Smart city for sustainable environment: A comparison of participatory strategies from Helsinki, Singapore and London

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ABSTRACT

The objective of this study is to critically review the smart city research paradigm and to find possible pitfalls, conflicting results and topics for further study and improvement. A qualitative comparison of the smart city initiatives in selected target countries and cities were done. The research strategy in this study approximates the grounded theory, utilising inductive reasoning to generate arguments and conclusions about the form, validity and future of the smart city. Various actors responsible to convert a traditional city to a smart city are defined and analysed within the context of this study. The main conclusion of this study was that the current research on smart city does not fully address the complex nature, conflicts and interdependencies of the smart city objectives. Moreover, the study found that the smart city initiatives form complex and multidisciplinary platforms that require holistic evaluation as the current evaluation methods and rankings of the smart cities vary considerably, making the evaluation of the success of the smart cities difficult.

Keyword: Smart city, Sustainability, e-governance, information and communication technology, internet of things, urbanization.

1. Introduction

Emergence of today's globalization and industrialization has created a major shift from rural areas to urban areas. This huge paradigm shift caused to develop cities globally, which consume three-quarters of the world's natural resources, generate three-quarters of its pollution, and waste (Hayat, 2016). In such consequences, it is necessary for the cities to get smarter by deploying innovative technologies and solutions. Deployment of such technologies and solutions contributes to overcome urbanization challenges and make the cities more liveable, competitive and self-reliant. The emergence of smart cities is growing increasing interest among the citizens all over the world. The accompanied features of smart cities are varied from one country to another that also depends on the geographical natures, ecosystems, available resources etc.

Today's world is facing two trends that greatly affect our way of life simultaneously: population growth and urbanisation. While the urbanization offers job opportunities, accommodation and infrastructure to support better quality of life (QoL) for the increasing number of citizens, the dramatic urbanisation also negatively impacts the environment, the lifestyles in the societies and the governance of the cities [1].The smart city is a common concept under which various research and development programmes are undertaken to overcome the negative impacts of the rapid urbanisation.

The term smart city is said to have first appeared in the middle of the 1990s, when the cities promoted themselves after introducing new information and communication technology (ICT) infrastructure or e-governance services, or when attracting technology companies to provide new economic growth to the region [2]. The word "smart" refers to an automated mechanism introduced to perform the desired activity within a given domain [3]. The core idea of smart city is to introduce smartness in every entity of the ecosystem that the people live in and interact with for example smart infrastructure, smart governance, smart transportation, smart healthcare, smart agriculture, smart education, smart economy, smart environment, smart industry, smart energy etc. [4]. The mission of the smart city research is to design and implement applied research and development linked to the smart city and the sustainable development of the living environment. Interesting phenomena within smart cities are digital services, IoT and 5G, bots, robots and automation. The solutions through smart city facilitate the handling of things, communication and housing-related activities, i.e. improving the functionalities of everyday life in many ways. One of the major issue in the smart city theme is to develop the carbon-neutral city, its green energy solutions, batteries and energy storage. Moreover, the research on smart city also links the perspective of the human city, including the themes of community, social environment, aging and employment.

Today, the development of smart city development is a global phenomenon, which is closely related to the 17 so called sustainable development goals listed in the 2030 Agenda for Sustainable Development of the United Nations (UN), Department of Economic and Social Affairs [5]. An inclusive, safe, resilient and sustainable city is one of the sustainable development goals. The focuses of such SDGs are to achieve long-term benefits and covers several dimensions of smart and sustainable cities. The initiative of smart city is generally backed up by the adoption of Information and Communication Technologies (ICT) enabled innovations that support to ensure a sustainable future for cities (Rodrigues & Franco, 2019). Based on SDGs, smart cities have diversified objectives that are undertaken by different countries to achieving such SDGs in the longer run. In such perspective, it is necessary to adopt a systematic decision support system at the countries strategic level (Pichler, 2017) to harmonize smart and sustainable city initiatives with the desired 2030 UN SDGs. There is a need to understand whether or not the innovations in smart city development are effective in improving the city sustainability, are the cities becoming easier to plan and govern with such innovation, is the

modern technology simplifying or it complicating the smart city development, do the citizens find the smart cities more liveable and desirable places to dwell and work in, etc. This study plans to analysis smart city initiatives all over the world with the objective to harness possible existing knowledge gaps. Thus, this approach will be worked as a backbone for the current and future smart city initiatives in order to uphold their strategies positions globally and to expand the current smart city initiative that connects cities and communities. Moreover, such new approaches contribute to connect the UN SDGs objectives to develop sustainable plans and strategies for smart cities. Furthermore, to achieve such goals, this study tries to identify and get answers to the following three research questions (RQs) on smart cities:

RQ 1: Is the evaluation of the smartness of the cities based on sound judgement?

RQ 2: Are there any issues or challenges that may have been overlooked or neglected in the smart city research so far?

RQ 3: What may be the opportunities for better future smart city research and development?

To understand the above mentioned issues, this study first focuses on the many definitions of smart city in order to find common nominators and differing factors among them. Second, the typical innovation areas within the smart city research are introduced. Special attention is paid to the smart city innovations touching the information systems science (ISS). At the same time, it is realised how multidisciplinary the smart city research needs to be in order to produce practical and useful results by which the cities and the life of their citizens can be further developed and improved. Third, a set of three representative smart cities – Helsinki, Singapore and London – are studied to compare what are the actual smart city research projects and innovations they are concentrating on, are there any similarities or differences to be found in their background assumptions, and how these cities value and utilise their results. Finally, this study then concludes with the evaluation on how the smart city ideology meets its objectives.

This study adds value to the research on smart cities by providing a critical review to the topic. The study combines the results of the latest academic smart city research and the practical smart city initiatives and draws conclusions on the practicality and usefulness of the smart city development. This study also endeavours to add a philosophical approach to the ICT research and to the discussion about the topic of the digital transformation of the society. The topic and the findings of this study hopefully also interest the broader audience and scientific community as the smart city concept considers so many of today's megatrends: urbanisation, sustainability, clean and safe environment, intelligent traffic and mobility solutions, internet of things (IoT), open data, and especially the privacy and safety of personal data, which is increasingly utilised as the smart city applications become more sophisticated and complex.

