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SMART CITIES OF THE 21ST CENTURY
CHYTRÁ MĚSTA 21. STOLETÍ

BACHELOR'S THESIS
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DOPORUČENÁ LITERATURA:

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Abstrakt

Tato bakalářská práce se zabývá konceptem chytrých měst 21. století. Jejím účelem je popsat zmíněný fenomén a diskutovat jeho zavedení. Konkrétně rozebírá šest oblastí, do kterých se koncept dělí a popisuje moderní technologie využívané v chytrých městech. Dále zmiňuje problematiku kyberbezpečnosti ve spojitosti s ochranou osobních dat a zajištěním správného fungování města. Jako příklady chytrých měst jsou uvedené Praha a Londýn, u kterých jsou rozebrány jejich individuální strategie pro zavádění konceptu společně s příklady chytrých projektů, které už města uskutečnila. Na základě dvou vybraných indexů je pak provedeno porovnání úrovně chytrosti daných měst.

Klíčová slova

Chytré město, informační a komunikační technologie, internet věcí, Praha, Londýn

Abstract

This bachelor's thesis is focused on the concept of smart cities of 21st century. Its objective is to describe this phenomenon and discuss possibilities of its implementation. It analyses six sections, into which the concept is divided, and describes modern technologies used in smart cities. Furthermore, it discusses the issue of cybersecurity in relation to personal data protection and security of proper city functioning. As examples of smart cities, Prague and London are mentioned, and their smart city strategies along with examples of executed smart projects are analysed. Finally, the evaluation and comparison of both cities' smartness is carried out via two different smart city indexes.

Key words

Smart city, information and communication technology, internet of things, Prague, London

Bibliografická citace

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Prohlášení

Prohlašuji, že svou závěrečnou práci na téma Smart cities of the 21^{st} century jsem vypracoval samostatně pod vedením vedoucí/ho závěrečné práce a s použitím odborné literatury a dalších informačních zdrojů, které jsou všechny citovány v práci a uvedeny v seznamu literatury na konci práce.

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Podpis autora

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1. Introduction

As the trend of urbanization does not seem to fade out, the need for optimization and facilitation of life in cities tend to be a higher and higher priority. According to the United Nations (2018), "It is expected that the ratio of the world's urban population will increase from 55% in 2018 (approximately 4.2 billion people) to 68% (approximately 6.7 billion people) by 2050." In order to cope with this massive growth, smart solutions of all kinds must be implemented in cities' environment, which is exactly what the concept of smart cities is concerned with.

In this bachelor's thesis, the aim is to describe the fundamental principles of this concept, explain some of its technological aspects, and discuss two of the existing smart cities with their implementation strategies. It becomes normal that people benefit from using technology in various situations to achieve the best possible result or performance, and a city, as a living organism, is not any different. This whole concept is based on the usage of modern technologies (information and communication technology, internet of things, etc.), enabling the municipalities to obtain necessary data in order to enhance living conditions. Overall digitalization then ensures that even the simplest operations will be as easy as possible for the citizens as well as the municipal governments.

Sustainability of cities is one of the reasons why this topic is so popular. Climate change and environmental issues have been an important subject of discussion lately, and only an efficient, sustainable smart city can have a beneficial impact on it. The concept interconnects all possible factors involved in the city's proper functioning, from single citizens to the whole infrastructure and the layout of the city. The relations between different aspects and the complexity of the issue are discussed in several chapters.

Due to its complexity, implementation of the smart city concept is not a simple task for municipal governments. Cities need to develop their strategies and usually entrust its realization to offices created for this particular purpose since the issue requires a certain degree of expertise. Subsequently, the question of how to evaluate cities' smartness arises. For this reason, different smart city indexes have been introduced with different criteria of evaluation. Based on these indexes, a comparison and evaluation of smart cities and their strategies can be made.

2. Concept of smart cities

The smart city has no fixed definition yet, and it can be interpreted variously. One of the most descriptive might be by Harrison et al. (2010), who defines the term "smart city" as "instrumented, interconnected and intelligent city". In this definition, "instrumented" means capable of collection and usage of real-life data gathered by sensors, meters, or personal devices, "interconnected" stands for the ability to share these data within the given platform so every part of the smart system can reach them and cooperate with each other, and "intelligent" represents the utilization of complex analytics, modelling, optimization, and visualization in order to make better operational decisions.

The focus of any smart city should be, as Eggers and Skowron (2018) propose, its people, provided with benefits such as:

- A better quality of life for residents and visitors
- Economic competitiveness to attract industry and talent
- An environmentally conscious focus on sustainability

To achieve these goals, cities implement information and communication technologies and build the network of computers, sensors and smart devices, which are the foundation of the whole system. An example of this network can be seen in Figure 1, which illustrates a parking space vacancy indicating system. In a nutshell, embedded sensors in the parking space send information about the status of the parking space to a gateway. The gateway transmits the data to the cloud. From the cloud, the data can be distributed to network servers and subsequently shared with other city services.

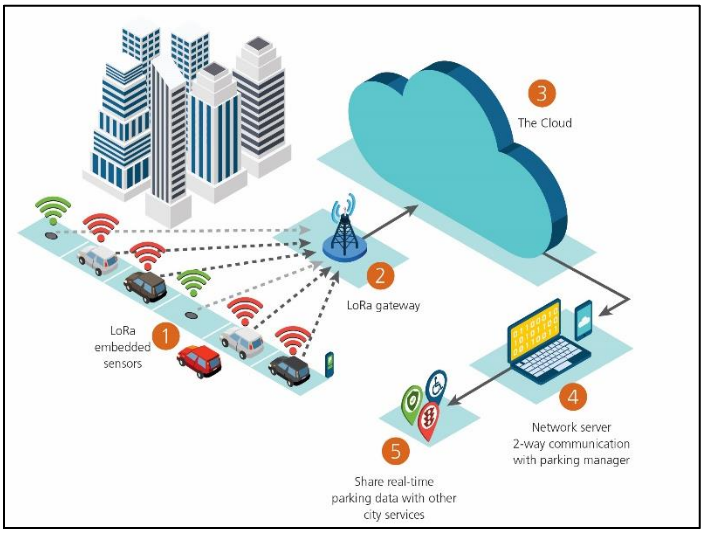

Figure 1: Parking space vacancy indicating network

These interconnected devices are commonly referred to as the internet of things (IoT). Clark (2016) describes IoT as "a giant network of connected things and people – all of which collect and share data about the way they are used and about the environment around them." This technology is crucial in the concept of smart cities. Devices with sensors and internet access are connected to the IoT platform, which stores and analyses the data. After analysis, the IoT evaluates whether the current conditions satisfy the requests of the user or certain actions (regulation, notification, etc.) should be performed.

Since the smart city concept is a very complex issue, it is vital to develop all social and economic systems to achieve the wanted benefits. According to urban and climate strategist B. Cohen (2012), the six main pillars of the smart city are the following:

- Smart environment
- Smart economy
- Smart people
- Smart living
- Smart governance
- Smart mobility

In the following Figure 2, the Smart City Wheel by Boyd Cohen is shown, which illustrates a common view on the mentioned areas and impact measurement indicators.

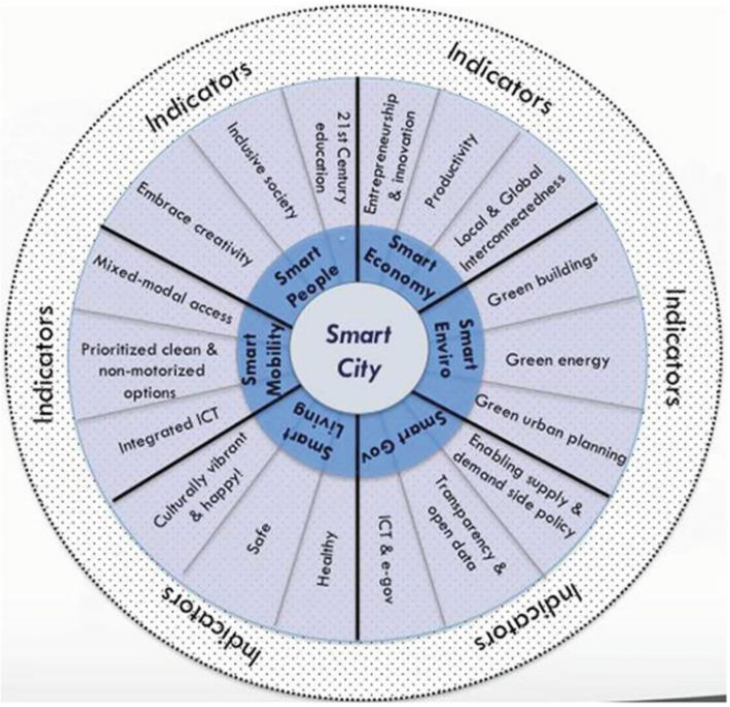

Figure 2: Boyd Cohen's Smart City Wheel

2.1 Smart economy

Behind every prosperous city must be a prosperous economy, at best, the smart one. The majority of global gross domestic product (GDP) (approximately 80%) is generated in cities, so it is necessary to manage cities' economies as efficiently as possible. Again, there is plenty of definitions of the smart economy, but the fundamental characteristics appear to be the same. Characteristics which are mentioned by Kumar and Dahiya (2017) in their book Smart Economy in Smart Cities are following: "diverse employment opportunities with labour market flexibility, diversification promoting entrepreneurship and innovation as well as more productivity through local, regional and global interconnectedness." (p. 196) According to what Kumar and Dahiya (2017) propose, the smart economy should also assure a high level of local and global competitiveness, connection to the global economy, economic success and growth of the city and the government ought to keep up with innovations in terms of economic policies to stay attractive for possible stakeholders.

