting to each other via wireless and wired networks [11]. Some examples of IoT applications in the city are listed below along with their main

advantages. Listed here are those that can secure the needs of the cities identified in chapter one. The first is **traffic monitoring**. Real-time monitoring of urban traffic has benefits such as avoiding traffic jams, maintaining controlled levels of congestion and ensuring that air pollution levels are kept relatively low. Traffic volume sensors or cameras can be used here. In both of these options, real-time traffic data is made available to city managers, who can take the appropriate decisions in time if necessary. The information is often also sent to city dwellers. In addition to making immediate decisions, the data collected is also analyzed to manage the city's mobility and protect the environment. The next application is **waste management**. In the traditional way of waste collection, trucks pull up to the containers every few days or weeks, emptying the overflowing ones as well as the nearly empty ones. With modern solutions, IoT sensors can verify how full the containers are and send the information to sites that can optimize garbage truck routes based on that information. Machine learning methods that predict how full the garbage containers are based on historical data are also helpful in this case. Another example of IoT application in the city could be **smart parking management** [12]. The smart parking system sends information about free parking spaces via mobile and web applications. The data is collected from sensors or cameras that are placed in each parking space. The user can then choose the space that is best for them, and the data that the spot has been occupied updates in real-time so that other users can see it. Similar to the previously described applications, the system can not only be used for real-time operation but can also be used to monitor traffic in car parks and facilitate decisions regarding the construction of new parking spaces. The next application is the system to **support active ageing** [13]. There are more and more ways to apply the Internet of Things to support older people in cities. Interesting systems are being designed and implemented, and campaigns are being organized to encourage their use. They are based on different ideas - activating the elderly people, monitoring and promoting health lifestyle or even facilitating new friendships. One interesting proposal is described in more detail in section 3.2. The last application is **public safety management** [14]. To enhance public safety, IoT-based smart city solutions offer real-time monitoring and decision-making tools. Data, in this case, comes from CCTV cameras and acoustic sensors deployed in the city, but also from social media. By analyzing these, potential crime scenes can be predicted. This will enable police to apprehend potential perpetrators or target them effectively.

The solutions indicated above are just some of the ways in which IoT-based technologies can be used in the smart city. New ideas are generated every day, and technological developments make it possible to put into practice ideas that only a few years ago seemed impossible to implement. The table below shows a number of Internet of Things-based solutions that have been used successfully in cities. The solutions are categorized into five key elements of a smart city, but "Smart People" and "Smart Living" are included in one column due to the fact that they are very similar concepts.

Table 4. IoT based applications in Smart Cities

Smart People & Smart Living	Smart Mobility	Smart Economy	Smart Governance	Smart Environment
Social Network Supporting	Connected Vehicle	Energy management in Office Buildings	Civic Engagement Platform	Monitoring Air Quality
Public Place Monitoring	Car Sharing	Equipment use management systems (in factors)	Citizen Grievance Management	Smart Lightening
Security Systems	Bike Sharing			Noise pollution Monitoring

The above table indicates that although it would seem that Internet of Things-based solutions will only find their application in the **technology factor** of the smart city, they can also find their application in the other two factors - **human** and **institutional**.

3.2 Internet of Things solutions in Smart Cities

In the last part of this paper, several real IoT-based smart city solutions will be presented, not just general concepts but actual solutions that have been successfully implemented and are in use, along with an indication of the city where they work.

1) Santander, Spain [15]

In the city of Santander, Spain, a system designed for both city dwellers and tourists has been implemented. The application contains information on almost 3000 places such as beaches, parks and gardens, monuments, tourist offices, stores, art galleries, museums, libraries, stores, public buses, cabs, bicycles, parking spaces as well as a calendar of public events. The app provides real-time access to cameras, sends reports and weather forecasts, and includes information on public transportation making it easy to experience the city. Thanks to the popularity of the application in Spain, other cities such as Lübeck (Germany), Guilford (United Kingdom) and Belgrade (Serbia) have decided to implement it [16].

2) New York, San Francisco, Las Vegas, Chicago and other cities, USA [17]

A system for the detection, location and analysis of gunshots and for the management of patrols has been implemented in many US cities, enabling resources to be dynamically directed to areas of greatest risk. A company offering solutions of this kind has announced that it plans to expand its operations in the near future, also in smaller

US cities. The software can pinpoint the exact location of any missile fired within seconds, with street-level accuracy. Once validated, the alert is sent to dispatch centers and to field workers via any computer or mobile device with internet access - all done in less than a minute. The system can determine the type of weapon used, the number of shooters is where and how fast they are headed.

3) Tilburg, The Netherlands [18]

In the city of Tilburg in the Netherlands, a decision was made to support elderly people on the roads. There are many busy road junctions where the time to cross the road was limited to the short period when the green light was on. This caused many problems, especially for the elderly and people with reduced mobility - many times they were only halfway across the street when the light changed to red. Now, thanks to the solution implemented in the city, such a situation is rare. The sensors in the traffic lights scan the sidewalk on both sides of the crossing, and if they "see" a waiting pedestrian who uses the discussed application, they adjust the time of the green light. The app has one of the four-time settings built-in, depending on the user's mobility level, to minimize delays for other traffic participants. The developers of the app emphasize that their system can be used not only by the elderly but also by trips, where a large group of people has to cross the pedestrian crossing at one moment.

Conclusion

The aim of the presented paper was to compare two popular concepts - Smart City and Internet of Things in order to verify the importance of using IoT-based solutions in the city. The first part presented the selected needs of modern cities and introduced the Smart City concept. The second part discussed the definition of the Internet of Things and described the technology with particular emphasis on the part that can be successfully implemented and used by city dwellers, city authorities and tourists. The third part showed general examples of IoT-based solutions and real solutions from smaller and larger smart cities. The paper shows that the implemented solutions can be used not only to meet strictly technology-based needs, which can be combined with the concepts of "Smart Mobility" or "Smart Environment" but also with the other elements of a smart city - "Smart People", "Smart Living" and "Smart Governance". In the future, the author would like to focus on indicating not only the positive effects of using the Internet of Things in the city but also pointing out the challenges that appear when trying to implement them. This would include aspects such as security and privacy, technological issues related to, for example, processing and analyzing large amounts of data, high costs and finally ethical dilemmas that arise in many discussions of the implementation of modern technological solutions. By comparing the benefits of implementing the Internet of Things in a city and the doubts that may arise, it would be easier to make decisions related to the development and functioning of smart cities.

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