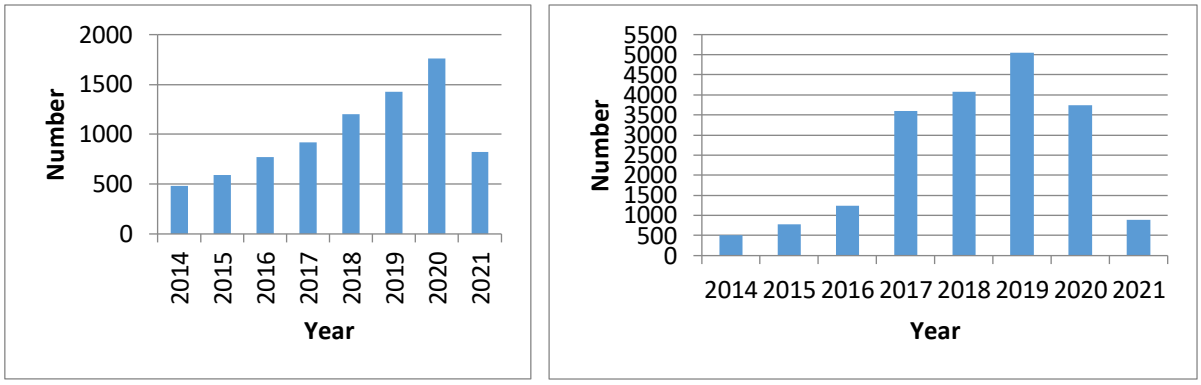
The remaining portion of the paper is structured as follows: Section 2 reviews the literature to understand various definitions of smart cities and their building block. Section 3 outlines the research methodology, while Section 4 highlights proposed conceptual framework to define smart city. Section 5 outlines the methods to measure the smart city performance, whereas, perspectives of smart city from local to international is stated in Section 6. A qualitative comparisons among three different study cities with respect to their smartness are explained in Section 7. Finally, the paper concludes with future research directions in Section 8.

2. Literature review

2.1 Smart city

Even though the concept of smart city is relatively new, it is gaining wider attention due to the emphasis governments throughout the globe are putting on to make their city smarter. Recently, the smart city as an urban development agenda has significantly increased globally due to the advent of information and communication technologies. Due to its explosive growth among the urban planners, the topic has also attracted considerable attention from academia. This fact is evident from the exponential growth of research articles published in this domain

in recent years. Fig. 1 shows the data obtained from the resources such as web of science and Scopus. As expected, the number of published paper extracted by Scopus database is higher than that of web of science. From Fig. 1, it is evident that the growth on the publication of research articles in this domain has accelerated especially from 2015 onwards. The data is collected by searching papers using the key word such as smart city, smart environment, smart energy and smart economy. It should be noted that for the year 2021 the publication number is less as the number represents only the papers published in the first quarter of 2021. The articles were published in the diverse subject areas such as Social science, engineering, decision science, energy, computer science, business & management, environmental science etc. However, the most prominent are in the area of social science, computer science and engineering.



(a) Source from web of science (Science direct) (b) Source from Scopus database

Fig. 1. Number of publications on smart city study in the last eight years

Irrespective of wider enthusiasm among the research community, private organizations and government alike, there is no universal definition of "smart city" [6]. European commission has defined a smart city as, "A smart city is a place where traditional networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and business. A smart city goes beyond the use of information and communication technologies (ICT) for better resource use and less emissions. It means smarter urban transport networks, upgraded water supply and waste disposal facilities and efficient ways to light and heat buildings. It also means a more interactive and responsive city administration, safer public spaces and meeting are the needs of an ageing population" [7].

This smart city definition suggests that the smartness of the city is built on the old, existing city infrastructure, instead of having to build a completely new infrastructure. The old infrastructure is put to better use with the help of digital ICT innovations. This should ensure higher efficiency, lower resource consumption and less waste and pollution, while making the city safer, more liveable, and the city administration more approachable. Interestingly, in the European context the ageing of the population is highlighted in the smart city definition over the accelerating population growth of the cities. Vienna University of Technology has been profiling and benchmarking medium and large sized European smart cities since 2007 [8]. According to Giffinger et al. [8], the smart cities are comprised by six key fields of smartness such as smart governance, smart economy, smart mobility, smart environment, smart people and smart living, which are displayed in Fig. 2.

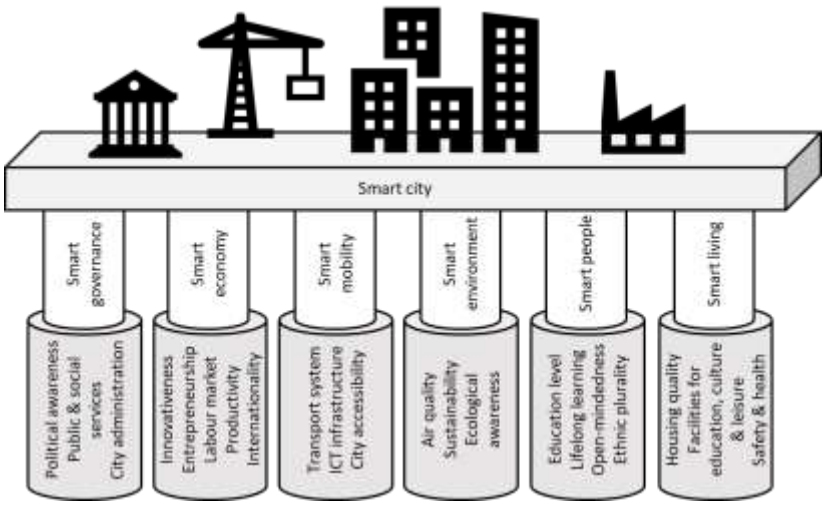


Fig.2. Six key fields of smart cities (adapted from Giffinger, et al. [8]).

2.2 Smart city infrastructure

According to Silva et al. [1], smart city is consisted of several infrastructures, which are categorized and defined in Table 1.

Table 1
Different types of infrastructure in smart city with definitions.

Index	*Type of infrastructure*	*Definition*	*References*
1	Institutional Infrastructure	This infrastructure consisted of the smart city governance that includes the political strategy development, transparency of the governance with the citizens participating in the decision making.	[9]
2	Physical infrastructure	This infrastructure consisted of the natural resources and energy, ICT infrastructure, buildings, and urban planning. The main goal of the physical infrastructure is to ensure the sustainability of the smart city today and in the future.	[1]
3	Social infrastructure	This infrastructure covers the intellectual and human capital, and the quality of life. The social infrastructure and social awareness are seen essential for the evolution and sustainability of the smart city.	[10]
4	Economic infrastructure	This infrastructure of the smart city ranging from the utilisation of e-commerce and e-business to the various performance indicators to analyse the public expenditure, energy consumption, employment rates, funding of the smart city projects and the GDP of the citizens.	[9, 11]

Further, exploring the published research articles in this domain, it is evident that researches so far have mainly concentrated on the development of smart city framework [Yigitcanlar et al. (2018); Heaton Parlikad (2019); Kumar et al., (2020)]. Others have focused extensively on the

technological aspect [Ismagilova et al. (2019); Bhushan et el. Al (2020)] and aspect related to the community to develop smart city [(Macke et al. (2018); Deakin and Reid (2017)]. Moreover, some papers have researched from the policy viewpoint to develop smart city [(Lu et al, (2019); Prasad and Alizadeh, (2020)]. Table 2 listed some state-of-the-art articles published in the last four years arranged according to their year of publication. The table shows the contribution of the articles and its application context. The table also discusses the findings of the paper and future research direction suggested. It should be noted that some papers provided multiple agenda as possible avenues for the future research. However, in the table, we limit ourselves with only the important agenda disused in the article.