The tools for smart economic growth do not have to be necessarily about implementing technology. It is mainly about smart decisions. The Office of Sustainable Communities of the Environmental Protection Agency (EPA) (2016) suggests three fundamental components of a smart growth strategy:

1. Supporting businesses

   This means helping with the expansion of existing businesses as well as attracting new businesses to contribute to the city's development. It is essential to be familiar with the composition and location of companies, jobs, and potential entrepreneurs in the community. By analyzing these factors, city governments get the image of where to direct their efforts and how to use their limited resources. Helping businesses create jobs, supporting entrepreneurship or expanding and diversifying the tax base are examples of the possible ways how to support the local economy.

2. Supporting workers

   A crucial aspect of economic prosperity is a developed workforce with a wide range of skills and education levels. This can be obtained by offering residents opportunities to learn skills for specific jobs and match the needs of an individual municipality. By analyzing the labour market, cities precisely know what fields need the help the most. It might also reduce the number of people who must commute to their work because they were unable to find a job in their city. Thus, the pollution caused by vehicles is reduced as well.

3. Supporting quality of life

A key prerequisite for a city to be attractive for potential workforce and businesses is a good quality of life. Higher quality of life is one of the main goals of the smart city concept, however, it is defined by plenty of factors which indicates it is a complex issue. One of the real-life examples of improving it is creating and supporting a thriving downtown with restaurants and neighbourhood-serving shops where people can meet, and businesses prosper. Reachability of medical and educational institutions, cultural and artistic resources, green and open spaces, or transportation options are also crucial factors which are taken into account.

The three components mentioned above might be considered fundamental prerequisites for the proper function of the smart economy. Analysis of the business environment in order to invest in spheres which need it most, supporting both employees and employers, and creating an environment attractive for entrepreneurs as well as for citizens in general; these are the actions which help the local economy to grow.

2.2 Smart environment

Sustainability and ecology are given much more attention than they used to be, and people start to realize the significance and inevitability of these topics. Human impact on nature and its consequences is enormous, so it appears to be every city's duty to operate as efficiently and ecologically as possible. ICTs have the ability of monitoring and control of the majority of processes going on in the city, which is why they have great potential in terms of making smart city environmentally friendly.

According to International Energy Agency (IEA) (as cited in Casini, 2017), the low energy efficiency of buildings and transportation systems in cities are responsible for 70% of greenhouse gases emissions and over 60% of the energy consumed worldwide. Furthermore, IEA noted that the value of the global increase in carbon dioxide emissions in 2016 exceeded over 50% of those in 1990. In addition to climate change, issues of air quality and acoustic pollution typically occur in urban centres. Data from IEA also show that in the European Union (EU), buildings alone represent 40% of the final energy use. Buildings are responsible for 36% of CO_2 emissions, and more than 40% of Particulate Matter emissions. Regarding the mobility system, which is still mainly based on fossil fuels, transport is accountable for 25% of pollutions emissions. The green transportation solutions will be more discussed later in chapter Smart mobility.

Casini (2017) claims that the smart city concept, more specifically the smart environment pillar, is supposed to provide "high environmental quality, the attractiveness of natural conditions, pollution, environmental protection and sustainable management of resources" (p. 2). In other words, its primary goals are minimization of the city's impact on the environment by utilization of ICTs in order to optimize the functioning of the city, reduce energy consumption, waste and pollution while using renewable resources and protecting its natural heritage.

Mitchell (as cited in Kramers et al., 2014) introduces five possible contributions of ICT to the sustainability of a city:

1. Dematerialization – Conversion of physical products or services to digital form (CD records into music streaming, banks into online banking, etc.).
2. Demobilization – Products and services which have been digitalized can be transported via telecoms network instead of physical transport.
3. Mass customization – Enables less resource use through intelligent adaption, personalization and demand management.
4. Intelligent operation – Involves more resource-efficient operations, such as transport, water or energy systems.
5. Soft transformation – Transformation of the existing infrastructure in order to benefit from opportunities presented by the new information technologies

ICT can be a great gamechanger in terms of sustainability; however, policies, laws and regulations enforced by authorities are the most important step forward. ICTs might improve the efficiency of the city, but as long as businesses and manufacturers are not forced to reduce their ecological footprint, the human impact on the environment will remain critical. A great example is the comparison of NASA's satellite images of China in Figure 3 showing air pollution before and during the coronavirus pandemic lockdown.

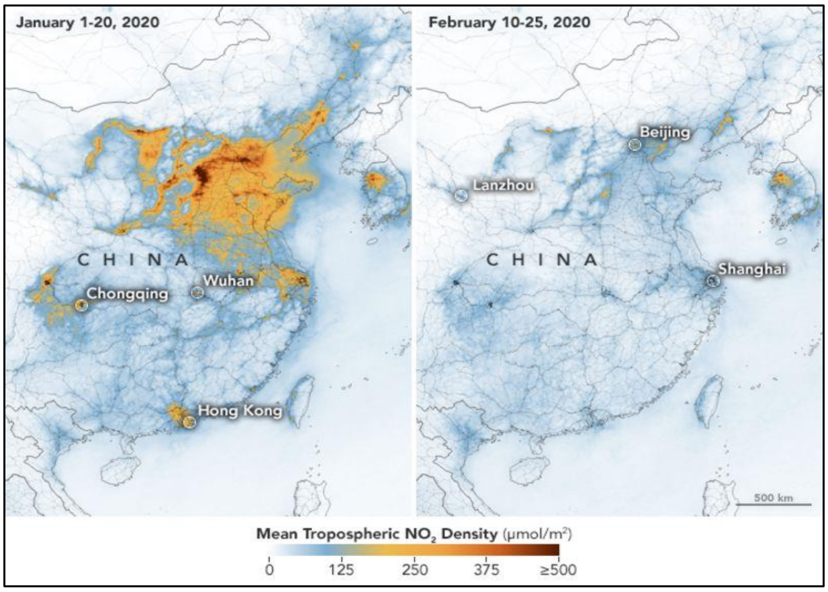

Figure 3 Satellite images of China showing air pollution

2.3 Smart people

As Chad Vander Veen (2015) points out in his article "Without Smart, Connected People There Are No Smart Cities":

> Intelligent transportation systems — a network of automated tolls, smart parking and driverless vehicles — serve no purpose if people aren't engaged. Homes and buildings that automatically adjust room temperature, lighting and window tinting make sense only if people inhabit those places. Even garbage bins that communicate to garbage trucks that they need to be emptied are pointless without people to fill them.

In order to develop a functional smart city, it is crucial to have smart citizens being part of it because it is not sensors which make it work, it is people who are the driving force of the whole ecosystem. The majority of data participating in the operations relates to human actions, whether it is traffic, energy consumption or waste production. However, citizens have to be aware of the benefits that a smart city offers. Otherwise, they will have no motivation to participate in it, and the whole concept will be meaningless.

The goal of the smart people pillar is, according to Casini (2017), to have citizens who are interconnected, qualified (on different levels and in different fields to satisfy the labour market needs), socially and ethnically plural, cosmopolitan, mentally open, creative, active and generally interested in what is happening within their city. There are several ways how to achieve this goal.

The first and most important one is reachable good-quality educational and training institutions. Whether it is primary school or a lifelong learning centre, it is fundamental to have places where the knowledge can be shared. Having a space to meet also helps the community to reach the mentioned interconnectivity. Another important way is to involve people in the decision making about the city's future. Citizens will be more interested in the issues and happenings within the city when they know they have the power to change something than when they are only in the role of spectator. Problems related to mental openness and cosmopolitanism (such as racism or discrimination) are still a big deal in modern society, and the solution still does not seem to arise. However, awareness surely helps. People naturally consider things they do not know (culture, religion, technology, sexual orientation, etc.) suspicious or even scary. Still, this feeling is usually based on the lack of information or on untrustworthy information (especially now, when fake news are an enormous issue, the ability of critical thinking appears to be vital). Therefore, awareness helps a lot. Being aware of health or environmental threats also makes a great difference and distinguishes smart citizens from others. Decisions towards a healthier and more ecological lifestyle start with single citizens. That is why it is important to share the knowledge about the actual issues, its possible consequences and the ways how to improve it.

2.4 Smart living

This topic interconnects all other building blocks because it generally represents the typical way of citizen's living in a smart city. As the Center of Regional Science of Vienna University of Technology (2007) states, smart living concerns aspects of quality of life, such as:

- Cultural facilities
- Health conditions
- Individual safety
- Housing quality
- Education facilities
- Touristic attractivity
- Social cohesion

The significance of culture might seem arguable. However, Gilmore (2014) believes that culture provides, besides the entertainment value, economic and social benefits. It enhances the quality of life by improving learning and health, creating opportunities for people to get together as a community, and increasing tolerance. Culture also relates to tourist attractivity, which can be boosted by supporting cultural, historical, and natural heritage as well as by maintaining a vibrant downtown. The importance of approachability of health and education institutions has been already mentioned in previous chapters.

