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Internet of Things in the Smart City Concept

1. Introduction

The smart city is a global trend of urban strategies aimed at recovering the quality of inhabitants living in urban areas and at leveraging innovation and high technologies to solve the difficult problems generated by high-population density[3]. It helps to solve issues of urbanization[4], especially environmental pollution, land consumption, urban sprawl, transport congestion, energy needs, difficulties in accessing public services and it contains a diversified set of public initiatives: from building better transportation systems to endorsements of creative innovation, knowledge for designing energy-saving policies[5]. In this paper, the possibility of using the concept of the Internet of Things (IoT) is evaluated. The concept is based on the automation of the main processes in six spheres of the smart city. Smarter cities start from the human capital perspective, rather than blindly adhering that ICT can automatically create a smart city[6]. The pur-

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[3] D. Marinova, J. Philimore, *Models of innovation*, in: *The international handbook on innovation*, L.V. Shavinina (Eds.), Elsevier, 2003, pp. 44–53; R.P. Dameri, *Searching for smart city definition: a comprehensive proposal*, "International Journal of Computers & Technology" 2013, 11(2), pp. 2544–2551; G.P. Hancke, B.C. Silva, *The role of advanced sensing in smart cities*, "Sensors" 2013, 13, pp. 393–425; S. Hajduk, *The Concept of a Smart City In Urban Management*, Business, Management and Education" 2016, 14(1), pp. 34–49.

[4] M. Jankowska, *Smart City jako koncepcja zrównoważonego rozwoju miasta – przykład Wiednia*, "Studia i Prace Wydziału Nauk Ekonomicznych i Zarządzania" 2015, vol. 2, no. 42.

[5] R. Florida, *Who's your city? How the creative economy is making where you live the most important decision of your life*, Basic Books, New York 2008; J.M. Eger, *Smart growth, smart cities, and the crisis at the pump a worldwide phenomenon*, "I-Ways" 2009, 32(1), pp. 47–53; R.G. Hollands, *Will the Real Smart City Please Stand up?*, "City: Analysis of Urban Trends, Culture, Theory, Policy, Action" 2008, 12:3, pp. 303–320; M. O'Grady, G. O'Hare, *How smart is your city?*, "Science" 2012, 335(3), pp. 1581–1582.

[6] J.M. Shapiro, *Smart Cities: Quality of Life, Productivity, and the Growth Effects of Human Capital*, "Review of Economics & Statistics" 2006, 88:2, pp. 324–335; R.G. Hollands, op.cit., pp. 303–320.

pose of the paper is to present the possibilities of using the Internet of Things concept in six spheres of the smart city idea on the basis of the chosen metropolises. The methodological aim is to prepare hypotheses to an in-depth statistical analysis. The methods of desk research and case study have been used to support the above-mentioned purpose.

2. The Concept of the Smart City

There are many smart city definitions and approaches[7], but the majority of them focus on three dimensions: quality of life, information technology and community. The smart city is often called "intelligent"[8], "innovative", "interconnected"[9], "high-tech"[10] or "green"[11]. Analysis of the international literature[12] concerning the smart city suggests that the present concept is the result of three trends of urban research, namely the digital city, the green city and the knowledge city[13]. ICT, knowledge and the environment are seen as inextricably linked with the implementation of more innovative cities.

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[7] V. Albino, U. Berardi, R.M. Dangelico, *Smart Cities: Definitions, Dimensions, Performance, and Initiatives*, "Journal of Urban Technology" 2015, vol. 22, no. 1, pp. 3–21.

[8] M. Deakin, H. Al Waer, *From Intelligent to Smart Cities*, "Intelligent Buildings International" 2011, 3:3, pp. 140–152; H.N. Hsich, C.C. Chen, C.Y. Chou, Y.Y. Chen, *The Evaluating Indices and Promoting Strategies of Intelligent City in Taiwan*, Proc. Multimedia Technology, 6704–6709, July 2011, pp. 26–28; N. Komninos, *Intelligent Cities: Variable Geometries of Spatial Intelligence*, "Intelligent Buildings International" 2011, 3:3, pp. 172–188.

[9] S. Zygiaris, *Smart City Reference Model: Assisting Planners to Conceptualize the Building of Smart City Innovation Ecosystems*, "Journal of the Knowledge Economy" 2013, 4:2, pp. 217–231.