Table 2
Recent State-of-the art literature on Smart City (SC) topic

Recent articles	*Application city/ context*	*Contribution*	*Findings*
Silva et al. (2018)	Sanfarncisco (USA), London (UK), Barcelona (Spain)	Presented an overview of smart cities, followed by the features and characteristics of smart cities.	Development of smart city highly relies on the expedition of data processing.
Macke et al. (2018)	Curitiba (Brazil)	Evaluate the perception of quality of life (QOL) in a smart city.	The overall perception of people revealed their low satisfaction with a smart city.
Caragliu and Del Bo (2019)	Data from 309 European metropolitan areas	Analyzed urban innovation impact of Smart City policies.	Smart city policies do have a non-negligible positive impact on urban innovation measured.
Desdemoustier et al., (2019)	113 Belgian municipalities	Based on a survey on municipalities, the paper established Belgian typology of perceptions on smart cities.	Territorial scales and influences are necessary to develop smart cities.
Camboim, et al. (2019)	Amsterdam (The Netherlands), Barcelona (Spain)	Identified driving elements that make a city smarter.	Cities, to become smarter, should upgrade the driving elements related to these dimensions
Sokolov et al. (2019)	Moscow (Russia)	Identified nine key factors to be considered for improving existing policy instruments for smart cities.	Recommendations were prepared for the three cities based on identified nine key factors.
Hatuka and Zur (2020)	10 Cities from Israel	Explored smart urbanism in cities from all over Israel.	Most municipalities are still at an early stage of implementing digitization and have the ability to shape a vision for the cities.

Bhushan et al. (2020)	Healthcare, transportation, grid and supply chain management	Presented the state-of-the-art blockchain technology to solve the security issues of smart cities.	Blockchain technology can improve the efficiency, security and performance of smart cities.
Wang et al., (2020)	32 Chinese cities	Explored the universal evolution process of smart cities.	The performance of smart city implementation is consistent with economic development.
Ylipulli Luusua (2020).	Helsinki and Espoo	Studied the urban digitalization and smart city development in the context of Nordic society.	The integration of new technologies and digitalization into cities lead to separate digitalization strategies that seemed somewhat detached from the smart city projects.
Ji et al., (2021)	Taiwan	Identified the preference of citizens and their perceptions about Smart City.	The people perceive Smart City services as both important and useful to their existence, relatedness, and growth needs.
Csukás and Szabó (2021).	9 cities (8 from Europe and one from North America)	Identified nine anticipated benefits or value proposition components of smart city activities.	Four different types of smart cities emerge from the analysis: Green City, App City, Socially Sensitive City and Participatory City
Abu Rayash and Dincer (2021).	20 cities worldwide	Introduced a novel model to assess cities for their smartness based the domains of economy, environment, and pandemic resiliency.	Enhancing the smart energy index by 25 % results in doubling the smart economy index for all cities.

3. Research methodology and strategy

This study is critically analysed the current status of the research related to smart cities. Such analysis is basically conducted after carried out a rigorous literature review and critical analysis to find out what are the current view points of interest in the smart city research. The emphasis was given on the latest academic and peer-reviewed literature, but the novelty of the subject also necessitates a peek into the popular business and science publications to see if there are any new trends or undercurrents that may have so far been neglected by the science community.

In order to conduct such a rigorous review of literature from the past to recent, several bibliographic databases were considered such as Science Direct, Scopus, Emerald, Springer, and Google Scholar portal, etc. To search the literature, several keywords were used such as “smart city”, “smart sustainability”, “smart governance”, “smart economy”, “smart traffic”, “smart mobility”, “smart technology, “smart data” and “smart citizens”, etc., were used. Some specific keywords such as “smart technology”, smart mobility, “smart data”, etc., resulted into numerous references to detailed topics of cloud-based services, internet of things, sensor networks, artificial intelligence, big data, information and communication technology, GNSS, etc. The used literature has a global reach, and the cities for the comparison have been selected around the globe as well.

Each of these topics would be an interesting study subject of their own. However, it is not feasible to describe and explain these topics in detail. Instead, the intention was to capture only their essence in forming and enabling the smart city. The selected research strategy for this study approximates the grounded theory. This exploratory strategy allows for the empirical study and perception of the largely unstructured smart city phenomena. The grounded theory also enables the building up of a more holistic conceptual model of the smart city as a synthesis influenced by the reviewed literature.

In this study, three smart cities namely Helsinki, Singapore and London were analysed with various perspectives. During the city selection process, several criterions were considered. For instance, Helsinki was selected based on the criteria such as – small, northern, not usually on top of smart city rankings, low resources and high technology; Singapore was selected based on the criteria such as – city/state peculiarity, Asian viewpoint, small size but high resources, centrally controlled by government; London was selected based on the criteria such as – big size, old infrastructure, high smart city rankings, centrally controlled by mayor, political challenges due to Brexit.

4. Smart city: conceptual framework

Smart city phenomenon can be synthesized in the form of a conceptual framework that explains how the various levels and factors of the smart city communicate and interact with each other. However, as the smart city development is partly symbiotic, partly top-down, partly bottom-up and partly co-created in nature, it is almost impossible to depict it as a conventional flowchart with inputs, outputs and feedback loops. There would simply be too many of these input, output and feedback permutations. Instead, a spherical framework, as depicted in Fig. 3, could be more illustrative in explaining the smart city interactions.

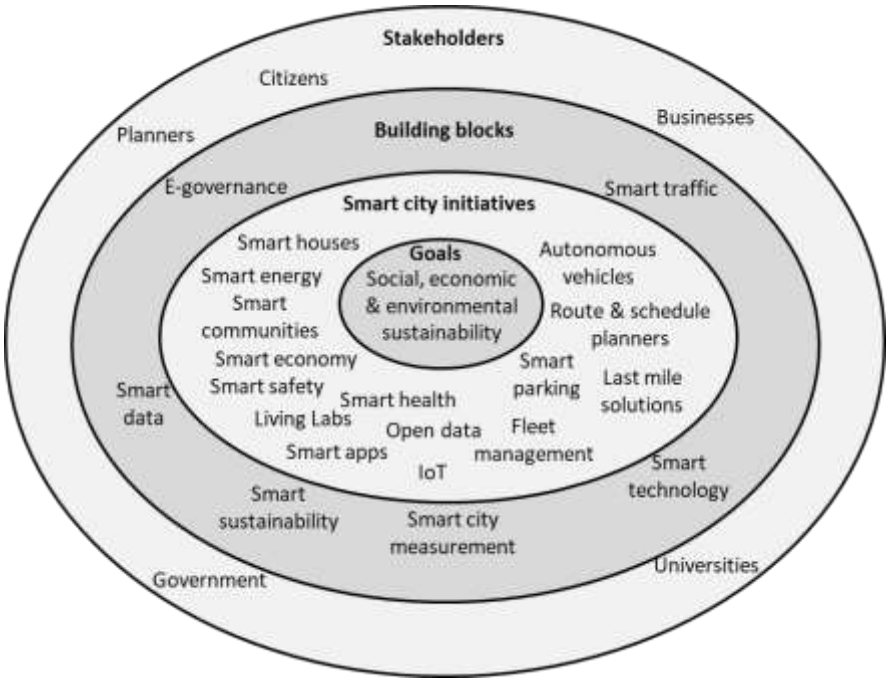


Fig. 3. Conceptual smart city framework

The conceptual smart city framework in Fig. 3, depicts the various smart city stakeholders on the outer sphere of the framework. The stakeholders interact in various ways with the smart city building blocks which are further divided into a multitude of smart city initiatives. The

successful execution and interplay of these smart city initiatives then enables reaching the core of the framework, thus, achieving the ultimate smart city goals of social, economic and environmental sustainability.