Regarding safety, emergency services are in charge of supervision over the city and of intervention in case of any security or health threat. In order to manage that, they utilize ICT. Police, for example, uses surveillance cameras, automated license plate readers, gunshot detection systems, facial recognition software, drones, body cameras, and numerous databases to prevent, respond and investigate crimes. There is immense untapped potential in the usage of such devices. For instance, wearable technologies could mean partial facilitation for medics since those devices are capable of monitoring and predicting possible health issues.

While discussing smart living, the smart home concept should be surely mentioned. Tech company Infenion (2017) says that the concept of smart home denotes:

> … the use of technical systems, automated processes, and connected, remote-controlled devices in apartments and houses. The main objective of the functions is to improve the quality of life and convenience in the home. Other goals are greater security and more efficient use of energy thanks to connected, remote-controllable devices.

By the use of IoT technology and smart devices, inhabitants can typically control temperature, lighting, security or window and door operations. Furthermore, they are able to monitor many aspects of a home and receive feedback in order to optimize the everyday processes in terms of energy consumption.

2.5 Smart governance

Mellouli, Luna-Reyes and Zhang (2014) define smart governance as the government's utilization of technology, for the purpose of the movement to open data and the technology ubiquity, which would help with the understanding social problems and develop better relationships between government and citizens, non-governmental organizations, private organizations, and other governments. Kumar and Dahiya (2017) also point out that smart governance should ensure accountability and transparency in its governance, e-governance innovations for the benefit of its citizens, effective public services delivery, participatory decision-making, and clear sustainable urban development strategy.

E-governance could be generally described as the use of ICTs, which are supposed to facilitate public services. This relates to "dematerialization" mentioned in the chapter Smart environment. Services (such as voting, tax-related operations, etc.) are transformed into an online version, and easily accessible from citizens' smart devices. The accessibility is also important in terms of the participation in and transparency of the city's governance. Therefore, people are able to oversee, for example, the use of funds and the general implementation of the budget, or to virtually participate in the decision or planning process. In addition, engaging 'non-experts' brings, according to Sovacool (2014), three following benefits:

> First, it increases democracy, satisfying the "democratic right" of citizens to be entitled to direct participation and effective representation in environmental or technological decisions. Second, laypeople tend to excel at articulating previously unforeseen ethical and moral concerns that experts might have "missed." Third, inclusive research can reduce costs by avoiding and reducing controversy and public disapproval proactively.

Another benefit of citizens' participation was already mentioned in the chapter Smart people. It is the general interest of people which is supported by the opportunity of influencing their own future.

2.6 Smart mobility

As Hannon et al. (2016) suggest, there are very few places where transportation, either of people or goods, "match the public's aspirations for safe, clean, reliable, and affordable ways to get from A to B, and back again". In order to solve these issues, smart mobility solutions should be introduced. The key aims of this pillar, which Abhimanyu (as cited in Bland, 2018) mentions, are establishing sustainable mobility for reduced air and noise pollution, reducing congestion, and developing intelligent/seamless traffic flows in response to increasing urbanization and promote cost-effective mobility for all.

A transport company HERE Mobility proposes the following factors which are crucial in the future development of mobility:

- Smart infrastructure – With new technologies, smart cities implement sensors, data analysis, and decision support system in order to make the traffic flow more efficient. Another possible step is a redesign of existing infrastructure, so it satisfies the future city's requirements (such as modifying roads to provide extra lanes for new forms of mobility).
- Public transit first – By utilization of autonomous driving, IoT, and real-time data analytics united into a digital transport management platform, public transportation might be transformed into an attractive way of transportation alternative.

- Autonomous driving – Autonomous vehicles are expected to provide effortless driving and increased safety on the roads.
- Electric vehicles – As the prices of electric vehicles are more affordable and governments support their use and production, their sales grow. With lower prices and developed charging network, electric vehicles could be the future of private transport.
- Parking space – Drivers could use real-time data services, which will guide them to available parking spaces. With the use of self-driving vehicles and car-sharing, there could be dedicated transit spaces where passengers would only switch the vehicles.
- Revenue – Collection of transport-related taxes executed through sensors. Tax rebates for using ride-sharing services to support them.

Alternative ways of transport, such as bike-sharing or scooter-sharing, should not be left out. These concepts are either docked (users have to reach located racks from which they can take the bike/scooter and to which they have to return it) or dockless (users can unlock the bike/scooter anywhere they find it through a smartphone app and leave it in their destination, as long as it is within a designated area). But regardless of all the mentioned ways of transportation, cities should not forget pedestrians. As Planet Smart City (2020) emphasizes, walking should remain an easy and safe transportation alternative. Infrastructures often lack spaces only for pedestrians. Cars parked on the pavement or poorly visible pedestrian crossings without traffic lights mean possible danger for residents; thus, cities' governments should not ignore them.

3. Key enabling technologies for smart cities

Since the smart city concept is to a large extent based on the utilization of modern technologies, two examples of the smart city enabling technologies are described in the following subchapters.

3.1 Information and communication technology (ICT)

The term information and communication technology has been mentioned numerous times in the previous chapters; however, it has not been mentioned yet what the term really represents. According to Pratt (2019), ICT means all devices, networking components, networking software and applications that enable their users to interact and exchange information within the digital world. Specifically speaking, as Huth, Vishik, and Masucci (2017) state:

> ICT components include any communication device or application, encompassing radio, television, cellular phones, computer and network hardware and software, satellite systems, and so on, as well as the various services and applications associated with them, such as videoconferencing and distance learning.

The list of ICT components is exhaustive, and as digitalization grows in popularity, the demand for new technologies increases and the extensive list of components grows with it.

The smart city concept bases its operation on information collected throughout the city. To be able to effectively manage the collection of data and ensure mutual communication of people and devices, a robust information infrastructure must be established. In addition, when it comes to the analysis of data, even the smartest person cannot compete with the computational performance of an average PC. Therefore, ICT is the fundamental tool for smart city realization.

3.1.1 Computer networks

As it was already mentioned, mutual communication between people and devices is an essential condition for a smart city, and that is what computer networking mostly deals with. Computer networking is "an engineering discipline that aims to study and analyze the communication process among various computing devices or computer systems that are linked, or networked, together to exchange information and share resources" (Computer networking, n.d.). In other words, computer networks could be considered the backbone of ICT and modern-day communication in general. These are the most common types of networks occurring in smart cities, divided according to the geographical area they cover:

- Personal area network (PAN) – PAN is the smallest type of network with a connectivity range of up to 10 meters. A typical example is a wireless Bluetooth connection between a client device (Personal computer (PC), smartphone, etc.) and its peripherals (wireless keyboard, headphones, etc.). A useful example of PAN usage in relation to smart cities is wearable technologies which might have a fundamental impact on health care quality. For example, they enable monitoring of vital functions, and in case of any abnormal events, they could notify the user's doctor or call an ambulance.
- Local area network (LAN) / Wireless local area network (WLAN) – This type of network usually represents a network within a building, and it operates under a single administrative system. The number of systems connected in LAN/WLAN may vary from as few as two to as many as thousands, making it a suitable solution for households, company offices, or schools. An example of LAN usage could be a smart factory, which connects all used industrial automation devices (sensors, actuators, computers, etc.) into one network to be easily and securely managed.
- Metropolitan area network (MAN) – MAN is a network covering an area as large as a city. It consists of a number of LANs and frequently, but not exclusively, uses fibre optic cables to form a connection between them. An example could be an infrastructure of a local internet provider.
- Wide area network (WAN) – WAN's usage slightly overlaps with the MAN's. It spreads over very large distances, such as cities, countries, continents, or even the whole globe. It can be either in wired form (using telephone lines, fibre-optic cables, etc.) or in wireless form (e.g., satellite links). As an example, smart grid solutions could be mentioned. Smart grid is an electricity supply network which also monitors and manages its consumption. Therefore, two-way communication over larger areas must be ensured.

IBM (2010) identifies three fundamental elements of networking: hardware, software, and protocols.

3.1.1.1 Hardware

Hardware consists of the physical elements of the network, and according to Cisco Press (2013), there are three types of hardware:

- End devices – These are the devices with which users mostly interact. In a network, end devices are either a source or destination of information transmitted through the network. Typical examples are computers, mobile handheld devices (such as smartphones or tablets), or sensors collecting data (about temperature, air pollution, noise pollution, etc.) throughout the city.

- Intermediary devices – The primary purpose of these devices is to provide individual hosts with connectivity to a particular network, interconnect multiple networks to form one larger network and ensure the desired data flows across the network. They are basically the network nodes within a smart city. Examples of intermediary devices are switches and wireless access points providing network access, routers enabling internetworking, and firewalls ensuring security.
- Network media – Network media represent the communication channels between individual hardware devices over which the message is transmitted. Three types of media are currently distinguished: Metallic wires within cables, glass or plastic cables (fibre-optic cables), or wireless transmission (electromagnetic waves). More detailed connectivity options within a smart city will be discussed in the chapter related to IoT.

