


# Smart cities survey: Technologies, application domains and challenges for the cities of the future

International Journal of Distributed  
Sensor Networks  
2019, Vol. 15(6)  
© The Author(s) 2019  
DOI: 10.1177/1550147719853984  
journals.sagepub.com/home/dsn  


**Ruben Sánchez-Corcuera**, **Adrián Nuñez-Marcos**,  
**Jesus Sesma-Solance**, **Aritz Bilbao-Jayo**, **Rubén Mulero**,  
**Unai Zulaika**, **Gorka Azkune** and **Aitor Almeida**

## Abstract

The introduction of the Information and Communication Technologies throughout the last decades has created a trend of providing daily objects with *smartness*, aiming to make human life more comfortable. The paradigm of Smart Cities arises as a response to the goal of creating the city of the future, where (1) the well-being and rights of their citizens are guaranteed, (2) industry and (3) urban planning is assessed from an environmental and sustainable viewpoint. Smart Cities still face some challenges in their implementation, but gradually more research projects of Smart Cities are funded and executed. Moreover, cities from all around the globe are implementing Smart City features to improve services or the quality of life of their citizens. Through this article, (1) we go through various definitions of Smart Cities in the literature, (2) we review the technologies and methodologies used nowadays, (3) we summarise the different domains of applications where these technologies and methodologies are applied (e.g. health and education), (4) we show the cities that have integrated the Smart City paradigm in their daily functioning and (5) we provide a review of the open research challenges. Finally, we discuss about the future opportunities for Smart Cities and the issues that must be tackled in order to move towards the cities of the future.

## Keywords

Survey, state of the art, smart city, definitions, challenges, best practices

Date received: 19 December 2018; accepted: 8 May 2019

Handling Editor: Paolo Bellavista

## Introduction

According to the Department of Economic and Social Affairs of the United Nations, DESAP,<sup>1</sup> in the 1950s around 30% of the world population resided in urban areas. In 2014, this value increased to 55% and is expected to keep growing in the next couple of decades (<https://www.unfpa.org/migration>), reaching 68% by the year 2050 (<https://population.un.org/wup/Publications/Files/WUP2018-PressRelease.pdf>).

This shift from rural to urban areas occurs due to two main factors: (1) the natural growth of local population and (2) migration. The latter is motivated by the search for better opportunities, the improved quality of

life and higher standards that cities provide to their residents. For example, more job offers with better economic opportunities, coverage of basic necessities, improved education, health and public transport services and urban amenities, among others.

However, the rapid and uncontrolled growth of cities brings to the table new issues that local governments

---

DeustoTech, University of Deusto, Bilbao, Spain

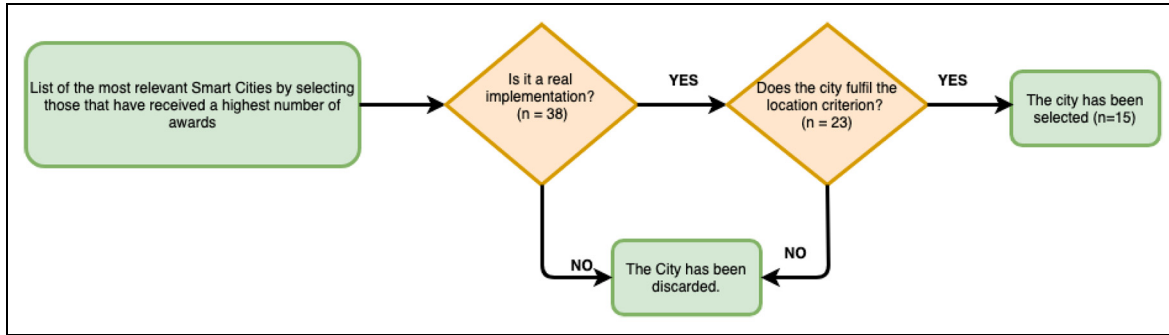
### Corresponding author:

Ruben Sánchez-Corcuera, DeustoTech, University of Deusto, Avenida de las Universidades, 24, Bilbao 48007, Spain.  
Email: [ruben.sanchez@deusto.es](mailto:ruben.sanchez@deusto.es)



Creative Commons CC BY: This article is distributed under the terms of the Creative Commons Attribution 4.0 License

(<http://www.creativecommons.org/licenses/by/4.0/>) which permits any use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (<https://us.sagepub.com/en-us/nam/open-access-at-sage>).



**Figure 1.** Methodology used to select the cities for the *Case studies* section. The used location criterion is that cities from each continent must be sampled.

and stakeholders need to pay attention to, such as increased traffic congestion and accidents, air and environment degradation due to higher amount of pollutants, higher cost of living, overcrowding, higher illness spreading, crime and security concerns.