The above example demonstrates how the parts of the smart city framework are intertwined. One stakeholder group does not represent just itself, but a mixture of other stakeholder groups, too. It is not possible to make an isolated decision on a specific topic without it affecting the other parts of the sphere. For example, a decision to increase the use of IoT may become a sudden burden for mobile telecommunication networks, or cause an unexpected cost, and a source of new revenue for the businesses, in the form of legacy IoT devices and sensors that require regular updating and replacements. An optimised solution to increase, for example, social sustainability may have a negative impact on economic or environmental sustainability. A simplified real-life example can illustrate the smart city framework even further. Detailed of each of the components within the conceptual smart city framework are illustrated in the following sub-sections.

4.1 Goals of smart city

From Fig. 4, it is seen that the core of the conceptual smart city framework is consisted of the goals of the smart city. There are several goals in smart city initiative however, most common and critical ones are social, economic and environmental sustainability which are briefly explained below.

4.1.1 Social sustainability

Social sustainability is an important issue towards the aim to future urban developments. In the concept of smart city, this issue has been considered to address issues related to negative environmental externalities (Monfaredzadeh and Krueger, 2015). Social sustainability issue is concerned with the people and communities living in the smart cities. It is consisted of different dimensions and themes. Social sustainability in a smart city relates to effective community engagement practices and it is associated with a positive effect on social structure. Although, social sustainability and smart city concept is highly related but it is not much researched as like as environmental sustainability (Shaw & Graham, 2017; Bouzguenda et al., 2019; Yigitcanlar et al., 2019).

4.1.2 Economic sustainability

Economic sustainability in smart city domain is necessary for sustainable human development. It is also considered as a matter of intergenerational equity and often it is not always straightforward as we think. It refers to the relationship between distributional equity, sustainable development, optimal growth, and pure time preference (Anand and Sen, 2000). In a smart city, economic systems should be managed in such a way that the available resources are distributed among city population in order to maintain and to improve the asset equally well or better. In such way, economic sustainability would appear as opportunities to enhance human productivity for the future. This approach will then be seen as a variety of economic and social circumstances, which are associated to the development of education and skills across the population within smart cities.

4.1.3 Environmental sustainability

Environmental sustainability is considered one of the important concerns globally. The major concern of this concept is to maintain our costly environment by preserving scarce resources and reducing CO2 emissions that supports to eliminate or reduce environmental degradation.

In the growing trend of smart cities, this environmental sustainability is a critical concern, where cities offer huge potentials with respect to sustainability (Chatfield and Reddick, 2016). Cities are responsible to degrade the environment through various factors such as mobility, energy and water consumption, and waste production, etc., (Brauer et al., 2015).

4.2 Smart city initiatives

From Fig. 4, it is seen that after the goals of the smart city framework, the next level is known as smart city initiatives. This level is consisted of several important initiatives such as smart houses, smart parking, fleet management, smart economy, smart safety etc. Among the stated factors, some of the critical smart city initiatives are outlined in the following paragraphs.

4.2.1 Smart houses

Smart homes assist citizen in finding a free parking spot or to catch the next approaching bus. The smart home application gets information from various IoT devices, by which the citizens can control their safety and living comfort. The comfortable and safe homes increase the social sustainability of the city. Smart city can support the transition from ordinary houses to smart houses, where smart devices can be operated automatically by the precision technology provided by global navigation satellite system (GNSS). This precision can be both indoor and outdoor environments. In case of indoor environment, precision technology supports to find location of objects inside the house and to support mobility such as automated robots, location of patients/doctors in case of hospital, items in the warehouse, etc. On the other hand, outdoor positioning also support to develop smart houses, where already existing camera hardware of a house can be utilized for position detection of marked devices [39]. In addition, various sensor technologies integrated with GNSS signals can extend surveillance cameras capabilities a general sensory system for localization of active (automated) or passive devices in the future smart houses and cities [40].

4.2.2 Smart energy

The optimised energy and water consumption of the houses, and the timely and congestion free bus traffic increase the environmental sustainability of the city. Space data from GNSS can be used as a tool for the decision-makers in developing, implementing and monitoring energy and environment. It is widely believed that security of energy production and supply with low carbon economy can be achieved through the application of space technologies [41]. There are number of applications of space technology in the energy sector, especially in renewable energy sources as well as in traditional oil-carbon and nuclear energy sectors.

4.2.3 Route and schedule planners

Navigation data from satellite also a valuable source to optimizing fuel efficiency in transport sector. This navigation data supports drivers finding vehicles location, road conditions and type of vehicle, which are useful information for the drivers to calculate routes and to advise schedule planning with proper velocity on the most economical driving style to use that lead to energy savings of 15–25% [42].

4.2.4 Smart parking

Both the parking service and the bus service may utilise traffic information, location information, schedule information and various other big data sources by which AI solutions can predict the availability of parking slots or the schedules of the approaching buses. The time

scales of information flows range from multiple decades to seconds for the operating and evolving urban area. The IOT information temporal basis of seconds is today implemented to provide transportation system details for optimizing traffic flows on entire urban area street systems. Smart parking control systems use traffic signals and vehicle flow measurements to dynamically respond to normal traffic or traffic accidents. Such systems may use various cost functions depending on the time of day to optimize for normal or special conditions (construction/repairs, parades, security counter measure, etc.). These control systems automate the data processing and control processes of parking management and permit operators to focus on strategic operations associated with parking management. Global navigation satellite system (GNSS) enabled routing/navigation services provide real-time tasking incorporating smart parking control data and position information over the street network of the city.

4.2.5 Smart health

The citizens may use their mobile devices to access their smart health services, to control their health related issues. The messages and commands from the citizens' devices are conveyed through fast mobile ICT networks. Moreover, the well-functioning healthcare services increase the economic sustainability of the city, to name a few. The health services access cloud-based big data solutions to find the correct medical records of the citizens. Each of these services, or smart city initiatives, are realised by using building blocks of smart technology and smart data.

4.3 Building blocks in smart city

The next layer after the smart city initiatives layer is termed as building blocks as depicted in Fig. 4. This layer consisted of several terminology as e-governance, smart traffic, smart sustainability, smart technology, smart city measurement and smart data, which are briefly highlighted in the following paragraphs.

4.3.1 E-governance

The smart city is often defined by requiring a citizen-centric, participatory, collaborative, integrated and transparent governance, which is achieved by e-governance solutions that rely on ICT infrastructure [12]. E-governance is the area of smart city development, where the innovations in information technology intersect with the political evaluation of the success of the administration [13]. E-governance enables collaboration, but this does not yet ensure that the citizens, communities, public institutions, corporations, voluntary organisations, and schools are committed or willing to collaborate [13]. It could also be asked, do the citizens really want to collaborate with the government, or do they want the government to increasingly collaborate with them just for the sake of city smartness [12].