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[11] V. Albino, R.M. Dangelico, *Green Cities into Practice*, in: *The Economy of Green Cities: A World Compendium on the Green Urban Economy*, R. Simpson and M. Zimmermann (Eds.), Springer Science Business Media B.V., Dordrecht, Netherlands 2012.

[12] S. Hajduk, op.cit.

[13] H. Chourabi, T. Nam, S. Walker, J.R. Gil-Garcia, S. Mellouli, K. Nahon, H.J. Scholl, *Understanding smart cities: an integrative framework*, in: System Science HICSS 2012, 45th Hawaii International Conference, IEEE, 4–7 January 2012, Maui, HI, 2289–2297; A. Vanolo, *Smartmentality: the smart city as disciplinary strategy*, "Urban Studies" 2014, 51(5), pp. 883–898; P. Neirott, A. De Marco, A.C. Cagliano, G. Mangano, F. Scorrano, *Current trends in smart city initiatives: some stylised facts*, "Cities" 2014, 38, pp. 25–36.

In the paper, it is emphasized that the smart city is an integrated and comprehensive vision of all aspects of urban life including: the economy, the people, the governance, mobility, the environment and living (table 1).

Table 1. Characteristics and factors of a smart city

Spheres of Smart City	Main factors	
SMART ECONOMY (Competitiveness)	• Innovative spirit • Entrepreneurship • Economic image & trademarks • Productivity	• Flexibility of the labour market • International embeddedness • Ability to transform
SMART PEOPLE (Social and Human Capital)	• Level of qualification • Affinity to life-long learning • Social and ethnic plurality • Flexibility	• Creativity • Cosmopolitanism/Open-mindedness • Participation in public life
SMART GOVERNANCE (Participation)	• Participation in decision-making • Public and social services	• Transparent governance • Political strategies & perspectives
SMART MOBILITY (Transport and ICT)	• Local accessibility • (Inter-)national accessibility	• Availability of ICT-infrastructure • Sustainable, innovative and safe transport systems
SMART ENVIRONMENT (Natural resources)	• Attractivity of natural conditions • Pollution	• Environmental protection • Sustainable resource management
SMART LIVING (Quality of life)	• Cultural facilities • Health conditions • Individual safety • Housing quality	• Education facilities • Touristic attractivity • Social cohesion

Source: R. Giffinger, C. Fertner, H. Kramar, R. Kalasek, N. Pichler-Milanoviü, E. Meijers, *Smart Cities: Ranking of European Medium-Sized Cities*, Centre of Regional Science (SRF), Vienna University of Technology, Vienna 2007, p. 12.

In association with the economy or jobs, the Smart City is used to describe a city with a "smart" industry[14]. That implies especially industries in the fields of information and communication technologies (ICT), as well as other industries

[14] R. Giffinger, C. Fertner, H. Kramar, R. Kalasek, N. Pichler-Milanoviü, E. Meijers, *Smart Cities: Ranking of European Medium-Sized Cities*, Centre of Regional Science (SRF), Vienna University of Technology, Vienna 2007, p. 11.

implying ICT in their production processes. Also, for business parks or own districts comprising of companies within this field the name Smart City is used. The term Smart City also includes the education of its inhabitants. A Smart City has, therefore, smart inhabitants in terms of their educational grade. The term Smart City refers to the relation between the city government administration and its citizens. Good governance as an aspect of a smart administration is also referred to as the usage of new channels of communication for the citizens, e.g. "e-governance" or "e-democracy". The Smart City is furthermore used to discuss the use of modern technology in everyday urban life. This includes not only ICT but also, and especially, modern transport technologies: logistics as well as new transport systems as "smart" systems which improve the urban traffic and the inhabitants' mobility. Moreover, various other aspects referring to life in a city are mentioned in connection to the term Smart City like security/safety, green, efficient & sustainable, energy etc. The spheres of smart city have been modified by several authors[15], but the idea of using the six mentioned spheres have been sustained.

3. Internet of Things: The Concept and the Areas of Application

The phrase "Internet of Things" (IoT) was introduced in 1999 as the title of a presentation made by Kevin Ashton at Procter and Gamble[16]. Since then, IoT has been a constant subject within scientific literature and has been defined in a variety of ways. While there is still no standard definition, it is possible to name the general IoT elements (figure 1). It should be also noted that the concept usually focuses on five elements, occasionally including more than one of them: networking, services, communications, data and things. Moreover, in most recent definitions and visions, the role of things as data producers and the network as an enabler of new services have been highlighted[17].