3.1.1.2 Software

Networking software represents a set of programmes that should serve as an instrument for the network administrator to easily enable, monitor, and manage operations within the network. Even though it might seem that networking software is not directly related to the smart city concept, probably because it is rather in the background of the whole operation, it still represents a necessary part of the infrastructure.

One of the examples of networking software is a network operating system (NSO). As Lewis (2019) states, NSO is designed to support primarily computers and workstations within the network and enable them to communicate and share their resources with each other. Moreover, it is supposed to provide simple network services and features which support multi-user environment as well as multiple simultaneous input requests. There are two types of NSO (with examples of their physical topology shown in Figure 4):

- Peer-to-peer NSO – This type enables network users to share their network resources saved in a common, accessible network location. It is cheaper to set up and suitable for small to medium local area networks.
- Client/server NSO – Client/server NSO uses a server to access its resources. Its implementation is usually more expansive, and it has higher requirements on

maintenance. On the other hand, since the client/server model is controlled centrally, any changes or extensions are easier to incorporate.

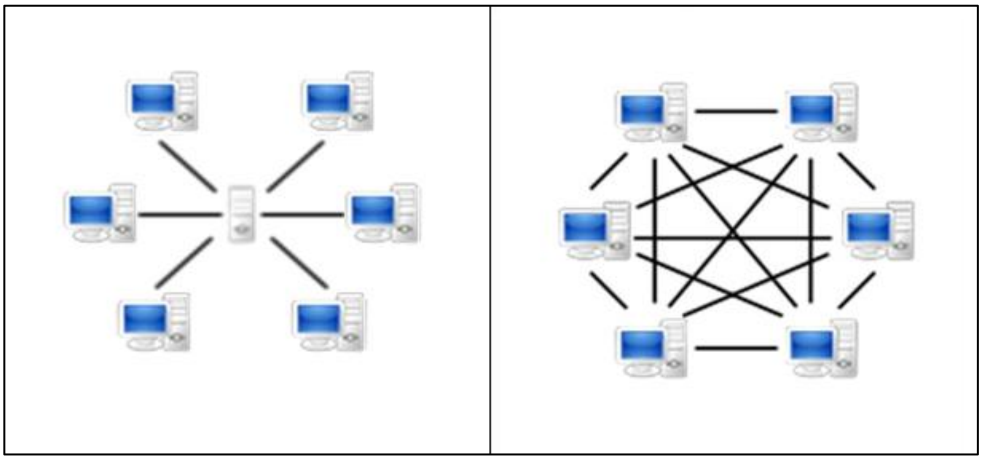

Figure 4:Client/server network (left); Peer-to-peer network (right)

3.1.1.3 Protocols

To explain what network protocols are, IBM (2010) uses an accurate analogy with real-life traffic: "If we think of a network as roads, highways, rails, and other means of transport, the network protocols are the 'traffic rules'." Protocols could also be compared to a language that both devices must understand for seamless communication. In relation to smart cities, protocols are simply a set of rules and conventions that define everything from the electrical specifications of how a networking device is connected to the infrastructure to the methods used to control congestion in the network and how application programs will communicate and exchange data.

Categorization of the protocols and their functionalities are largely based on something called Open Systems Interconnection (OSI) model. OSI model might be considered the fundamental architectural model for internetworking communication. As ManageEngine (2014) mentions, the OSI model splits the communication process between two devices into seven layers, and each layer is assigned its own task (or group of tasks). These seven layers can be divided into two groups: upper layers (application, presentation, session) dealing with application issues and lower layers (transport, network, data link, physical) dealing with the data transport. Examples of protocols in different layers and their area of operation can be seen in Figure 5.

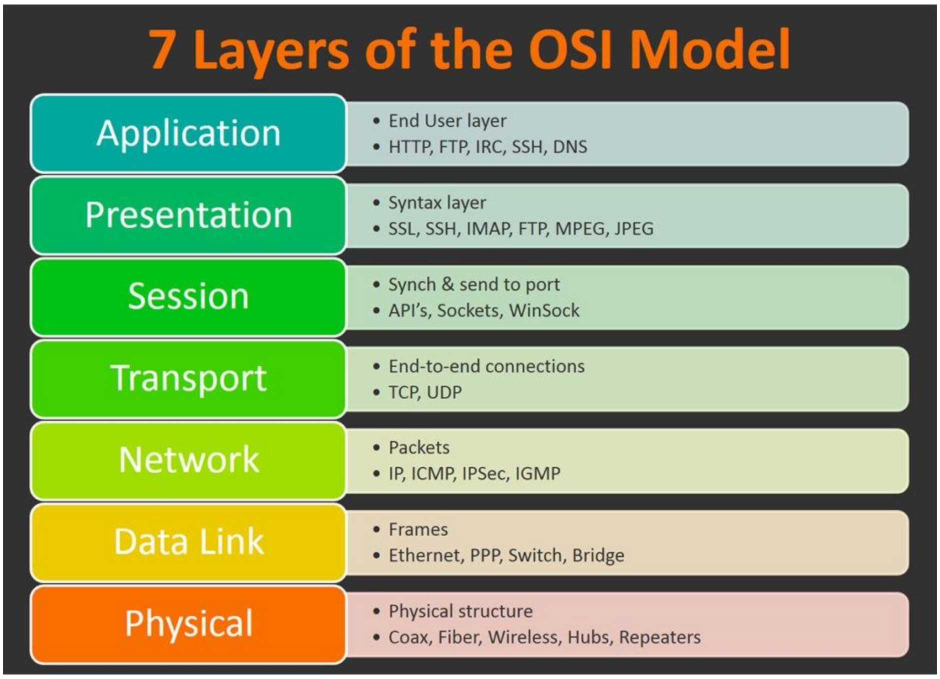

Figure 5: Description and protocol examples of each layer of the OSI model

3.2 Internet of Things (IoT)

According to Lopez Research (2013), the internet of things is a term firstly used in 1999 by Kevin Ashton. At the time, he was trying to describe physical objects equipped with identifiers and wireless connectivity, which enabled these objects to communicate with each other and be remotely managed from a computer. Twenty-two years later, with incomparably more technological possibilities, the aim of IoT remains fundamentally the same: Connect physical items with embedded sensors to the internet in order to collect real-life data. These data will be then analysed and used to increase efficiency and to automate the particular environment. As Ma (2011) says, it basically interconnects and integrates the physical world with the cyberspace.

Briefly described, the IoT components (embedded sensors located throughout the city monitoring different quantities) are connected to the internet according to the network architecture via wires or wirelessly, and they form or become a part of a LAN/WAN. Every device has its own assigned address (for example, in the internet environment, it is the internet protocol (IP) address) which works as its identification (ID). Since all devices are interconnected, they can communicate with each other, make decisions based on the collected data, or react to other devices' decisions, which makes the IoT network smart. However, the whole network must be directed by the central control hardware, which manages the data traffic. Another essential element is a data cloud which deals with and stores the enormous amount of data produced by the IoT system. Finally, the part with which a user interacts the most, the user interface (UI). In UI, users can set their specific requirements on the system, monitor the collected data, or remotely control the components within the system.

As an example, the smart system for parking space vacancy (shown in Figure 6) mentioned in the first chapter could be described in more detail. Some of the technologies mentioned in this description are further explained in the following chapters. First are the end devices, a smartphone at one end, and a parking space vacancy sensor at the other end. The sensor (using either magnetometer technology, ultrasonic sensing technology, or any other) wirelessly sends the vacancy related data to its gateway (connection point to a network) using the Low-Power Wide Area Network (LPWAN) technology. From the gateway, the data are sent to cloud storage on the internet either wirelessly or via cables. When the data are processed and accessible on the cloud, a network server linked with a given parking space mobile application takes the useful data and forwards them to the application, which incorporates the processed data into its user-friendly interface. A driver then opens the given application for searching free parking spaces on his smartphone, imposes the requirement, and the application displays available options. Moreover, the data can be shared from the network server with other city services and ensure the interconnection of individual projects within a smart city.

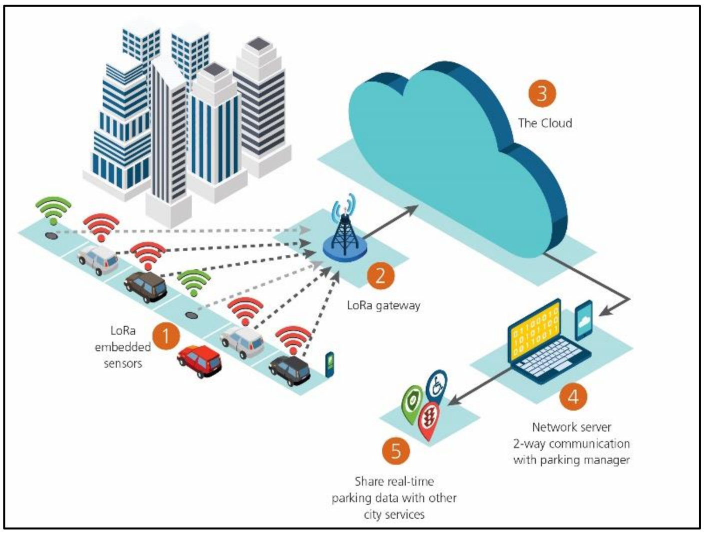

Figure 6: Parking space vacancy indicating network

3.2.1 Connectivity

Interconnectivity is a fundamental condition for an IoT network to function properly. However, as a wide variety of connectivity technologies has been developed during the last three decades, it might seem challenging to evaluate what technology would be best for a given IoT solution. McClelland (2019) defines the connectivity technology into three main groups based on three criteria: power consumption, range, and bandwidth.