4.3.2 Smart traffic

Smart traffic or more broadly smart mobility is one of the key initiatives of all smart city developments today. The challenges of the traffic largely include the same topics that drive also the development of the smart cities in general: fast urbanisation, mobility issues of the aging population, control and reduction of the climate change and pollution, mobility service development through innovative digitalisation, and discovery of sustainable and efficient energy sources for the traffic [14]. In an assessment of urban transport, it is noted that the urbanisation and the related increase in road traffic will cause congestion and air pollution, simultaneously reducing the quality of life [15]. The EC has made a forecast that the freight transport will increase by 40 % and the passenger transport will increase by 34 % from 2016 to 2030. The

development of intelligent transport systems allows the management of public and private traffic on the roads, including rail traffic, fleet, and cargo transport, and even information for the drivers about traffic congestion and the availability of parking spaces [16].

4.3.3 Smart sustainability

The sustainability of the smart cities usually focuses on three dimensions: the economic, social, and environmental sustainability. The economic sustainability is addressed by smart economy solutions, like e-commerce and e-business [1]. The maturity of the social infrastructure and the social awareness of the citizens drive the social sustainability of the smart city. The overall urban ecosystem must also maintain environmental sustainability, otherwise the longevity of the smart city and the entire planet is in danger. The smart city can contribute to the sustainable environment directly by smart environment initiatives that address the air quality, resource management and ecological awareness of the city [8].

4.3.4 Smart technology

Much of the smartness of the smart city relies on the innovative, interoperable and synchronised use of various ICT, forming a network on top of which the socio-technical information systems of the smart city can operate. Fast communication networks are needed to convey the massive amounts of data generated and collected by the smart cities. The data is processed in powerful cloud-based computing systems. The use of IoT technologies have a pivotal role in enabling the collection, access and utilisation of the data that makes the cities smart [17]. According to Silva et al. [1], the generic smart city architecture comprises of four bottom-up technology layers: data collection layer, data transmission layer, data management layer and application layer. The protection of the sensitive data moving between the layers is handled by various security modules that vertically cover all the other four layers. The generic smart city technology architecture is illustrated in Fig. 4.

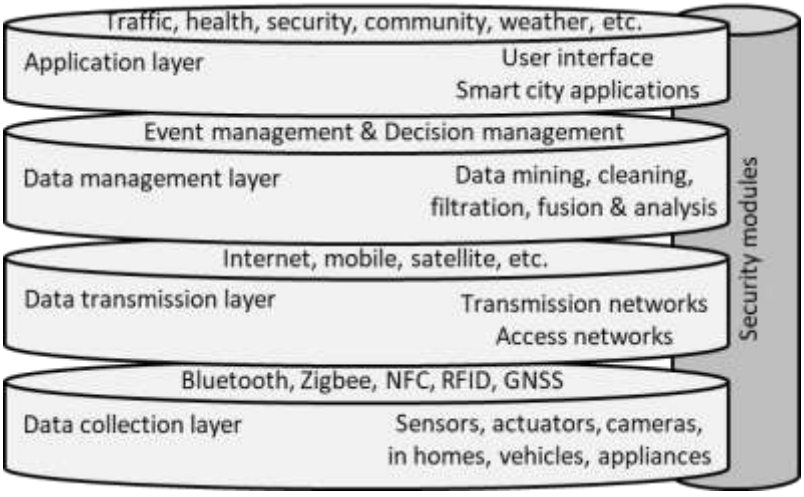


Fig. 4. Smart city technology architecture (adapted from [1].

4.3.5 Smart city measurement

In a smart city, there involves various technologies and sensors that collect all kinds of information (traffic, waste collection, energy consumption, etc). Although, several data collect collection technologies make it quite simple to collect such data or information, but often it is not that easy to manage it and to establish what to measure, as several aspects are involved (Illana, 2021). In such perspective, it is necessary to formulate standardized metrics and criteria which can eb used to measure and manage the overall performance of smart city.

4.3.6 Smart data

Transition to smarter cities requires the simultaneous assessment of eco-socio-technical factors across the full spatial dimensions of urban areas. The shape of the urban expanse plus its physical attributes (called urban form) is fundamental factors used to characterize the urban environments making this local geography important. More advanced GIS technologies and related smart data have been and are further developing to support smarter cities. Urban form spatial information or data is understood to affect how the urban areas function and it conveys some of the ecological and technical factors in their spatial contexts. The GIS technologies are used to bring together all these relevant data to allow citizens, urban planners and city governments to comprehend and monitor their cities' characteristics. This smart data management works to evolve the form and functions of cities towards new efficiencies while also providing improved social well-being. The more static databases under the GISs of yesterday are today also including automated connections for monitoring the high temporal dynamics of the eco-socio-technical processes within cities.

4.4 Stakeholders in smart city

In a smart city, there are several stakeholders involved such as citizens, planners, businesses, government, universities etc. All the stakeholders are an intrinsic part of the smart city. It is therefore, essential to monitor and to measure the status of such stakeholders and to make the smart city successful. There also need interactions among the stakeholders. In case of citizens, there needs to monitor the population growth, increasing pressure and economic burdens. For planners, it is essential to ensure good quality of life for the city populations.

Businesses and enterprises are directly interfaced with smart city phenomenon, where it is essential to develop smart infrastructure and to implement smart solutions to real estate developers, technology providers, system integrators, etc. The sustainability of a smart city is highly dependent on its government system that supports to develop the policies on smart cities. Universities or educational institutions play a big role in the development and operation of smart cities. Researchers are motivated to develop solutions for intelligent cities with respect to both technical and socio-economic perspectives.

5. Performance measurement in smart city

The smart city can be characterised by three main categories such as (i) the level of utilising the ICT infrastructure to improve the efficiency of the urban development, (ii) the level of competitiveness the city offers to increase the prosperity, and (iii) the level of sustainability and social inclusion the city can provide. But how can these characteristics be measured? The smartness of the city cannot be properly evaluated, unless there are some commonly accepted and reliable measurement and assessment methods in place. Typically, the smartness is measured by various global and regional smart city rankings, provided periodically by research institutions and private consulting companies. There are also municipal environmental services that provide physical measurement data on environmental variables. There is nowadays also an ISO standard for measuring the performance of city services and quality of life.

The perspective to the evaluation of the smart cities is the way how the cities themselves measure and report the success of their smart city initiatives. The intention of the ISO 37120:2014 standard: Sustainable Development of Communities – Indicators for City Services and Quality of Life is said to be the most practical method for the cities to measure and monitor the performance and efficiency of their sustainable development [18]. The standard and its methodology can be applied regardless of the size, location, or position of the city. The standard also provides five certification levels – aspirational, bronze, silver, gold and platinum – for the cities to make comparisons and learn from each other. The ISO 37120:2014 standard defines 100 city performance indicators structured around 17 themes as displayed in Fig. 5 [19].