Moreover, alongside the evolution of the society, there has been an exponential development of the Information and Communication Technologies (ICTs). Technologies such as Big Data, Internet, Internet of Things (IoT), Cloud Computing and Mobile Computing have been gaining importance during the last years, becoming a key part in the evolution of cities. Urbanisation and ICTs have resulted in the conception of the Smart City (SC) paradigm. A concept that increasingly more cities are striving to adopt by developing new SC initiatives.

This work includes over 200 papers, most of them recently published, on a wide variety of topics around SCs, for example, architectures, theoretical approaches, applications or specific domain projects. To find the most relevant works, Google Scholar was queried for papers containing ‘Smart City’ in their title or abstract, ordering them by relevance. In addition, we also queried Google Scholar and ArXiv for works with city attached to terms belonging to specific domains or applications (such as ‘healthcare’ or ‘education’). The bibliography of the selected papers was also analysed in order to extract relevant references which could enrich our study.

In order to select the cities in the *Case studies* section, the following methodology was used: first, we created a list of the most relevant Smart Cities by selecting those that have received the highest number of awards (Figure 1). After that, a meticulous analysis of each of the gathered cities was performed to differentiate press releases from real-life implementations, in order to study only already working Smart Cities. To do so, we searched for specific real case smart city scenarios in each of the gathered cities using reliable sources of information: city council’s websites, developed tools’

websites or developed smart city research projects in the city. Also, two other factors have been taken into account to select the use cases: cities with a specific department responsible of the development of the city as smart city and geographical location of the city so that cities from each continent were sampled.

This survey aims to analyse the work done so far in the area of SCs. The article is divided into the following parts: (1) the ‘Definitions of smart city’ section gathers the multiple SC definitions that have been formulated in the literature; (2) the ‘Smart City architectures’ section describes the general technological data pipeline of a SC and some specific architectures; (3) in the ‘Application Domains’ section, we review the taxonomies of the applications to specific domains of the city (such as healthcare and education); (4) the ‘Case studies’ section provides real examples which implement the SC paradigm; (5) the ‘Open challenges’ section presents issues not yet solved in the literature that need further research; and, finally, (6) the ‘Discussion’ section compiles a discussion of each of the previous sections and a summary of the best practices for the implementation of SCs, including the next steps that should be taken inside the research field.

## Definitions of smart city

Even though the SC paradigm is a promising approach, there is little consensus on what characteristics or requirements define a SC or what should humans expect of a SC, as discussed in Cocchia.<sup>2</sup> In this section, we review the literature on the different definitions of the *smartness* of a city. In order to organise this section, we follow other authors’ taxonomy of definitions. Specifically, Cocchia<sup>2</sup> categorises the definitions between (1) technological dimension, (2) human dimension and (3) institutional dimension. Javidrooz et al.<sup>3</sup> present their review of definitions according to the following categories: (1) technology, (2) visions of well-being in the future (shortened as *people*), (3) systems

integration and (4) process. Similarly, Yin et al.<sup>4</sup> make use of four categories: (1) technical infrastructure, (2) domain application, (3) system integration and (4) data processing. In the first two proposals, a definition may have various focuses, therefore it can be placed in various categories. Our aim is to provide a taxonomy of definitions to avoid this multiple assignment. We opted for the following taxonomy proposed by Yin et al.<sup>4</sup> to avoid the later issue: (1) technology-based definitions, (2) domain-based definitions, (3) definitions based on the integration of the system and (4) definitions focused on the data.

### *Technology-based definitions*

The definitions in this section are centred around the importance of the technology, that is, the sole inclusion of the ICTs is enough to make a city smart. Authors like Coe et al.<sup>5</sup> define a SC as the response for the growing pressure of globalisation. The communities around the world begin to sketch the first drafts of the *networked* communities, that is, networks of individuals and firms linked electronically. For Palmisano,<sup>6</sup> a SC is defined by the use of ICTs to sense, analyse and integrate the key information of core systems in running cities. For Washburn et al.,<sup>7</sup> what makes a city smart is the combined use of software systems, hardware and network technologies (referred as smart computing technologies) to improve the services in seven key areas: (1) city administration, (2) education, (3) healthcare, (4) public safety, (5) real estate, (6) transportation and (7) utilities. Similarly, Hall et al.<sup>8</sup> also acknowledge the importance of the sensors, networks, algorithms and other technological advances to design, build and maintain the infrastructure of the city (power, water, transportation and so on). Their aim is to create a safe, environmentally green and efficient city. Although the previous two definitions aim to improve the performance of the city in some domains (which may point that they have a domain-based definition), their emphasis is put on the technologies and, thus, they are categorised as technological definitions. Harrison et al.<sup>9</sup> define a SC as an urban area that exploits operational data, that is, data extracted from traffic, power consumption and so forth, in order to optimise the operations. In their definition, they stress the importance of three features of the city: (1) the near-real-time data obtained from physical and virtual sensors, (2) the interconnection between different services and technologies inside the city and (3) the intelligence from the analysis of the data and the process of optimising and visualising it. Su et al.<sup>10</sup> explain that, in general, a SC is the product of a digital city combined with the IoT. Finally, Harrison and Donnelly<sup>11</sup> define a SC as an environment which is attractive to the new generations. This city should interact with its citizens using digital

interfaces, allowing an instant access to the required information rather than using traditional solutions like waiting in a long queue or using paper forms for requests.