3.2.1.1 High power consumption, high power range, high bandwidth

Unsurprisingly, it takes a lot of power to send data over a great distance. For example, smartphones are able to transmit or receive large amounts of data across the whole world through a cellular network, but it needs to be recharged every 1-2 days. Two technologies belong to this group, including the one already mentioned.

- Cellular – This type includes standards like 3G, 4G, or currently emerging 5G, and it is probably most known for its telephone usage. However, it can be employed in many more solutions. For example, an application from agriculture could be mentioned where drones use cellular connectivity for sending image and video data during field mapping and crop monitoring. It is reliable technology with nearly global coverage (the device must be within the coverage of cell towers) and low latency.
- Satellite – In terms of range, the satellite has no competition among other connectivity technologies, as the Digiteum team (2019) emphasizes. However, its properties make it the most expensive one. Thus, satellite connectivity is usually used only for sending data to remote areas (ocean) where the IoT system switches into a more affordable technology. A typical example is ocean oil rigs which use it to transfer real-time data to the onshore base.

3.2.1.2 Low power consumption, low range, high bandwidth

If one wants to decrease power consumption but keep the high data rate, it will naturally result in a range reduction. This group contains three following technologies:

- Wi-Fi – According to the Digiteum team (2019), it is one of the best options for IoT systems with high data speed requirements within a small area. Since Wi-Fi is highly compatible with different boards and easy to set up, the costs are lower than in the case of the previous types. On the other hand, Wi-Fi has high power requirements, so it is suitable for plugged appliances or devices that can be easily recharged. Moreover, if the Wi-Fi source is off, the IoT applications cannot send any data. It is commonly used in smart home applications or in the vast majority of businesses.
- Bluetooth – Bluetooth, similarly as Wi-Fi, is a short-range technology used in smart homes or industrial IoT applications. However, unlike Wi-Fi, it is more resilient to signal noise and its power consumption is lower. Bluetooth Low Energy (BLE) is a version of traditional Bluetooth developed for IoT solutions but with even lower power requirements. Though, its bandwidth, in comparison with Wi-Fi, is lower. Bluetooth is best for small devices (wearables, etc.), so it can be used for smart medical solutions to monitor patients.

- Ethernet – It is the only wired technology in this group, which means slightly different properties than in the case of the previous two. Since it is not freely spread, it provides better security of the system, and it is not so sensitive to interference. On the other hand, the range is limited by the wire length, the cost might be higher, and the scalability is more complicated. Ethernet-based solutions can be built upon an existing cable network which means it is suitable for plants with their established network. Its typical usage might be a connection of PC to LAN within a factory or the connection of industrial sensors which use the ethernet technology.

3.2.1.3 Low power consumption, high range, low bandwidth

The only connectivity technology comprised in this group is called Low-Power Wide Area Network (LPWAN). This technology enables sensors to collect data and send it to another device miles away without any higher requirements on power. However, this technology is designed to send only small amounts of data. Therefore, it is suitable for sensors powered by a battery, which collect and send only bytes of data, such as a single number, in longer time intervals (e.g., once in 2 hours). An example of LPWAN's usage might be monitoring in agriculture. The surrounding of a city should be involved in the smart city concept too. Thus, as McClelland (2019) suggest, LPWAN can be used to monitor the moisture level of land since the moisture sensors send small amounts of data every few hours, and they are usually powered by an accumulator because power through a cable might be difficult in rural areas.

3.2.1.4 Other

Besides these three groups, there are other technologies which McClelland does not discuss. These are, for example, Near-Field Communication (NFC) which offers very short-range communication with high power efficiency. Probably the most frequent usage of NFC is a contactless payment either with a debit/credit card or with a smartphone through services such as Apple Pay or Google Pay.

Another technology not included in the previous groups is Radio Frequency Identification (RFID). The operation of this technology, as the name implies, is based on radio frequency signals. The parameters of RFID devices slightly vary according to their usage. As the Digiteum team (2019) mentions, there are either active RFID devices (they have their own battery and can continuously communicate) which can be used for real-time location monitoring or passive devices (they communicate only when another RFID device pings them), which might be used as an upgraded version of bar codes in supply chain management.

4. Cybersecurity and data protection

The Smart City concept employs various smart devices to facilitate and improve citizens' life. On the other hand, the use of any device connected to the internet means a potential threat to security or privacy. Different smart applications collect their users' personal data to function properly, and unauthorized access of someone else could mean an enormous problem. Cui et al. (2018) point out that although people use protection methods (e.g., encrypting or biometrics) in computing-related fields, some of the IoT devices and sensors have limited computing performance, so only basic protection tools can be implemented. Their insufficient computing power and constantly developing cyber-attack techniques subject the users to high-security risks. Despite that, Deloitte Pandey et al. (2019) do not perceive the 'edge layer' (sensors, etc.) as the most vulnerable one when they say:

> During the initial stage, when data is being collected through a small number of city-controlled, hard-wired sensors, the potential breach points are generally limited. However, at the next (intentional) stage, when a city starts to collect data from citizens' smartphones and connected infrastructure, there are suddenly millions of uncontrolled potential breach points, most of which are beyond the city's control. In the most advanced stages, when software bots at the core use artificial intelligence to make decisions and act without human involvement, the potential attack vectors are nearly endless—and continuous.

Cui et al. (2018) identify four main security issues in their research on security in smart cities:

- Botnet activities – Botnets are networks of devices which are infected with malicious software without the owner's knowledge and controlled by the attacking party. The infected devices spread the malware to other connected devices and eventually cause a distributed denial-of-service (DDoS) attack against the chosen server.
- Threats of driverless cars – Autonomous vehicles are supposed to increase safety on the roads; however, there is a possibility that the vehicle can be hacked. When it happens, a hacker can take control of the vehicle. Except for that, its computer system collects personal data as every smart device does, so it may cause privacy issues.
- Privacy issues of virtual reality (VR) – VR has been employed in various fields (e.g., healthcare, architecture, or design), and in some case, it uses sensitive information as well. But because of the rushed demands of the market, these technologies are designed without appropriate security features.

- Threats posed by artificial intelligence – AI is not a sci-fi movie issue anymore. It is being utilized in all kinds of appliances (e.g., automatic control, pacemakers, etc.), and its usage is irreplaceable in terms of effectiveness. However, companies can use AI for data mining to analyze users' shared personal data, so they obtain sensitive information which exceeds the primary objectives of the given service. And it is equally effective when hackers use it; therefore, a hacker with deep AI knowledge means even more significant threat.

In relation to these problems, Cui et al. (2018) suggest four requirements in order to manage them:

- Authentication and confidentiality – Proving identity and ensuring that the person accessing the data is authorized is a fundament of cybersecurity. And even in case of unauthorized access, confidentiality is required (by encryption-based technologies), so the information is not exposed.
- Availability and integrity – Availability, corresponding to the topic of cybersecurity, means that the device has the ability to manage vital functions even when under attack. Detection and elimination of the virus to stop further damage should be ensured as well. The integrity of the transmitted information is also important. Firewalls and protocols are used to manage data traffic.
- Lightweight intrusion detection and prediction – This represents the ability to detect abnormal events in the system and prevent an attack. However, due to devices' limited resources, exiting solutions are not implementable. Therefore, lightweight intrusion detection and prediction methods must be developed.
- Privacy protection – To avoid misuse of personal information by an unauthorized person, sufficient countermeasures (e.g., encryption, anonymous mechanism or differential privacy) must be implemented. In the case of data mining by different service providers, there should also be non-technical protection, such as policies protecting the user.

Apparently, the importance of cybersecurity cannot be underestimated. With growing interconnectivity and the amount of users' data being transmitted, the chance of becoming a victim in an online crime has increased. As Alibasic et al. (2017) suggest, the matter of cybersecurity should be concerned from the beginning of every system since any backward extensions of an existing system are complicated.

5. Smart city indexes

The main purpose of smart city indexes is to evaluate and rank the cities' smartness. Since the smart city concept is a very complex issue, it might seem challenging to find the right criteria on which the evaluation will be based. There are several different smart city indexes established by different organizations with different evaluation approach. In order to be able to assess various smart city strategies in the following chapters, two smart city indexes will be introduced.

5.1 IESE Cities in Motion Index (CIMI)

This index is published by the IESE (Instituto de Estudios Superiores de La Empresa) Business School University of Navarra and includes 174 cities worldwide. As IESE (2020) states, their conceptual model is based on the information collected from city leaders, entrepreneurs, academics and experts who are engaged in smart city development within their municipality. These information are then a subject of analysis, and subsequent diagnosis of the situation, the development of a strategy, and its future implementation are proposed.