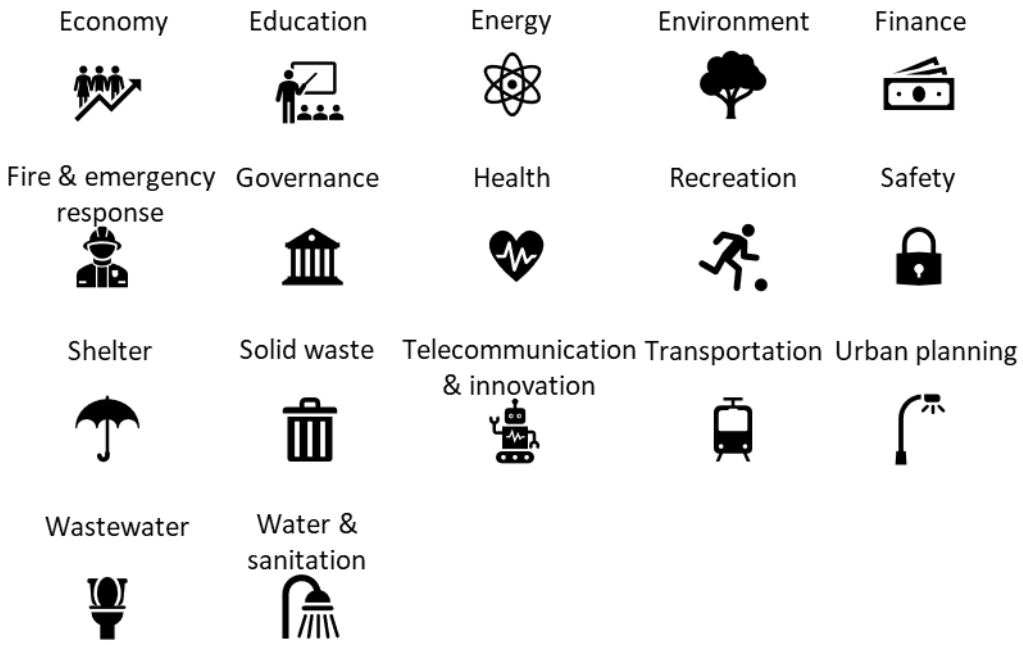


Fig. 5. 17 themes of ISO 37120:2014 (adapted from [20]).

On the local level it is also possible for the individual cities to provide metrics and measurements of their performance. For example, Helsinki climate watch (Helsingin ilmastovahti), Finland measures the progress towards the goal of carbon neutrality by year 2035 [21]. The web page displays over 200 functional, tactical, and strategic measurements by which the city of Helsinki monitors how the goals of the 147 agreed actions are reached. Similar kind of climate change related measurement data is also provided by HSY, Helsinki Region Environmental Services Authority [22]. This kind of public measurements data does not only inform the city about the progress, but it is also a good way of getting the citizens committed to the common sustainability goals.

6. Perspectives of smart city from local to international

The objective of a smart city initiative is to reform a city from ordinary to technically advanced ones. The major concern to transform an ordinary city to a smarter city is to offer improved services and to deliver a better quality of life to its citizens (Odendaal, 2003). Until 2018, it is estimated that 473 smart city projects are initiated and/or ongoing in 57 nations globally (Smart City Expo World Congress, 2018). Fundamental aspects of smart cities are to overcome the existing challenges of urban areas such as unavailability of safe and clean drinking water, absence of sufficient healthcare facilities, rate of unemployment, inaccessible social benefits etc.,

(Yigitcanlar, et al., 2019a; Yigitcanlar, et al., 2019b). Moreover, smart city initiative also tries to overcome other related challenges such as increasing rate of poverty, abnormalities in the traffic system, increasing rate of environmental pollution, insufficient city infrastructure, unhealthy community living etc., (Yigitcanlar et al., 2018).

The spread of urbanization is growing rapidly from regional level to international level. Such spreading is promoted due to the advancement and implementation of smart technologies and related tools. Application of ICT based intelligent services contributes to transform local cities into being smarter, greener, and sustainable that consequently promotes better quality of citizens life as well as enhanced economic activities (Rodrigues & Franco, 2019). In order to promote smart city concept from local to international level, there needs to collect and disseminate essential data or information across the city through data centers. This information exchange supports to optimize city services and helps to develop more sustainable and intelligent solutions within smart city boundaries. The stored data is also worked as an intelligent base and support to the anti-poverty initiative and contributes to tackle the social inequality problems (Murray, 2018).

In order to internationalization of smart city concept, it is essential to form public-private partnerships (PPP) strategy. This PPP initiative supports city planners and decision makers to address necessary funding mechanism to collect required funding to develop urban infrastructure. It is studied that about 35% of the urban investments are comes from the private investors (Kutty et al., 2020). In case of PPP, the city government works as a mentor, policy adviser and enabler to facilitate essential services and economic growth within the smart cities. This partnership supports smart city initiatives through eliminating common urban development challenges. The funding received from the PPP can also be used to invest mitigating existing smart city challenges by utilizing data and services from intelligent technologies, like location intelligence, Geospatial technology, Internet of Things, Big data, and Cloud systems (Kutty et al., 2020). This partnership scheme can be very practical, viable and demanding to provide a better understanding of the city operations globally.

7. Study of three case smart cities with comparisons

In order to experience with real-life smart city, this research studied three cities considering different geographical locations globally. The name of the selected three smart cities were namely Helsinki (Finland), Singapore, and London (UK). The selection criteria for Helsinki was the capital city of a Nordic country with lower population, whereas, Singapore was considered as a small Asian country with densely population. The city of London was selected as a very old capital city of a European country with densely population. In this study, these three cities were selected for a comparative study of their smart city initiatives. These cities should provide for an interesting viewpoint on the similarities and differences of the targets, initiatives, and results of the smart city development in three different geographical locations, political governance models, and cultural surroundings.

7.1 Selection criteria for the three cities

The three selected cities are compared based on their various criterions. Helsinki brings a North European viewpoint with its aspiring smart city platform, but with supposedly the most limited financial resources, serves as the smallest and perhaps not so highly recognized home base for this comparison. Singapore brings an Asian cultural viewpoint and its ambitious and highly considered smart city platform to the comparison. Being a young, small, and populous city-state, Singapore exemplifies how the smart city ideology can be incorporated also into the national level strategy. London, having the biggest population, oldest infrastructure, and most interesting geopolitical situation at the self-proclaimed fringe of European cooperation, would at first sight have the most challenges to develop its smartness. London was selected as the

representative in the category of old and large cities partly because of its peculiar political situation amidst the other European smart cities.

7.1.1 Helsinki

Helsinki usually pales in comparison with Singapore and London in the global smart city rankings. However, in a comparison by the European Parliament Helsinki is "one of the top six" smart city initiatives in Europe [23]. Helsinki has also recently gained increasing recognition having been named during 2019 as the European capital of smart tourism, having the best digital twin in the Kalasatama neighbourhood, the most innovative region in Europe, the best European mid-sized region for foreign investments, the third best city for start-up companies globally, and both the fifth and eighth best smart city in the world in two different rankings.

A study performed in Helsinki noted the need to develop new kinds of performance measures to evaluate the effectiveness of the smart city and its services [24]. Traditionally measured vertical performance of each municipal service on its own is not adequate anymore. Instead, new inter-departmental and horizontal performance measures are needed in evaluating the results of the entire service system of the smart city. The study revealed that these new performance measurement initiatives could potentially improve the identification of the problems in the structures of administration, the communication, and the transparency of the smart city. These could also help in streamlining the operations and in reaching the societal and sustainability goals.