[15] P. Lombardi, S. Giordano, H. Farouh, W. Yousef, *Modelling the Smart City Performance*, "Innovation: The European Journal of Social Science Research" 2012, 25:2, pp. 137–149; G.C. Lazaroiu, M. Roscia, *Definition Methodology for the Smart Cities Model*, "Energy" 2012, 47:1, pp. 326–332.

[16] K. Ashton, *That 'internet of things' thing*, "RFiD Journal" 2011, 22(7).

[17] J.E. Ibarra-Esquer, F.F. González-Navarro, B.L. Flores-Rios, L. Burtseva, M.A. Astorga-Vargas, *Tracking the Evolution of the Internet of Things Concept across Different Application Domains*, "Sensors" 2017, 17(6), p. 1379.

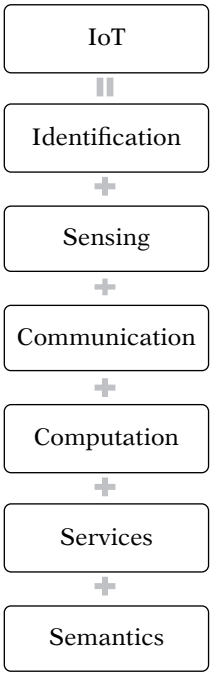

Figure 1. IoT elements

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, 17(4), pp. 2347–2376.

The reasons for this lack of uniformity in the approaches to IoT derive mostly from the simple fact that technology and the ideas which the IoT concept is built on do change over time[18]. Additionally, it is also a consequence of the name ''Internet of Things" itself, which syntactically is composed of two terms. The first one pushes towards a network oriented vision of IoT, while the other one moves the focus on generic ''objects" to be integrated into a common framework.[19] Apart from the above-mentioned difficulties, one of the most commonly used definitions is the one describing IoT as "a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual *things* have identities, physical attributes, and virtual personalities and use intelligent interfaces,

[18] E. Borgia, *The Internet of Things vision: Key features, applications and open issues*, "Computer Communications" 2014, 54, pp. 1–31.

[19] L. Atzori, A. Iera, G. Morabito, *The internet of things: A survey*, "Computer networks" 2010, 54(15), pp. 2787–2805.

and are seamlessly integrated into the information network"[20]. According to the above, undoubtedly the very essence of IoT are so called "self-configuring capabilities", meaning primarily that the objects operating within the network are capable of gathering and exchanging data independently (i.e. without the help of human beings), which then could be used for different purposes. As a result, in the foreseeable future, Borgia's IoT scenario could emerge (figure 2) with smart devices forming so-called sensory swarm, the cloud replacing traditional computing and storage systems, and humans being completely immersed in the world of technology with mobile access to the cloud.

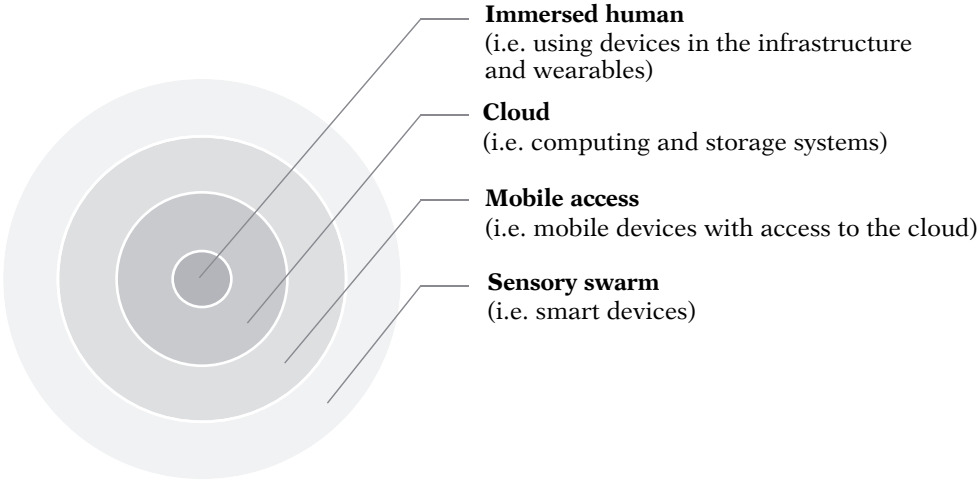

Figure 2. IoT scenario

Source: E. Borgia, *The Internet of Things vision: Key features, applications and open issues*, "Computer Communications" 2014, 54, pp. 1–31.