### *Domain-based definitions*

A city comprises several domains such as healthcare, education and government. There is a part of the literature that aims to explain SCs from the point of view of those domains. For example, Odendaal<sup>12</sup> sets the definition of a SC as a region which capitalises the opportunities presented by ICTs in promoting its prosperity and influence. The author shows the importance of the *e-governance* as a way to connect citizens with the city and governments and improve the city governance. Caragliu et al.<sup>13</sup> believe that the *smartness* of a city is achieved when the human and social capital combined with traditional and modern communication systems (transport and ICTs, respectively) augment the sustainable economic growth and the quality of life, taking into account the management of natural resources and through participatory governance. Other authors like Lazaroiu and Roscia<sup>14</sup> propose a general definition of a SC: a city that performs well in some applied domains. For the case of Lazaroiu and Roscia,<sup>14</sup> the domains are smart economy, government, mobility, environment, living and people. Similarly, Giffinger et al.<sup>15</sup> argue that a SC is composed of or defined by 6 characteristics, 31 factors and 74 indicators. The characteristics are broad domains like governance or environment, while the factors and indicators are more specific. In the 'Application domains' section, a literature review of domain applications is provided to extend the possible definitions of a SC based on a taxonomy of domains.

### *Definitions focused on the integration of the system*

In this category, the definitions are focused on the integration of all the elements that compose a city. Therefore, even though the city may have ICTs included in every sector, if the system is not integrated as a whole, the city cannot be considered smart. Cook and Youngblood<sup>16</sup> set the basis of SCs creating the concept of smart homes (pivotal building blocks of SCs), which are intelligent houses where smart environments can be developed. In their concept, they do not define directly what a SC is; instead, they define what a *Smart Home* is: *a house able to acquire and apply knowledge about its inhabitants and their surroundings in order to adapt to the former and meet the goals of comfort and efficiency*. This can be used as a starting point to develop the concept of SCs based on intelligent systems. Moss Kanter and Litow<sup>17</sup> see the city as a connected system, not just separate elements. Therefore, in

contrast to the importance given to the nodes or domains of the network (healthcare, education and so on), the attention in this approach is put on the connections (between healthcare and education, for example). In Dameri,<sup>18</sup> the author makes a literature review of the definitions of SCs and reports a comprehensive definition based on them: a SC is a well-defined geographical area where the cooperation between ICTs, logistics, energy production and so on are able to provide benefits for the citizens such as well-being, inclusion, environmental quality and intelligent development, among others. With a novel point of view, Javidroozi et al.<sup>3</sup> see the city as a company. In their analogy, the suppliers of the company are the service providers of the city, the company's systems integration (sales, marketing, finances and so on) is the city's systems integration (transport, healthcare, education and so forth) and the customers are the citizens. Furthermore, local government or authorities are the managers of the company. Monzon,<sup>19</sup> with the aim of having a criterion to select SC projects, synthesises the definitions of the literature, providing the following one: a SC is an integrated system where human and social capital are combined using the ICTs in order to achieve a sustainable and resilient development with a high quality of life. Although they do not provide their own definition, Petrolo et al.<sup>20</sup> assume the definition of a sustainable and intelligent city thanks to the integration of the services and infrastructure into a whole and using intelligent devices for monitoring and control.

### Definitions focused on the data

In these definitions, the authors put the stress in the transmission or the use of the data. For example, Al-Hader et al.<sup>21</sup> define the *smartness* as the ability of transmitting and receiving the data using the communication protocols. Although this could be categorised as a technology-based definition, as the stress is put on the data, it is classified as a definition focused on data. Yamamoto et al.<sup>22</sup> argue that the foundation of a SC is gathering the data first and, then, provide services using it. Moreover, they emphasise that it is pivotal to use data from houses, as these are the building blocks of a city.

### Smart city architectures

In this section, the common architectures in SCs are presented, as well as specific architectures and adaptations of common ones used on several SC projects.

### Common architectures

Since the creation of the SC paradigm, different researchers have tackled the creation of the most suitable architecture based on ICT solution. Due to the different requirements and daily situations in cities that have implemented SC architectures, these implementations have not been following a standard and, therefore, they have different characteristics. That is, there is not a unique and standardised architecture for SCs; however, there are some popular paradigms that fulfil the requirements cities may have. These architectures are differentiated by the characteristics of the layers in charge of acquiring, processing and making use of the data. Among them, we can distinguish the most popular ones: (1) cloud computing, (2) fog computing and (3) edge computing. These architectures are complementary and can be implemented in the same city, see Longo et al.,<sup>23</sup> for different projects or applications. As Almeida et al.<sup>24</sup> discuss, architecture-level design decisions must be analysed properly, in order to gauge their effect in the final system.