7.1.1.1 Forum Virium Helsinki

Forum Virium Helsinki reports having 81 projects for co-created smart city solutions, involving 750 companies, 170 research facilities and 60 partner cities [23]. The many projects of Forum Virium are loosely grouped under four main headlines: IoT, Smart City, Smart Mobility, and Forum Virium being the fourth headline under which there are two projects concentrating on the development of a European AI ecosystem and the cooperation of the smart city development of the six largest cities in Finland. The aim of Forum Virium is to make Helsinki the most functional smart city in the world.

The IoT initiative includes projects ranging from the development of disruptive ICT technologies for the city infrastructure to the modelling of digital solutions to attract tourists to the Helsinki archipelago [23]. The Smart Mobility initiative lists nine current projects [23]. One of the drone projects in the Smart Mobility initiative has the objective of piloting carbon neutrality in logistics, remote security and environmental supervision. The projects study the last mile delivery problems, including drone transportation, replacement of automobile deliveries by lighter, electricity-assisted, autonomous vehicles, and robot bus projects using autonomous minibuses as part of public transportation services [23].

7.1.1.2 Smart traffic of Helsinki

Taking a closer look at the Smart Mobility initiative of Forum Virium four main research themes can be identified: utilization of low carbon energy, development of advanced vehicles, smart mobility services and transport systems. Low carbon or carbon neutral energy is utilised in the drone service trial and in the electric autonomous minibus trials [23]. These are also examples of advanced vehicles. In addition to the autonomous bus trials, the smart mobility services and transport systems are present in the smart last mile city logistics project, too.

The same themes are visible in the five smart mobility solutions piloted in the ports of the Helsinki–Tallinn ferry route [23]. The first project experiments a queue management system controlling truck movements at the downtown passenger ports to reduce congestion. The second project studies passenger flow management by travel service packages. These packages

could offer complimentary services, like free beverages, included in the travel ticket price. The third project concerns the use of smart containers as a short-term storage for the purchases made by the travellers. The same containers could also be used in the sharing economy concepts of the citizens. Fourth, an automatic hands-free tram ticketing system is tested to see how the passenger movement in the ferry terminals could be expedited. The fifth project experiments with the anonymised mobile subscribers' location data to analyse the movement trends of the ferry passengers in the city.

7.1.2 Singapore

Singapore is often named as the prime example of a smart city. In the Smart City Ranking by ABI Research in 2018, Singapore took the lead, scoring highest on the criteria related to innovation [25]. Especially mentioned are Singapore's innovations related to freight as a service (FaaS), mobility as a service (MaaS) and the innovative use of next-generation technology and disruptive paradigms in solving difficult structural problems. Again, in 2019 Singapore took the smartest city ranking in the first ever smart city index by International Institute for Management Development [26].

7.1.2.1 Smart Nation Singapore

Singapore's smart city development is concentrated under the Smart Nation initiative, launched in 2014 [27]. At that time the Singapore government aim was in building a technical architecture for the word's first Smart Nation. Infocomm Media Development Authority of Singapore was given the leadership in the holistic development of both hard and soft infrastructure. This included standardisation of the use of IoT and the development of Smart Nation Platform. The Smart Nation Platform was targeted at being a new enhanced connectivity network, which provides heterogeneous networks, pervasive connectivity and a nationwide IoT sensor and data analytics capability. The Smart Nation Platform would then allow companies and government agencies to innovate smarter services for the citizens.

7.1.2.2 Smart traffic of Singapore

A closer look at the Transport initiatives of the Smart Nation programme reveals some interesting projects and facts. Strategically, the objective in Singapore is to optimise the use of the limited space with more efficient, reliable and safer vehicles, with enhanced transportation methods and systems [28]. Autonomous vehicles seem to play a key role in these projects: there are, or have been, three trials with self-driving sedan-sized cars, four trials with autonomous shuttle buses of various sizes, including autonomous on-demand shuttles, autonomous electric minibus service for garden visitors, driverless shuttle buses in a university campus, and a larger, 40-seater autonomous electric bus. One project trials driverless trucks that are guided by transponders installed in the road, and another project trials platooning, with heavy vehicle leader-follower formations [29].

7.1.3 London

London usually achieves top rankings in the smart city comparisons. The smart city initiatives of London are organised under the Smart London platform, directly under the governance of the mayor of London [30]. One of the main Smart London initiatives is the Smarter London Together roadmap with its target of making London the smartest city in the world [31]. The open innovation platform is concentrated under London Living Labs [32]. The utilisation

of smart data and data collaboration is promoted in the data analytics programme, which is part of the London Datastore open data-sharing portal [33].

7.1.3.1 Smart London

The Smart London Board is a collection of digital technology academics and entrepreneurs constructing the vision how London should utilise digital data and technology to make the city a better place for citizens, businesses and visitors [30]. The London Office of Technology and Innovation is a collaboration platform for the many local districts of greater London to enhance digital innovation in the public services. The Mayor of London's Civic Innovation Challenge invites technology start-up companies to innovate applications and solutions to tackle some of the most serious problems of London.

Smarter London Together is a roadmap, launched directly by the mayor of London in 2018, targeting to transform London into the smartest city in the world [34]. The major role in this transformation is given to data innovation and digital technology, with the aim to serve three target groups: those who live or work in London as well as those who are visiting London. The Smarter London Together is divided in to five key missions: user-designed services, data analytics and data sharing, connectivity and smarter streets, digital leadership and skills, and city-wide collaboration.

7.1.3.2 Smart traffic of London

The Smarter London Together roadmap only briefly mentions the smart traffic initiatives of London. Instead, these activities are motivated by another document: Mayor's Transport Strategy [35], and the related website [36], which list three key themes for the smart transport in London: First, healthier streets are achieved by reducing dependency on private cars and encouraging the use of public transport, cycling and walking. Secondly, a good public transport system could reduce the number of vehicles on the streets of London. Thirdly, the planning of the city around public transport, cycling and walking should enable the city to grow in new areas for the growing amount of people moving or working in London.

7.2 Comparison among three smart cities

When comparing the smart city initiatives and activities of Helsinki, Singapore and London, Singapore has one clearly visible main advantage over the others. Being a small island city state, any smart city initiative will automatically have a national and government dimension, too. Thus, the smart city Singapore has quickly evolved into Smart Nation Singapore. Scaling the smart city activities in London and Helsinki to the national level would be much more challenging, because the cities and rural areas in Finland and the UK would not have the same uniformity of connectedness and quality of infrastructure as in Singapore. Related to the tolerance aspect required from the smart citizens, it is also noted that Singapore, with its multi-ethnic national history and the absence of so called ethnic or cultural hinterland, gives Singapore the advantage when accommodating strangers and ethnic differences that may surface during rapid urbanisation [37].

Most components of the smart city vision by Airaksinen et al. [38] are well included in the smart city initiatives of Helsinki, Singapore and London. All three cities involve their citizens and companies in the smart city innovation. Open data is made available to support the innovation. The utilisation of IoT sensor networks is include in all three cities. However, London uses IoT mainly for the environmental trials in the parks, whereas Helsinki and Singapore try to build grids of IoT sensors and the related big data analytics capabilities especially for the

purposes of energy efficiency of the smart buildings, and cleanness and safety of the neighbourhoods.