There is a lot of discussion over IoT applicability, in which various authors offer different areas of application (and that is often despite using the same criteria for division, i.e. providing a competitive advantage over existing solutions/improving the quality of life). Therefore, IoT applicability can include:

- domains like: transportation and logistics, healthcare, smart environment (home, office, plant), personal and social[21];

[20] H. Sundmaeker, P. Guillemin, P. Friess, S. Woelfflé, *Vision and challenges for realising the Internet of Things*, Cluster of European Research Projects on the Internet of Things, European Commision, 3(3), 2010, pp. 34–36.

[21] L. Atzori, A. Iera, G. Morabito, op.cit., pp. 2787–2805.

- areas like: smart homes/smart buildings, smart cities, environmental monitoring, health care, smart business/inventory and product management, security and surveillance[22];
- or domains like: transportation, industry, healthcare, market, agriculture, vehicles, school and smart home[23].

In spite of the absence of consensus on the possible areas of IoT applications, it should be highlighted that the Internet of Things is a concept constantly driven by technological evolution. It should come as no surprise that the possible areas of its application are naturally expanding with time (e.g. a growing number of mobile devices, sensors implemented in different buildings and vehicles, etc.). It can be also argued that "smart cities" seem to cover the widest possible range of solutions. In addition, it could be said that each of the remaining areas are implemented within the smart city concept.

4. IoT Solutions within the Smart City

Undoubtedly, the Internet of Things could be named the foundation on which smart cities are built. The number of IoT applications already working (or tested) within different cities is constantly growing, therefore bringing them closer to the futuristic vision of the fully connected cities[24]. While it is still impossible to name a city that fully utilises the potential of IoT solutions, there are cities which could be used as benchmarks in given areas of IoT application i.e. Singapore, London and Chicago. The selection of the above-mentioned cities was dictated by their presence in the latest global rankings (e.g. IESE Cities in Motion Ranking 2017[25], EasyPark Smart City Index 2017[26], Global Cities 2017[27]) where, taking

[22] D, Miorandi, S. Sicari, F. De Pellegrini, I. Chlamtac, *Internet of things: Vision, applications and research challenges*, "Ad Hoc Networks" 2012, 10(7), pp. 1497–1516.

[23] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, M. Ayyash, *Internet applications and research challenges*, "Ad Hoc Networks" 2012, 10(7), pp. 2347–2376.

[24] See: NLC, *Trends in Smart City Development*, p. 5, http://www.nlc.org/resource/smart-city-development (accessed: 26.11.2017).

[25] *IESE Cities in Motion Index 2017*, http://blog.iese.edu/cities-challenges-and-management/2017/05/25/164/ (accessed: 17.12.2017).

[26] *EasyPark Smart Cities Index 2017*, https://easyparkgroup.com/smart-cities-index/ (accessed: 17.12.2017).

[27] *Global Cities 2017*, https://www.atkearney.com/global-cities/full-report (accessed: 17.12.2017).

into account certain criteria (especially deployment of IoT solutions), they are often presented as top in their regions.

4.1. Smart Nation Singapore

Singapore, a sovereign city-state and island country in Southeast Asia, is one of the worldwide leaders when it comes to the trials of smart city solutions. Since 24th of November, 2014, when Prime Minister Lee Hsien Loong launched the programme which called for an unspecified number of sensors and cameras to be deployed across the island to track everything from cleanliness to traffic, the city has been turned into a "living laboratory"[28]. The areas in which IoT solutions dominate include among other things[29]:

- **Healthcare** – i.e. TeleHealth service brings medical help to patients' doorsteps by supporting virtual elderly monitoring services and telerehabilitation, while the Healthhub web portal and mobile application give access to medical records and useful health information;
- **Living** – i.e. home applications to save energy and water savings, and to help monitor the elderly to make sure they are alright;
- **Mobility** – i.e. contactless fare payments on public transport and trials for autonomous mobility-on-demand services, which are envisaged to comprise a fleet of shared self-driving shuttles or pods that commuters will be able to book through their smartphones to bring them from their doorstep to the train station or other neighbourhood amenities.

Based on the information collected via many trials, Singapore is able to deliver more tailored solutions for the needs of the residents.

4.2. London Data Store

One year since the relaunch of Data Store, London is a leading city in the field of data sharing. The London Datastore[30] is a free and open data-sharing portal where anyone can access data relating to the capital. The categories of data include categories like for example: Housing, Transport, Environment,

[28] *Singapore – the world's first smart city?*, https://www.gemalto.com/review/Pages/Singapore---the-world%27s-first-smart-city.aspx (accessed: 26.11.2017).