**Cloud computing architecture.** Cloud computing is defined by the National Institute of Standard and Technologies (NIST)<sup>25</sup> as follows:

Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.

This architecture, by default, is splitted in several layers, for example, Infrastructure-as-a-Service (IaaS) or Platform-as-a-Service (PaaS) layers. Each of the layers consumes the services provided from the other layers and also provides them with its own services. Due to the architecture being divided into services, the bases of it are in the decentralisation and computation of the information.

Regarding the projects that used this architecture, Kaur and Maheshwari<sup>26</sup> proposed a healthcare framework based on the presented architecture. Biswas and Muthukkumarasamy<sup>27</sup> developed a framework for security in smart cities that integrates blockchain with IoT devices via cloud computing architecture. Mazza et al.<sup>28</sup> present a mobile cloud computing framework describing the flows of data and operations taking place in the smart city. Khanna and Anand<sup>29</sup> proposed a monitored parking system based on IoT and cloud computing architecture.

**Table 1.** Projects using cloud computing architecture for Smart City projects.

Project	Description
Smart car parking system <sup>38</sup>	An IoT middleware to detect where is the best free parking lot for each user
DIMMER <sup>39</sup>	Collects energy-related data for district management, reduce energy consumption and CO <sub>2</sub> emissions
FLEXMETTER <sup>39</sup>	Smart metering middleware architecture to obtain data from different energy vectors
CiDAP <sup>40</sup>	A Big Data top implementation of the <i>Smart Santander</i> project
VITAL <sup>41</sup>	A Cloud of Things–based architecture for SCs
CityHub <sup>42</sup>	A hybrid cloud infrastructure-based in IoT hubs to develop <i>Smart City</i> data hub applications
SAaaS <sup>43</sup>	An IoT cloud connected devices architecture called Sensing and Actuation as a Service
IoTCloud <sup>44</sup>	A cloud-based IoT middleware which can be used in different IoT-based architectures
City4Age <sup>45</sup>	An EU project which uses a cloud-based IoT storage solution to foster healthy ageing
PrevenIT <sup>46</sup>	A cloud-based implementation to use wearable devices to promote active and healthy ageing
ACTIVAGE <sup>47</sup>	This project connects IoT devices to a cloud repository to elderly monitoring
NITICS <sup>48</sup>	IoT-based platform which uses ultra-wideband technology to monitor elderly citizens. It analyses the acquired data in order to create behavioural patterns or fall detection
ALMANAC <sup>49</sup>	This project develops an IoT and metropolitan access-based networks infrastructures to create a <i>Smart City</i> information system to provide green and sustainable application services
RADICAL <sup>50</sup>	A Big Data–based platform to analyse data obtained from social networks and IoT devices to provide different services such as carbon footprint monitoring, social-oriented urban noise measurement or city reporting applications for the use of urban services
New York City Noise <sup>51</sup>	An architecture to make a model of the noise produced from different sources of New York City such as: complain calls to specific numbers, noise sensors and citizens check-in data

IoT: Internet of Things; SCs: smart cities.

**Fog computing architecture.** Fog computing was coined by Bar-Magen Numhauser<sup>30</sup> in CISCO as an extension of the Cloud computing paradigm. This extension is done by improving the performance and the responsibilities of the end-nodes of the network. Furthermore, the differences rely on the location of the data storage and processing devices installing them in the same local network as the devices acquiring the data and, therefore, creating a low-latency communication between them. Due to these characteristics, this architecture is used for applications where low latency is required, geographically dispersed infrastructures or applications where the data acquired is not practical to send to the cloud and wait for its processing.

Regarding the projects that used this architecture, Bruneo et al.<sup>31</sup> present a smart mobility use case using fog computing paradigm. Chen et al.<sup>32</sup> developed a dynamic video stream processing scheme based in fog computing architecture to offer real-time information processing and decision making. Santos et al.<sup>33</sup> proposed a fully integrated node management system to exchange application information between nodes. Barik et al.<sup>34</sup> created a fog computing–based framework for mining analytics from geospatial data.

**Edge computing architecture.** Edge computing is a paradigm that follows the statement that if the data are generated at the edge of the network it should also be more efficient to process that data at the edge of it. This is a similar approach to fog computing but with the

difference that fog focuses more on the infrastructure and edge on the things side. It is important to note that the edge is not always the smallest sensor in a network but the bridge between the local network and the cloud.

Regarding the projects that used this architecture, Shi et al.<sup>35</sup> explain why this paradigm is different from the ones mentioned before and in which occasions it would be convenient to implement it. Taleb et al.<sup>36</sup> propose a project to enhance users experience of video streaming in SCs using mobile edge computing. Wang et al.<sup>37</sup> present a cloud and edge architecture–based system for cyber-physical-social systems.

Several projects have used the architectures presented in this section. These projects tackled the problem of SCs providing different end-user solutions. As we have stated before every city is different so the architectures may adapt to them. Furthermore, the architectures discussed above are not excluded from each other so the same city can implement disparate architectures for different services. Tables 1–3 depict various projects and software solutions proposed in the literature that implement or support creating services in different cities and with diverse architectures.