The use of sustainable energy is highlighted as well in the smart building initiatives of the cities. However, the sustainability of the building construction and the used construction materials is not evidently visible except in London. It looks like London has more trouble with its older infrastructure to simply build new housing to tackle the quick urbanisation, while Singapore and Helsinki are already experimenting more with the smart home projects. Robotics initiatives, apart from the robotic cars, are not currently evident in Helsinki or London, while there are robotic trials in the health care sector in Singapore.

The smart traffic initiatives in all three cities follow the international smart mobility trends remarkably well. It is evident that the cities all concentrate on the development of smart public transportation supported with multi-modal transport means. The confidence in, preferably, electric self-driving robot vehicles and their ability to solve the first or last mile problematics is strong in each city. Distinctively, the lost time and money spent in searching a parking space for private vehicles is a recognised issue in all three cities. Nevertheless, solving the problem with smart solutions is not clearly on the official smart city agenda of the compared cities.

Helsinki is the most active city in promoting the bottom-up approach for the innovations, where the citizens are encouraged to collaborate and propose their solutions to shape the smart city vision. Singapore, on the other hand, seems to prefer a slightly more tightly government controlled top-down approach, where the city is the driving force in defining and driving the smart city vision. The citizens are encouraged to provide their innovativeness to build this vision, but not to really shape it. Also, London shows some indications for a more top-down controlled approach, with many of the smart city projects and goals presented in the vision document and roadmaps coming directly from the office of the mayor of London.

Table 3 below, summarises the similarities and differences in the smart city comparison between Helsinki, Singapore and London. The table lists how the cities in general form their smart city strategies, what is their approach in domestic and international smart city collaboration and are the cities able to form coordinated nation-wide smart city initiatives. The way how the compared cities approach their smart data and smart traffic initiatives is also recapped by two or three keywords and key projects.

Table 3
Smart city comparison summary**.**

Measurement metrics	**Helsinki**	**Singapore**	**London**
City size	Small	Medium	Large
City age	Medium	Young	Old
Available resources	Small	Large	Large
Smart city initiative	Forum Virium	Smart Nation	Smart London
Strategy development direction	Bottom-up	Top-down	Top-down
Domestic collaboration	Active Inter-city	Active National coordination	Active Within Greater London
International collaboration	Active Bidirectional	Active Unidirectional	Passive
National reach	None	Active	None
Smart data approach	City Citizens	Government Citizens	Academic institutions

			Citizens
Smart traffic approach	Public transport Maritime transport Autonomous buses	Public transport Autonomous vehicles Autonomous freight	Public transport Autonomous vehicles

8. Discussions, conclusions and future research directions

Global cities are facing major challenges due to scarcity of resources and technological advancement. In order to improve city populations it is necessary to adapt technological advancement for the benefits of city populations. Such adoption of technology promotes to transition of ordinary city to a smart city. Nowadays, almost all regions in the world are adopting various pilot projects to emulate such smart cities. Different countries globally have rolled out mega-projects for the establishment of smart cities. There are accompanying challenges of smart cities such as information security, privacy threats, etc., which are caused due to the adoption of advanced technologies and tools. However, in comparison to the challenges there are greater advantages as well as necessity of smarter systems in cities for ensuring a quality life for citizens.

In a transition from local or regional level to international level, the revolution of upcoming smart cities need to most holistic approaches that require extensive participation from all the sectors of the society to ensure a truly substantive development. Nevertheless, in a holistic environment the smart cities need to measure resilient for various major portion of all urban areas on earth. This study introduces the overall smart city approach and discusses its various attributes. In addition, various technological aspect as necessary for smart city development are also investigated and presented. Moreover, related vulnerabilities of the smart cities are also addressed with a holistic and far-sighted approach.

Even though the smart city concept can be defined and described in many ways, the basic principle is simple: the smart city should improve the quality of life of its citizens, while simultaneously simplifying the management of the city. The global megatrends of population growth and fast urbanisation have caused the cities the need to invent new ways to improve their social, economic and environmental sustainability. The cities are struggling to consume less resources, pollute less and still make the cities more manageable to their authorities, more profitable to their businesses, more attractive to their visitors, and more liveable to their citizens. Smart city is the high-level concept that combines the socio-technical efforts, initiatives and developments that all aim to achieve these targets simultaneously. The aim of this study was to find out how the literature defines smart city, what its basic assumptions are and how the success of the smart cities is determined. The study was further complemented by a qualitative comparison of three representative smart city initiatives in Helsinki, Singapore and London to see how the smart cities are implemented in practice. From the many smart city building blocks, a closer look was taken to the smart activities and smart traffic projects in the three selected cities. The study was conducted as a literature review, covering the recent academic and peer-reviewed publications on smart city research, and the public websites of the smart city initiatives on the local, regional and global level, The selected research strategy for the study approximated the grounded theory, using inductive reasoning to create discussion, arguments and conclusions from the source material about the validity and the future of the smart cities.

The study revealed that for a large part the smart city is seen only as a technology exercise, where the latest ICT innovations are expected to solve the problems especially in city governance, planning, transportation and mobility, citizen engagement and participation, sustainability, economy, and safety. However, the solutions too many of these problems would require a human viewpoint and more holistic evaluation which are still largely missing from the smart

city evaluation. The literature reveals that there are many ways of defining and categorising these problematic smart city topics, from a simple three-part division of technology, human and institutional dimensions to the seventeen themes of the ISO 37210 standard and anything in between. Most of these definitions and topics are, however, overlapping and providing synonyms to each other. For example, the topic of education can be covered under institutional, city planning, technology and smart citizenship themes. Categorising the problems into three social, economic and environmental issues, and the measured smartness into six groups of smart governance, smart economy, smart mobility, smart environment, smart people and smart living already covers the concept of smart city adequately well.

The comparison of the smart city initiatives of Helsinki, Singapore and London revealed interesting differences in the attitudes towards involving the citizens in the creation of the smart city vision. In a typical top-down fashion the smart city vision comes directly from the mayor's office in London and from the prime minister's office in Singapore. In Helsinki, the smart city vision and strategy development seems more distributed and welcoming bottom-up participation from the citizens. Helsinki also seems the most interconnected with international cooperation, partly because of the scarcity of its own resources and partly because of the readily available EU cooperation. Singapore is keen to partner with and collect knowledge from international experts. There is not much evidence of reciprocity, though. London is currently struggling with their willingness to continue EU level smart city cooperation and their national decision to quit the EU altogether.

The smart cities are a wide and interesting subject for future study. This study recommends that the future directions of the smart city research should address three main topics: First, the smart city research should become a truly multidisciplinary approach because of the complex causality of the smart city phenomena, problems and solutions. Second, the novel methodologies and frameworks of the information systems science research, providing the much-needed tools to address the multidisciplinary socio-technical issues, should be utilised more often in the smart city research. The smart city research is such a young platform that clearly the most optimal interactions between the disciplines are not fully known yet. Therefore, as the third future research direction, the efficacy of the multidisciplinary cooperation in smart city research could be a study subject of its own. . This is especially important as the current ranking and measurement methods of smart cities still leave room for purposeful self-promotion and well-meaning initiatives that are counterproductive to the goals of improving quality of life, reducing social polarisation, or increasing sustainability.

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