IESE (2020) considers nine main criteria (with examples of their indicators in parentheses):

- **Human capital** (proportion of population with secondary and higher education, per capita expenditure on education, per capita expenditure on leisure and recreation, number of museums and art galleries per city, etc.)
- **Social cohesion** (crime rate, happiness index, unemployment rate, number of hospitals per city, suicide rate, etc.)
- **Economy** (ease of starting a business, the average hourly wage in US dollars, GDP, number of headquarters of publicly traded companies, etc.)
- **Governance** (e-government development index, strength of legal rights index, corruption perceptions index, democracy ranking, etc.)
- **Environment** (average amount of generated solid waste, CO_2 emissions, methane emissions, environmental performance index, etc.)
- **Mobility and transport** (traffic inefficiency index, bicycles per household, length of a metro system, possibility of bike-sharing, etc.)
- **Urban planning** (average number of people per household, number of completed buildings in the city, number of buildings over 35 meters high, etc.)

- **Technology** (percentage of households with internet access, innovation index, 3G coverage, percentage of households with a personal computer, etc.)
- **International projection** (number of passengers per airport, number of McDonald's restaurants, number of international conferences and meetings, etc.)

5.2 IMD Smart City Index

IMD Smart City Index is published by Institute for Management Development (IMD), in collaboration with Singapore University for Technology and Design (SUTD) and includes 109 cities worldwide. In comparison with the previous index mentioned above, IMD (2020) proposes a different approach than IESE. Instead of interviewing people involved in the smart city initiatives, it assesses the perceptions of the city residents on the issues related to the smart city solutions since these people should be the ones who benefit from the smart city solutions the most. This index could also serve as residents' feedback for the authorities of involved cities.

IMD (2020) determined two main pillars divided into five key areas which are involved in the survey. The main pillars are structure (representing the existing infrastructure) and technology (representing the technological services and provisions available to the residents). The five areas comprised in each pillar (with examples of their indicators in parenthesis) are:

- **Health & Safety** (public safety, air pollution, medical services provision, online arranging of medical appointments, free public Wi-Fi, etc.)
- **Mobility** (traffic congestion, public transport satisfaction, online scheduling and ticket sales, car-sharing apps availability, etc.)
- **Activities** (cultural activities, green spaces availability, online ticket purchasing to cultural events, etc.)
- **Opportunities – Work & School** (good-quality education accessibility, lifelong learning opportunities, online public services for an easy business start, etc.)
- **Governance** (Easily accessible information about government decisions, degree of corruption, the possibility of online voting, etc.)

6. Examples of smart cities

6.1 London

The authorities of the city of London, the UK's capital with more than 9 million residents, are surely aware of the need for smart city initiatives in order to keep the city thriving. For this reason, the Smart London Board was created in 2013, which interconnects academics, businesses and entrepreneurs who eventually advice the authorities on smart city issues. As the Greater London Authority (GLA) (2013) states, the first significant contribution of the Smart London Board was their Smart London Plan, which was published in 2013 and updated in 2016. Subsequently, the GLA published the Smarter London Together roadmap based on the Smart London Plan, which calls for the city's authorities and public services to work with the digital technologies and data in order to accomplish the determined goals. This roadmap serves as London's current smart city strategy.

6.1.1 Smarter London Together

Smarter London Together roadmap was launched by the Mayor of London in 2018. It defines the ways how should all services and boroughs smartly collaborate not only with each other but also with universities or the tech community to work more effectively. The GLA (2018) determines five key missions in the roadmap:

- More user-designed services
- Strike a new deal for city data
- World-class connectivity and smarter streets
- Enhance digital leadership and skills
- Improve city-wide collaboration

These missions might be considered rather smart city fundaments but at this moment they are crucial for future development. There are other Mayoral strategies published on the official website of GLA, which are subdivided into seven fields (transport, environment, health inequalities, housing, culture, economic development, the London Plan) which are explored in greater depth from a long-term perspective.

6.1.1.1 More user-designed services

Since there is often a rush towards integration of the smart city solutions, the residents' needs are sometimes put aside. For this reason, the GLA decided to cooperate with partners to design the services with respect to the diversity of the city and its citizens, and to put emphasis on the design because it ensures the right understanding of different issues. Besides that, this mission includes digital inclusion support initiative or promotion of diversity in technology companies to address inequality.

6.1.1.2 Strike a new deal for city data

As the name implies, this mission deals with the data sector in general. There is no smartness without data; therefore, possibilities of data-sharing, appropriate cybersecurity, or data related policies should be introduced. This mission consists of single steps such as launching London Office for Data Analytics (LODA), the development of a city-wide cybersecurity strategy, or building trust in how public data are used through transparency, data rights and accountability.

6.1.1.3 World-class connectivity and smarter streets

Connectivity is another crucial condition for a proper function of a smart city. The GLA is aware of insufficiencies in connectivity provision within London's area. Thus, they want to improve the coverage so smart solutions can be adopted, and the city can benefit from them as a digital economy. This mission includes enhancement of Wi-Fi in public places, coordination of 5G projects, full fibre home connectivity for all new developments to enhance future connectivity, etc.

6.1.1.4 Enhance digital leadership and skills

Since digital services represent a significant part of London's economy, the demand for a skilled workforce increases. Fields like automation or artificial intelligence are rapidly growing and changing the labour market as well as our everyday life. For this reason, initiatives such as support of digitally capable workforce, support of computing skills from an early age, or enhancement of digital and data leadership were started.

6.1.1.5 Improve city-wide collaboration

This is the final mission of London's current strategy, and its main goal is to promote consistency in quality of service, technology preparedness, and participation in the smart city transformation. It is subdivided into single missions, including exploring new partnerships with the tech sector, promoting medical technology innovations in health care, establishing a London Office of Technology and Innovation, or collaboration with other smart cities on challenging issues.

6.1.2 Examples of executed smart projects

6.1.2.1 London Datastore

London Datastore is "a free and open data-sharing portal where anyone can access data relating to the capital", as GLA states on its official web portal data.london.gov.uk. This project is a part of the second mission, "strike a new deal for city data". Its main aim is to transparently provide city-related data to all citizens and help London's government to deal with various challenges, such as tackling the road congestion within the city. According to Smart London (2020), the platform is monthly visited by approximately 60,000 users and offers more than 6,000 data sets, including data related to the economy, health, transport, or the ongoing COVID-19 pandemic.

6.1.2.2 Digital talent programme

This project is a part of the fourth mission, "enhance digital leadership and skills". The programme was initiated because of the demand for digitally skilled employees within the digital, creative, and technology sectors. Its goal is to offer opportunities for people between 18-24 years old, support the educators and employers, and enable research or case studies. With a £7 million budget, the programme ensures higher quality and volume of the professional trainings chosen in cooperation with representatives of the particular industries. A focus on making the technology sector more attractive for women is also included in the programme.

6.1.3 Smart city ranking

London regularly occupies the top places in smart city rankings. The IESE's CIMI even classified London as the smartest city in the world in the last four years. According to Forbes (2020), "London houses more start-ups and programmers than almost any other city in the world", which might be considered one of the reasons for London's success. Another interesting fact is that the smart city ratings are rather led by European cities than cities from any other continent. For example, from the top 30 cities in the CIMI 2020 are 16 of them located in Europe.

As it was already mentioned above, London was ranked the smartest city in the CIMI 2020. IESE (2020) states that London has earned the first place by a good performance in almost all individual dimensions, as shown in Figure 7. It ranked first in the human capital and international projection dimensions, second in the governance and urban planning, third in the mobility, sixth in the technology dimension, fourteenth in the economy, thirty-fifth in the environment, and sixty-fourth in the social cohesion. The main reasons for the first place in human capital are the level and number of educational organisations within the city and the broad offer in terms of cultural activities, such as museums, theatres, or art galleries. The high score in the international projection is due to London's high number of hotels and international conferences hosted in the city, and the number of airline passengers. Even though the position of London in dimensions such as social cohesion or environment is not the best, in comparison with the previous years' results, consistent improvement can be observed, indicating the intention to work on its weak spots.

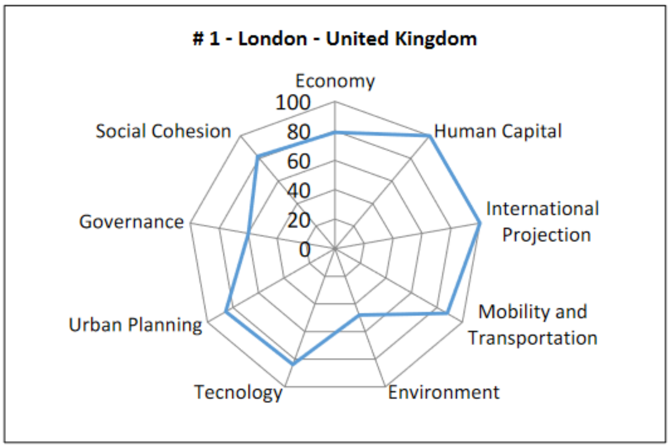

Figure 7: London's results in the IESE CIMI

Another ranking taken into account is the IMD's 2020 Smart City Index, in which London is still in the top 30 smartest cities worldwide, but it ranks 15 places lower than in case of the previous index. Since it is an index based on the perceptions of citizens, there might arise a question whether the slightly worse results could be the reflection of the insufficient social cohesion observed in the IESE's index. The survey emphasises three main weak spots of the city: affordable housing (score of 24.6/100), air pollution (score of 28.2/100), and traffic congestion (score of 25.9/100). On the other hand, the areas which Londoners are fairly satisfied with are green spaces (71.6/100) and cultural activities (80.4/100), which were also highlighted in the previous ranking. In terms of technology implementation topics, the lowest score was obtained in online possibilities of air pollution monitoring (42.5/100), reduction in journey time by using apps showing available parking space (42.9/100), and in the reduction of traffic congestion by using car-sharing apps (43.0/100).