## Application domains

A SC comprises various domains where the introduction of the ICTs creates a pivotal change. The ‘Review of the taxonomies of application domains’ section compiles the different taxonomies of application domains

**Table 2.** Projects using fog computing architecture for Smart City projects.

Project	Description
Stack4Things <sup>52</sup>	An OpenStack-based IoT framework that allows to manage IoT devices without caring about their physical location, their network configuration or their underlying technology. This is currently being used in several Italian countries
Hierarchical Fog Computing <sup>53</sup>	A hierarchical distributed fog computing architecture to support the integration of massive number of infrastructure components and services in the future SCs
Urban Surveillance Video Stream <sup>32</sup>	A dynamic video stream processing scheme using fog computing to meet the requirements of real-time information processing and decision making
Fog orchestration for SC apps <sup>33</sup>	A fully integrated fog node management system alongside the foreseen application layer Peer-to-Peer (P2P) fog protocol based on the Open Shortest Path First (OSPF) routing protocol for the exchange of application service provisioning information between fog nodes
FogGIS <sup>34</sup>	A fog computing-based framework for mining analytics from geospatial data

IoT: Internet of Things.

**Table 3.** Projects using edge computing architecture for Smart City projects.

Project	Description
Follow-me-edge <sup>35</sup>	An approach to enhance users' experience of video streaming in the context of smart cities using the concept of mobile edge computing
Follow-me-edge <sup>36</sup>	An approach to enhance users' experience of video streaming in the context of smart cities using the concept of mobile edge computing
CPSS cloud-edge <sup>37</sup>	A cloud-edge computing framework to develop and implement cyber-physical-social system applications on SCs

SCs: smart cities.

used in the literature while the following sections review the literature on specific categories following the taxonomy presented at the end of the 'Review of the taxonomies of application domains' section.

### Review of the taxonomies of application domains

Washburn et al.<sup>7</sup> reference seven critical infrastructure components and services which can be interpreted as application domains: (1) city administration, (2) education, (3) healthcare, (4) public safety, (5) real estate, (6) transportation and (7) utilities.

Giffinger and Gudrun<sup>54</sup> define the *smartness* of a Smart City with six characteristics, where the city should perform well, that can be considered general smart city application domains: (1) smart economy, (2) smart people, (3) smart governance, (4) smart mobility, (5) smart environment and (6) smart living.

In a layered fashion, Harrison and Donnelly<sup>11</sup> divide various subdomains into five categories: (1) social systems, (2) services, (3) resources, (4) infrastructure and (5) natural environment.

Neirotti et al.<sup>55</sup> create a taxonomy of domains divided into two big categories: (1) hard and (2) soft domains. In hard domains, the improvement in the

sustainability is given by the deployment of ICT systems (natural resources management, public security and so forth), whereas in soft domains the ICT systems have a limited role and the users are free to use them (education, e-government and so on).

Liu and Peng<sup>56</sup> classify the applications of SCs into three areas: (1) life enrichment (home, community, healthcare and education), (2) public administration and service (public safety supervision, food safety supervision, smart traffic and environmental protection) and (3) widescale resource management (water, electricity and agriculture). Their approach draws on their definition of Smart City: one that enriches citizens' lives and upgrades urban management and industry while protecting the environment.

Yin et al.,<sup>4</sup> based on their SC definition, create four big branches in which they divide the taxonomies used in the literature: (1) business-related categories, (2) citizen-related categories, (3) environment-related categories and (4) government-related categories.

Lombardi et al.,<sup>57</sup> after a literature review, gather 60 indicators from two focus groups with experts. These are divided between five clusters: (1) smart governance, (2) smart economy, (3) smart human capital indicators, (4) smart living and (5) smart environment. Albino

**Table 4.** Domain taxonomy used to categorise different SCs approaches following Yin et al.<sup>4</sup>

Domain	Subdomain	References
Business-related domains	Advertisement	60–64
	Agriculture	65–67
	Entrepreneurship	68–70
	Enterprise management	71–73
	Logistics	74–76
Citizen-related domains	Transaction	21, 27, 77–79
	Education	80–84
	Entertainment	85–91
	Healthcare	45, 92–100
Environment-related domains	Public transport	101–106
	Smart traffic	107–113
	Tourism	114–120
	Building	121–125
	Housing	126–129
	Pollution control	130–132
	Public space	133–135
	Renewable energy	136–139
	Smart grid	140–143
	Waste management	144–146
Government-related domains	Water management	147–149
	City monitoring	133, 150, 151
	E-government	152–155
	Emergency response	97, 156, 157
	Public safety	158–160
	Public service	10, 69, 161–163
	Transparent government	161, 164–166

et al.<sup>58</sup> adapt the later taxonomy and relate each cluster with an aspect of urban life: (1) smart economy with industry, (2) smart people with education, (3) smart governance with e-democracy, (4) smart mobility with logistics and infrastructures, (5) smart environment with efficiency and sustainability and (6) smart living with efficiency and sustainability.