[29] *Smart Nation Singapore*, https://www.smartnation.sg/ (accessed: 26.11.2017).

[30] *London Data Store*, https://data.london.gov.uk/ (accessed: 26.11.2017).

Community Safety and Health. The portal helps to create smart London by using data and information, among others, to:

- create smart solutions which can help the capital e.g. providing data for journey planners;
- support growth, infrastructure and services e.g. giving access to infrastructure maps;
- be more responsive to Londoners' and businesses' needs e.g. providing information about current investments and creating a London School Atlas.

The most popular use of London's Open Data has been the creation of mobile journey planning apps. Transport for London (TfL) has helped London to lead the way in open data by releasing large volumes of real-time data and engaging developers to deliver and innovate using open data. Developers have created hundreds of applications, reaching millions of active users. Open data has facilitated the development of technology enterprises, small and medium-sized businesses, generating employment and wealth for London and beyond. It has also delivered innovation by having thousands of developers working on designing and building applications, services and tools with their data and APIs (Application Programming Interfaces)[31].

4.3. Chicago's Array of Things Project

In 2016, Chicago started its project called "Array of Things"[32] (AoT) by installing the first of an eventual 500 nodes on city streets to collect real-time data on the city's environment, infrastructure, and activity for research and public use. Essentially, AoT serves as a "fitness tracker" for the city, measuring factors that impact liveability in Chicago such as climate, air quality and noise. Nevertheless, due to the fact that the data is published openly and without charge, it also supports the development of innovative applications, such as a mobile application that allows a resident to track their exposure to certain air contaminants, or to navigate through the city based on avoiding urban heat islands, poor air quality, or excessive noise and congestion. Obviously, there are many potential applications of data collected with the use of AoT (table 2).

[31] *Transport Apps*, https://data.london.gov.uk/case-studies/transport-apps/ (accessed: 26.11.2017).

[32] *Array of Things Chicago*, https://arrayofthings.github.io/index.html (accessed: 26.11.2017).

Table 2. Potential applications of data collected by the Array of Things

Data collected	Possible application
air quality, sound and vibration (to detect heavy vehicle traffic), and temperature	suggesting the healthiest and unhealthiest walking times and routes through the city, studying the relationship between diseases and the urban environment etc.
urban flooding	improving city services and infrastructure to prevent property damage and illness
micro-climate in different areas of the city	providing up-to-date, high-resolution "block-by-block" weather and climate information
areas of the city that are heavily populated by pedestrians at different times of day	suggesting safe and efficient routes for walking late at night or for timing traffic lights during peak traffic hours to improve pedestrian safety and reduce congestion-related pollution

Source: the authors' own elaboration based on: https://arrayofthings.github.io/index.html (accessed: 26.11.2017).

At the end of 2018, Chicago is planning to finish the installation of all the nodes, therefore the full potential of this solution is yet to be discovered.

5. Conclusion

The Internet of Things can be described as a Smart City foundation. Taking into account each of the spheres distinguished within the concept (i.e. smart economy, smart people, smart governance, smart mobility, smart environment and smart living), it seems impossible to point even one area in which IoT implementation would not be required in order to fully justify the use of the "smart" adjective. Nevertheless, literature review and current solutions that are used in cities around the world show that it is still a bit too early, to name it fully evolved IoT infrastructure i.e. most of the solutions implemented still require relatively a lot of human help to fully operate (table 3), which contradicts the essence of IoT.

The sphere that seems to be the closest to the actual IoT adaptation is smart mobility, while there are already a lot of working solutions that help with traffic management and public transport within cities, there are also a lot of trials and plans on autonomous vehicles (e.g. in San Francisco or Singapore). Once such vehicles become marketable, IoT within this sphere could be fully brought to life with little to none of human help required. It should be also noted that

despite smart living being one of the main areas of interest when it comes to companies developing the necessary technology, the scale of its adoption is quite small (undoubtedly one of the reasons being relatively high costs). Nevertheless, it should be noted that when it comes to this sphere, the technology is already there, therefore, the potential of IoT adaptation is very big.