6.2 Prague

As Jon Glasco (2018) accurately points out, the city of Prague has moved from building a bridge to connect the city's Staré Město (Old Town) with Malá Strana (Lesser Town) to building a bridge of urban transformation connecting today's city to a smart city future. The Smart Prague 2030 concept was firstly introduced in 2017 at the Smart Prague conference. This concept was created by Operátor ICT, which is a municipal company managing the Smart City Projects Office. It could be compared to the Smart London Board mentioned above, since it has an advisor and coordinator role in terms of fulfilling the given goals and implementing the smart city solutions. The decision-making remains up to the local authorities.

6.2.1 Smart Prague 2030

Glasco (2018) describes Prague's smart city strategy as "wide-ranging and ambitious" with technology-centric and human-centric topics. It puts emphasis on digitalization and modernization of city services, technology innovation, and knowledge sharing. It is, as Operátor ICT (2017) says, "based on the long-term priorities defined in the city's Strategic Plan and on the present global trends in technological development". There are six main areas determined in the strategy, which are anticipated to benefit from the smart technology implementation the most:

- Mobility of the future
- Smart buildings and energy
- Waste-free city
- Attractive tourism
- People and the urban development
- Data area

Based on the Smart Prague 2030, the Action Plan for Smart Prague 2030 was published in 2020, containing specific projects and ideas which could be realized, and setting the success measures for their eventual evaluation. According to Operátor ICT (2020), this was because the general strategy itself did not determine sufficient short-term goals of the concept.

6.2.1.1 Mobility of the future

In this area, the main goals are mobility without oil combustion, reduction of personal car ownership through car-sharing, intelligent transport and traffic management based on data, mobility-related services accessible from the citizen's smartphone, and autonomous transport (autonomous metro system or vehicles).

6.2.1.2 Smart buildings and energy

Regarding energy, the strategy aims to make energy consumption lower and more efficient. Another important aspect mentioned is sustainability, meaning local generation, storage and management of renewable resources energy. The last topic is public buildings which are meant to be intelligent, ensuring a healthy environment.

6.2.1.3 Waste-free city

Since a smart city should not negatively impact the environment, waste management is a great issue. Therefore, the goals in this area are material and energetic exploitation of waste, exploitation of sewage and rainwater, optimization of waste collection and storage, and responsibility towards the environment according to European Union (EU) legislation.

6.2.1.4 Attractive tourism

According to Prague City Tourism (2020), 6.8 million tourists visited Prague in 2019. Therefore, it is desirable to make the tourist experience as enjoyable as possible. For this reason, the strategy aims to enable tourists to have all needed information and tools accessible from their smartphone, use Big Data for optimal management of tourism, and involve modern technologies in order to make the navigation, entertainment, and communication tourists friendly.

6.2.1.5 People and the urban development

Safe, modern and informative public space. That is the main objective of this area. The strategy suggests immediate automatic detection and prediction of hazardous situations to ensure safety, new functions available in public spaces (such as charging stations), and available information about a particular place in real time. For disabled citizens, it proposes smart assistance using modern technologies to make them more independent.

6.2.1.6 Data area

In terms of data, smart Prague should have, according to the strategy, uniform and complete optical fibre network and communication infrastructure possessed by the city, easily accessible open data related to all smart city projects, and safe data transmission protecting the citizens' personal data.

6.2.2 Examples of executed smart projects

6.2.2.1 Golemio

Golemio is a project related to the data area. It is a data platform which similarly as the London Datastore, provides storage, access, and visualization of data related to the capital city. On this website, residents of the city are provided with charts and tables displaying information about the current traffic situation, air quality, or COVID-19 pandemic (vaccination rate, number of infected people, etc.), and they can download individual data sets. Besides providing information access to citizens, Golemio offers its data-related services to all municipally owned companies within Prague.

6.2.2.2 Smart waste collection system

This project belongs to the "waste-free city" part of the strategy. Since the collection of separated waste from underground containers or containers with bottom discharge is costly and time-consuming, the city of Prague decided to use ultrasonic IoT sensors to monitor the fullness level of the containers. According to Operátor ICT (2019), the sensors send data in four-hour intervals to the collecting company, which efficiently manages the waste collection based on the provided data. Moreover, the data are also forwarded to the Golemio platform, so anyone can access real-time data related to this issue. Currently, there are 424 waste containers with embedded sensors involved in this project.

6.2.3 Smart city ranking

Even though Prague is usually not considered one of the smartest cities in the world, its smart city innovations are being noticed. In the CIMI 2020, Prague placed thirty-ninth. However, among the cities from Eastern Europe, Prague ranked first and beat cities such as Warsaw, Tallinn, or Bratislava.

The evaluation of different CIMI dimensions can be seen in Figure 8. The areas in which Prague does best are, according to IESE (2020), the social cohesion (22nd place) and international projection (23rd place). These two are followed by the environment dimension (30th place), governance (35th place), human capital (37th place), and mobility and transportation (44th place). The remaining areas which were evaluated worst within Prague are technology (79th place), economy (88th place), and urban development (90th place).

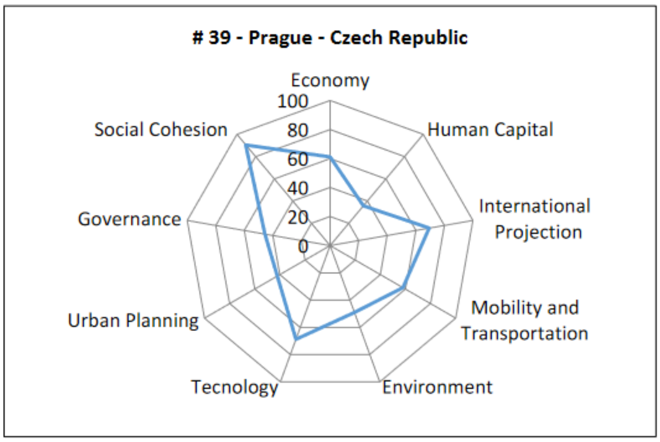

Figure 8: Prague's results in IESE CIMI 2020

The IMD Smart City Index (2020) shows slightly different results again. In this ranking, Prague appears on the forty-fourth place. Similarly, as in London, traffic congestion (21.6/100) and affordable housing (24.7/100) are the topics with the lowest score. However, instead of air pollution, the third biggest concern is the corruption of city officials (33.1/100). On the contrary, the topics Prague residentials appreciate most are cultural activities (82.7/100), employment finding services (78.5/100), and children's accessibility to good schools (75.8/100). The weakest spots regarding technology implementation are reduction of traffic congestion by using car-sharing apps (38.0/100) and reduction of corruption by providing online public access to city finances (38.3).

In comparison with London's IMD evaluation, interesting differences regarding citizens needs can be observed. Among the top of the citizens' priorities are in both cases affordable housing, traffic congestion, and air pollution. After these three, the priorities differ. In London, residentials require improvements primarily in health services, security, and unemployment, while in Prague, the only topic from these three which responders partially consider is security. More weight is put on corruption, green spaces and citizen engagement in Prague. Dissatisfaction with the corruption in Prague is probably related to insufficient transparency of the city's operation. While the Smart Prague 2030 strategy promises transparency, it relates specifically to the data about smart projects, so the overall improvements in corruption are questionable. Another interesting aspect is that even though Prague citizens are generally more satisfied with the technology implementation than Londoners, they are less willing to be indirectly involved (providing personal data, being comfortable with face recognition, etc.) in the smart city operation.

7. Conclusion

On the basis of literature review presented in this thesis, it can be concluded that the main goals of the concept are to provide its citizens with a good quality of life and maintain a growing economy while supporting sustainability and reducing the ecological footprint of the city. It proposes the implementation of information and communication technologies, IoT devices, and the application of progressive government approaches in order to achieve the given goals within its six major fields: smart economy, environment, people, living, government, and mobility. These fields might be considered the building blocks of the concept. Every field has its own aims, however, since a smart city is based on networking and interconnectivity, these fields are dependent on each other, and they overlap in some cases. Therefore, a holistic approach and mutual cooperation between individual building blocks are crucial.

The second chapter of this thesis then provided an insight into modern technologies involved in the smart city concept. Specifically speaking, information and communication technology, and internet of things were introduced, along with examples of their utilization in smart cities. It is apparent that modern technologies offer immense possibilities in terms of city management and development. However, every single process within a city which is planned to be transformed into a smart process requires deep analysis in order to choose the most appropriate technical solution, since there is a large number of options. The aspects such as uniformity, or compatibility with other processes within the city must be taken into account to ensure smooth operation of the city as a whole.