Gharaibeh et al.<sup>59</sup> present a taxonomy based on their literature review including (1) smart lighting, (2) smart traffic management, (3) smart grid, (4) smart emergency and (5) smart health.

Even though different authors specify similar categories, they end up defining very tight subdomains with extensive descriptions. This may pose a problem, as specific features of SCs could be positioned inside different categories, that is, they do not belong to a single category. Therefore, for our literature review, we chose to divide the application domains into fewer categories with a broader extension following Yin et al.<sup>4</sup> In the following sections, we present the summary of applications of specific domains inside the SC paradigm divided into the following clusters: (1) business-related domains, (2) citizen-related domains, (3) environment-

related domains and (4) government-related domains. We also present a summary of the literature on application domains in Table 4.

### Business-related domains

This category, as defined in Yin et al.,<sup>4</sup> includes the following subdomains: advertisement, agriculture, entrepreneurship, enterprise management, logistics and transaction. We review proposals done in each subdomain one by one.

**Advertisement.** Advertisement has been integrated in our lives by means of the technology, since the city becomes an advertisement showcase where the citizens are the main target. On one hand, it makes advertisement reach a wider range of the population but, on the other hand, it can make the advertisement invasive. This balance makes the difference between providing good services and creating a rejecting perception. Understanding how to address the population is paramount for getting satisfactory experiences and hence increase the engagement. Finn and Wadhwa<sup>63</sup> analyse the ethics of smart advertisement, as they identify smart surveillance practices behind advertising strategies. The authors mention issues with identifiability, inequality, a chilling effect, the objectification, exploitation and manipulation of consumers as well as information asymmetries. They conclude that existing and proposed regulatory initiatives do not provide adequate consumer and citizen protection. Yang et al.<sup>62</sup> analyse the integration advertising model that combines the effect of mobile technologies and the advertising itself. In Salo,<sup>60</sup> this type of advertising is called *m-advertising*. They inspect its value from the industry and the consumer viewpoint. Their study points out that the management of the 5Cs is the key of the value of the m-advertising: (1) content, (2) cross-media marketing, (3) campaign management, (4) customer database and (5) carrier cooperation. Another technology used in advertisement is augmented reality (AR), as in Shiva and Raajan,<sup>61</sup> where they employ the AR for advertising different products of the same party. To change behaviours such as smoking habits, Carter-Harris et al.<sup>64</sup> recruit long-term smokers for a lung cancer analysis. They found that Facebook can be a good medium for recruitment as it is more cost-effective and effective, in terms of costs and number of participants, than other channels.

**Agriculture.** Cities and their population are growing at an uncontrollable rate (<http://www.worldometers.info/world-population/>) and a consequence of this is the reduction of land used for crops and agriculture. Cities have faced this potential problem with different

approaches. The first one is the control of agriculture by adding sensors and management systems to it. In Lipper et al.,<sup>65</sup> the authors propose the Climate-smart Agriculture (CSA) as a mean to support and transform agricultural systems to ensure food security and taking into account the issue of the climate change. Also, in Baranwal et al.,<sup>66</sup> an IoT-based device to ensure the security of crops and grain warehouses against diseases and rodents is proposed. Both systems explained above focus on the traditional agriculture located outside of cities. Otherwise, the second approach focuses on generating a new style to mitigate the loss of fertile land by the expansions of cities by introducing farming into the city itself. In Kalantari et al.,<sup>67</sup> the authors review the insights of vertical farming through the analysis of 62 different papers. The review explains how the introduction of farming in cities can help to reduce food poverty and increase the security over its production, as well as generating jobs for the people leaving villages to join cities.

**Entrepreneurship.** Smart cities, through services and data generated by citizens, provide the supporting infrastructure so that new companies can be created, especially in services and knowledge economies. Harvey<sup>68</sup> explores the shift from managerialism (the focus on local provision of services, facilities and benefits to urban populations) to entrepreneurialism (fostering and encouraging local development and employment growth) in urban governance. With the technological advances of the last years, new ways of understanding the *smart entrepreneurship* have arisen. Hollands<sup>69</sup> discuss if there is any difference between the concept of a SC and a high-tech variation of the *entrepreneurial city*. Datta<sup>70</sup> explains the situation of Dholera, the first SC in India. In addition, the authors explain the entrepreneurial urbanisation model, which is focused on promoting audacious policies by means of laws.