Table 3. Internet of Things in the Smart City idea

Spheres of Smart City	Current scale of IoT implementation	Current scale of human assistance required
SMART ECONOMY	**medium** (e.g. various data collectors aid at making the most suitable economic decisions)	**high** (e.g. distribution of data collected to interested parties)
SMART PEOPLE	**medium** (e.g. smart devices and wearables provide their users with a lot of useful information)	**low** (e.g. configuration of the devices in order to get the most relevant information)
SMART GOVERNANCE	**medium** (e.g. a lot of online database platforms launched to help and communicate with residents)	**high** (e.g. administration of online database platforms)
SMART MOBILITY	**high** (e.g. a lot of public transportation solutions are already working like traffic light management)	**low** (e.g. monitoring the data provided by IoT infrastructure)
SMART ENVIRONMENT	**medium** (e.g. growing number of sensors deployed in cities monitor a city environment more thoroughly)	**medium** (e.g. actions required based on the gathered information)
SMART LIVING	**low** (e.g. a lot of solutions are either in trials or hard to access for average residents)	**low** (e.g. configuration of the system)

Source: the authors' own work.

To sum up, based on the implementation of IoT solutions, it seems too early to fully justify the phrase "Smart City" when it comes to particular cities. However, it is possible to present cities which undoubtedly lead the race to become a smart city in the future (like the above-mentioned Singapore, London and Chicago to name a few which could be seen as benchmarks for others). The methodological aim was to prepare hypotheses to in-depth statistical analysis. The basic thesis of the consideration bases on a presumption that automation, related to the Internet of Things concept, should not be implemented in every sphere of the Smart City idea at the same level. The first proposed hypothesis expresses the assumption that the full implementation of IoT will reduce the

level of "smartness" for the city. The second proposed hypothesis expresses the assumption that the highest reduction of "smartness" for the city will be observed in "smart people" and "smart governance" spheres. The third proposed hypothesis expresses the assumption that the more machine-oriented process of the Smart City, the more demand for automation will be observed. The fourth proposed hypothesis expresses the assumption that the more human capital oriented process of the Smart City, the less demand for automation will be observed. The presented assumptions correspond with different perspectives represented by varying needs and preferences of human beings, including democratic processes of the "smart governance" sphere, and clear and precise aims and tasks of different types of machinery, demanding full automation.

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Internet rzeczy w koncepcji Smart City

Streszczenie

Niewątpliwie można wskazać na różnice w podejściu do koncepcji Smart City, która różni się m.in. w zależności od miasta i kraju, poziomu ich rozwoju, chęci przeprowadzania zmian i reform, zasobów i aspiracji mieszkańców miasta itd. Niemniej jednak należy podkreślić, że koncepcja ta jest nierozerwalnie związana, napędzana i technologicznie możliwa dzięki Internetowi rzeczy. Internet rzeczy opisuje swego rodzaju rewolucję, która ma obecnie miejsce, tj. rosnącą liczbę urządzeń z dostępem do Internetu, które mogą się łączyć i komunikować ze sobą oraz innymi gadżetami z dostępem do sieci. Internet rzeczy odnosi się do stanu, w którym rzeczy (np. przedmioty, otoczenie, pojazdy i odzież) na skutek gromadzonych informacji są w stanie wyczuwać rozmaite sytuacje w otoczeniu, komunikować się, tworzyć własne powiązania sieciowe i generować zupełnie nowe informacje, stając się integralną częścią Internetu (*Technology Strategy Board*). Celem niniejszego artykułu jest przedstawienie możliwości zastosowania Internetu rzeczy w ramach sześciu sfer koncepcji Smart City na przykładzie wybranych metropolii. Wpływ Internetu rzeczy na koncepcję Smart City można podzielić na dwa rodzaje: sfery w pełni obsługiwane przez maszyny (rzeczy) i sfery wymagające ludzkiej pomocy. Wdrożenie pierwszego typu wykazałoby wysoki poziom automatyzacji. Do realizacji tego celu wykorzystano metody *desk research* oraz studium przypadku. Celem metodologicznym było przygotowanie hipotezy do pogłębionej analizy statystycznej. Wśród głównych wniosków postawiono podstawową tezę rozważań, tj. automatyzacja związana z koncepcją Internetu rzeczy nie powinna być realizowana w każdej sferze Smart City na tym samym poziomie. Ponadto w artykule zostały sformułowane cztery hipotezy, które odpowiadają różnym perspektywom reprezentowanym przez różne potrzeby i preferencje człowieka, w tym demokratyczne procesy „inteligentnego zarządzania", a także jasne i precyzyjne cele i zadania różnych typów maszyn, wymagające pełnej automatyzacji.

Słowa kluczowe: Smart City, Internet rzeczy, studia przypadków, technologie informacyjne.