The concept might appear like utopia. Self-driving cars, dwellings adapting its features to inhabitant's requirements, citizens choosing the direction of the city's development, and economy where no one struggles. However, even this scenario has its downsides. The most significant one is the extensive security requirements. Since the fundament of the concept is internet and data transmission, there is a high risk of hacker attack, which could mean either misuse of the data or control over the city's operation by an unauthorized person. According to experts, the existing security solutions are not sufficient from a long-term perspective, and further development is necessary.

For the purpose of discussing different approaches of the concept implementation, London, the capital of the United Kingdom which usually tops the smart city rankings, and Prague, the capital of Czechia, were chosen as examples. To be able to evaluate and compare these smart cities, two smart city indexes were introduced, each with a slightly different approach to the evaluation: Cities in Motion Index introduced by IESE, which bases its evaluation on information collected from people involved in the implementation of the concept, and the Smart City Index published by IMD based on the perception of residents of the city.

As for the strategies, London has the Smarter London Together roadmap with five main missions, which currently serves as a guideline to establish the fundaments on which the smart city can be built. Whereas Prague has the Smart Prague 2030, which does not appear to be as specific as London's strategy, and it rather sets the general goals of the concept. Both of the cities have established offices which are in charge of the smart city transformation; however, their primary roles are to advise, implement, and maintain. The final decision making is still on the authorities of the city.

Even though Prague, along with the whole Czechia, is sometimes considered to be a part of the "underdeveloped" Eastern Europe, it is actually active in terms of the smart city concept. Its activity is reflected in the rankings in which it ranks around the 40^{th} place from 174 cities worldwide, and it was declared the smartest city in Eastern Europe (in the Cities in Motion Index). When the cities' results in both indexes from 2020 were compared, interesting differences could be observed, such as the difference between the perception of residents of the city and people who take part in the smart city transformation. Although Prague cannot compete with London in the overall ratings, it is ranked better in two of the individual areas (social cohesion and environment) in the CIMI 2020. In both cities, citizens agree that issues of housing affordability, traffic congestion, and air pollution need improvements. However, variations between the needs of Prague and London residents also occurred. While Londoners would appreciate improvements in healthcare or unemployment, citizens of Prague put more emphasis on green spaces, corruption, or citizen engagement. From these varying results, it is apparent that the smart city concept cannot be implemented in the same manner anywhere in the world since the situation in every city is different and requires different approaches. Further research on how the local culture or political context of the city influences the approach to the smart city concept could be interesting.

To sum up, the smart city concept is a great way how to take advantage of the potential which modern technologies have. The inefficiency and unsustainability of some cities are on a high level, and technologies in combination with the right policies and regulations might mitigate the consequences of human actions. However, what can be considered as a possible obstacle, besides security, is the citizens' participation. As the cases of data misuse by third-party companies emerge, the mistrust towards technologies increases among people. Therefore, the citizens' support for becoming a fully smart city might be questionable.

Extended abstract

Tato bakalářská práce se zabývá konceptem chytrých měst 21. století. Cílem práce je popsat tento fenomén a diskutovat jeho implementaci ve městech. V první kapitole obecně rozebírá koncept jako takový a konkrétně popisuje šest oblastí, do kterých se koncept dělí. Chytrá města jsou založená na využívání moderních technologií pro efektivní správu a chod města. Zároveň je pro ně zásadní komplexní přístup při zavádění prvků tohoto konceptu a vzájemné propojení mezi zmiňovanými oblastmi.

První oblastí je chytrá ekonomika, která má za cíl obecnou prosperitu města, a která může být rozdělena do tří hlavních sekcí: podpora podnikání, podpora pracovní síly, zvyšování kvality života. Dále následuje oblast pojednávající o udržitelnosti a životním prostředí. Ta zahrnuje kroky ke zvýšení efektivity využití elektrické energie, širšímu využití obnovitelných zdrojů nebo snížení úrovně znečištění vzduchu s cílem minimalizace negativního dopadu lidské civilizace na životní prostředí. Třetí pilíř konceptu je pojmenovaný „chytří lidé“. Vzhledem k tomu, že obyvatelé jsou základní jednotkou města jako takového, koncept věnuje velkou pozornost i jim, např. v souvislosti s jejich vzděláváním, angažováním se v řízení města nebo snahou o vytvoření přátelské a otevřené komunity. Na tuto oblast navazuje „chytrý život“, který zajišťuje co nejvyšší kvalitu života v daném městě pro jeho obyvatele i návštěvníky, proto se do něj zásadně promítají i výsledky ostatní oblastí. Aspekty, kterými se tato oblast zabývá, jsou např. úroveň zdravotnictví, bezpečnost, možnosti vzdělávání nebo dostupnost bydlení. Pátou sekcí tohoto konceptu je „chytrá správa“. Ta má mimo jiné zaručit digitalizaci veřejných služeb, politickou transparentnost a zmiňované zapojování obyvatel města do rozhodování o jeho budoucnosti. Poslední, ale neméně důležitou oblastí, je chytrá mobilita. Tato sekce si dává za cíl co nejefektivnější přepravu lidí i věcí, tzn. přepravu, která co nejméně zatěžuje dopravní infrastrukturu města a je zároveň šetrná k životnímu prostředí.

Druhá kapitola je věnována dvěma technologiím, které jsou v konceptu chytrých měst klíčové: informační a komunikační technologie (IKT) a internet věcí. U informačních a komunikačních technologií je diskutován jejich význam v rámci chytrých měst a následně je detailněji popsána problematika počítačových sítí, které do IKT spadají, včetně typů hardwaru, softwaru a protokolů využívaných v tomto odvětví. Druhá zmiňovaná technologie, internet věcí, je pak také popsána v kontextu chytrých měst, společně s příkladem chytrého řešení pro sledování obsazenosti parkovacích míst. V souvislosti s internetem věcí jsou v kapitole diskutovány různé druhy propojení zařízení. Rozdělení je provedeno na základě jejich vlastností (spotřeby elektrické energie, dosahu a šířky pásma). U všech typů konektivity jsou uvedeny příklady využití v rámci chytrých měst.

Na klíčové technologie navazuje kapitola týkající se kyberbezpečnosti a ochrany dat. Tato problematika může být jednou z největších slabin celého konceptu. Jsou zde rozebrána možná rizika týkající se krádeže a zneužití osobních dat, se kterými koncept pracuje, nebo riziko narušení některých funkcí města v případě kybernetického útoku. Na základě odborné literatury je pak uvedeno i několik požadavků na kybernetickou bezpečnost s cílem prevence jakékoli hrozby spojené s narušením komunikační infrastruktury města.

Čtvrtá kapitola je věnována popisu dvou indexů chytrých měst. Indexy chytrých měst představují soubor kritérií, podle kterých je možné zhodnotit „chytrost" daného města. Pro účely zhodnocení příkladů chytrých měst v dalších kapitolách jsou zde představeny Cities in Motion Index (CIMI) publikovaný Navarrskou Ekonomickou Univerzitou a Smart City Index (SCI) publikovaný švýcarským institutem pro rozvoj managementu. Důvodem výběru těchto dvou konkrétních indexů je rozdílný přístup v získávání podkladů pro hodnocení chytrého města. Zatímco CIMI zakládá své hodnocení na informacích získaných od lidí přímo zapojených v procesu přeměny v chytré město (vedení města, akademici, experti apod.), SCI je založený na tom, jak chytrost svého města hodnotí jeho obyvatelé. Oba indexy pak do hodnocení zahrnují různé aspekty týkající se momentálního stavu chytrých měst.

Následně jsou diskutovány dva příklady existujících chytrých měst, Londýn a Praha. Londýn, který pravidelně obsazuje přední příčky žebříčků chytrých měst, se momentálně drží své strategie „Smarter London Together" zahrnující primárně kroky pro zajištění pevných základů pro rozvoj konceptu chytrého města po celé jeho rozloze. Vzhledem k tomu, že se jedná o poměrně odbornou problematiku, vedení města zřídilo výbor nazvaný „Smart London Board", který slouží pro realizaci a poradenství v tématech spojených s konceptem chytrých měst. Praha aplikovala podobný přístup a zřídila projektovou kancelář Smart Prague, kterou svěřila společnosti Operátor ICT, která plní stejnou funkci jako londýnský „Smart London Board". Pražská strategie nazvaná „Smart Prague 2030" je pak v porovnání s její londýnskou obdobou více obecná a tolik se nezaměřuje na krátkodobé cíle, jako spíš na celé oblasti, které chce v rámci konceptu chytrého města zlepšit. Součástí podkapitol popisujících obě města s jejich strategiemi je i jejich hodnocení pomocí obou zmiňovaných indexů a následné porovnání těchto hodnocení.

V závěru jsou pak zhodnoceny hlavní poznatky z celé práce, zahrnující primární cíle jednotlivých pilířů, možnosti využití moderních technologií a požadavky s nimi spojené, nebo případná úskalí chytrých měst. Dále jsou shrnuty výsledky porovnání strategií a hodnocení obou měst a je navržen další postup pro případné budoucí práce zaměřené na koncept chytrých měst a jeho zavádění.

List of figures

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