**Enterprise management.** SCs may provide profitable opportunities for enterprises and their management. As they have both appropriate infrastructure and tools, efficient operating can lead to an increase in the city's business activity. In this sense, Mulligan and Olsson<sup>73</sup> provide a review about the architectural implications of SC business models. They also give examples of possible business models that may rise in SCs. In addition, they remark that those business models create new opportunities, but also new challenges for the telecommunication and ICT players, and city leadership. In Chourabi et al.,<sup>72</sup> the importance of smart business and enterprises for SCs is observed. Furthermore, they identify the economy as a growth engine for SCs as it does not only provide economic wealthiness but also fosters job creation and improves the life quality of

their citizens. Authors in Allwinkle and Cruickshank<sup>71</sup> also discuss about enterprise management and the need to shift their architectures and models to fit into the SC paradigm.

**Logistics.** This term refers, in general, to the flow of things from one point to another, involving organisation and implementation of complex processes. In SCs, the ICT is a key factor in logistics as a competitive factor. However, only big enterprises can afford such systems and, thus, small to medium companies have limited options. In order to alleviate this, Kawa<sup>74</sup> proposed the SMART model, based on cloud computing and agent technologies to make (1) the management of information easier and (2) get cheaper access to logistics management systems. Nowicka<sup>75</sup> explains that there is an urge to make a more efficient and effective logistics management that takes into account the cost and the environmental impact (i.e. pollution, noise and so forth). They present the SC logistics on the cloud computing model as a tool to solve this problem. Regarding sustainable logistics, Pelletier et al.<sup>76</sup> review the current state of electric cars for goods distribution. They analyse their strengths and weaknesses and conclude that, although optimisation can be done for refuelling and also for delivery routes, due to the current limitations of the battery technology, their usage is only suitable for last-mile urban deliveries.

**Transaction.** Transactions are at the core of business processes. Simplifying and automating them for enterprises and local businesses is an important feature of SCs. Authors in Al-Hader et al.<sup>21</sup> identify *Transaction Management* as one of the main components of process management in SCs. They point out the relevance of conducting business transactions while simultaneously optimising the IT applications and infrastructure where those transactions are executed. Perera et al.<sup>78</sup> investigate the concept of sensing as a service model. In the later, transactions are of major relevance as they register communications between devices, being businesses one of the stakeholders involved. Blockchain technology<sup>77</sup> does perfectly fit for transactions in SCs. It does actually hold a distributed list of records using cryptographic techniques in a verifiable and permanent way. Few conceptual frameworks have been presented for integrating Blockchain into SCs, for example, the ones proposed by Sun et al.<sup>79</sup> and Biswas and Muthukkumarasamy.<sup>27</sup> Being Blockchain a rising topic, more work will appear in the years to come.

#### **Citizen-related domains**

Yin et al.<sup>4</sup> define the following subdomains inside this category: education, entertainment, healthcare, public

transport, smart traffic and tourism. We review proposals done in each subdomain one by one.

**Education.** As cities grow, the importance of sustainability becomes more apparent as a means to solve urban issues.

The raise of SCs initiatives reveal how cities can move towards a more sustainable future. To achieve this goal, Wolff et al.<sup>83</sup> state that SCs require citizens with 21st-century skills in order to be able to drive SC innovations actively. Therefore, education plays a fundamental role in the formation of these *smart citizens*. Although traditional education has remained in proper academia environments, such as schools or universities, the learning environments have been expanded to more places around the city. Zhuang et al.<sup>84</sup> categorise SC learning environments as follows: (1) families, (2) schools, (3) communities, (4) workplaces and (5) public places. The decentralisation of education into different locations within the city and the inclusion of ICT elements from SCs into education opens a door to new education services with multiple interaction channels that aim to support students in their online and real-world learning activities. As a means to determine what characteristics the different learning environments should have, Hwang<sup>82</sup> define a context-aware ubiquitous learning framework for smart learning environments capable of instant and adaptive support to learners. The paradigm of SCs also facilitates the inclusion of citizens into scientific research studies with Citizen Science (CS). Roy et al.<sup>80</sup> define citizen scientists as volunteers who engage in scientific thinking, in all the steps of the scientific process and whose contributions go beyond the collection and processing of ecological or environmental data. Thanks to the benefits that CS brings to both scientist community and the citizens, the European Commission has fomented CS with the funding of multiple projects that address this topic around Smart Cities initiatives. As stated in Craglia and Granell,<sup>81</sup>

SCs are not only about ICT, energy and transport infrastructures. SC are about smart citizens, who participate in their city's daily governance. They are concerned about increasing the quality of life of their fellow-citizens and about protecting their environment. Technology may facilitate, but it is no solution per se. Therefore, CS projects in SC are more than collecting data: they are about raising awareness, building capacity, and strengthening communities.

**Entertainment.** The use of technology can also provide new ways of entertainment or enhance already existing proposals. For example, improving cultural activities through the addition of the ICTs, such as in Prandi

et al.<sup>91</sup> In the later, the authors point out the unofficial source of data generated from tourists in cultural heritage places. They propose a system to generate personalised urban paths and share multimedia about those points of interest, engaging users using gamification elements. A mobile application prototype was created to assess the feasibility of their approach. Nijholt<sup>86</sup> investigates how sensors and actuators in the urban environment can create a *playable city* and engage users in their daily activities. In fact, these data can later be used to analyse the behaviours and preferences of the citizens. Nijholt<sup>90</sup> reviews some playful city proposals, analyses if these projects are adapted to users not qualified as *smart* and, finally, compares these cities with those that aim to be child-friendly. Inside SCs, an important source of entertainment comes from the use of augmented reality games (ARGs) that are integrated with the cities. This kind of applications, location-based, can be beneficial for the health of the players (as they motivate the users to move), although they have poor usability and privacy issues. Andujar et al.<sup>87</sup> discuss about the humour interaction implications from playing Pokemon GO in the real world and provide guidelines on incorporating humour in mobile ARGs based on what players have experienced. Hamari et al.<sup>89</sup> also analyse the case of Pokemon GO. With the results from an online survey, they argue that the game enjoyment, outdoor activity, ease of use, challenge and nostalgia are associated with reuse intention. Nijholt<sup>88</sup> investigated the role of humour in game environments and compared it to the humour that may appear or is created in playful and SCs. Edirisinghe et al.<sup>85</sup> try to go one step further from playful cities, where play is a continuous process of the city living that is integrated in the infrastructure of the SC, adapting the later to the former.

**Healthcare.** The rapid adoption and evolution of mobile devices that enable ubiquitous computing have opened new research domains like mobile health for remote monitoring. The recent conceptualisation of SCs is changing how we think about healthcare and brings the opportunity to offer new city oriented healthcare services. In Solanas et al.,<sup>95</sup> they introduce the concept of *smart health* as a complement to mobile health; the former adds context-awareness from the sensing structure of SCs. In addition, they explore the opportunities and challenges of *smart health* that are to overcome yet. Holzinger et al.<sup>96</sup> review the application of context-aware SC structures paradigm to *smart health* environments applied to hospital monitoring. The former aims to enhance emergency assistance, autonomy and comfort of patients. The current trend in patient monitoring consists in deploying a network of sensors in the body

of the patients (as in the work by Movassaghi et al.<sup>94</sup> or around the ambient.<sup>93</sup> This enables the capture of vital signs and the behavioural- and activity-analysis of patients for event detection, prevention, and prediction.<sup>92</sup> As patient monitoring use cases, Mulero et al.<sup>45</sup> and Almeida et al.<sup>99</sup> present the City4Age project, whose goal is to enable age-friendly cities. To do so, the project has created a set of ICT tools and services that can be deployed in cities in order to improve the early detection of risk related to frailty and Mild Cognitive Impairments, providing personalised interventions to promote behaviour changes. To do so, City4Age detects behaviour changes using activity recognition techniques, as stated in Azkune and Almeida.<sup>100</sup> Hussain et al.<sup>97</sup> propose a people-centric sensing framework for the healthcare real-time monitoring and emergency care of elderly and disabled people. The platform provides a service-oriented emergency response using context manipulation from the mobile devices. Bilbao-Jayo et al.<sup>98</sup> propose an approach for active ageing in cities by combining a social network with information inferred using in-home sensors.

**Public transport.** One of the main additions to public transport in the last years is the use of smart cards, which can be an important source of information.<sup>104</sup> Blythe<sup>101</sup> analyses what smart cards are, why they are being recently used and the benefits and impact on the public transport domain. Bagchi and White<sup>102</sup> consider their use for behavioural analysis. They identify a weak point in their use for analysing behaviours: travel length or purpose is not recorded and requires a complementary survey. Agard et al.,<sup>103</sup> with the same problematic, present a transportation planning for their behavioural analysis that combines the use of the smart card with data mining. Devillaine et al.<sup>105</sup> present a method to detect and estimate the location, time, duration and purpose of the use of public transport based on the smart cards and other information. The method was put in practice in two cities: Santiago, Chile, and Gatineau, Quebec, Canada. Yonezawa et al.<sup>106</sup> built and tested two systems, named *Eno-kama Tnfo-Surfboard* and a smile coupon, which aim to avoid build-ups in main station of Fujisawa city. To do so, the systems try to convince potential passengers to take the train from the secondary station in order to distribute them over two different stations. The former system collects and visualises data about the secondary's station area (weather, events, temperature and so on). With respect to the latter, this system provides coupons to spend in the other area depending on the weather and the smile of the user when passengers take a photograph for the system.

**Smart traffic.** With the increasing number of vehicles, traffic issues (jams and congestions) are becoming a common event in cities. Consequently, other problems such as the number of accidents, the pollution, time spent in the road and so forth arise. The traffic management systems (TMSs) are pivotal to solve this, although they need to be improved to become more efficient. Djahel et al.<sup>112</sup> present a survey on the different technologies in TMSs and a study on the security threats that can affect drivers and the efficiency of the TMSs. De Souza et al.<sup>113</sup> review the available TMSs in the literature, classifying them into three categories: (1) information gathering, (2) information process and (3) service delivery. Cambridge Systematics<sup>108</sup> research in traffic congestion trends, concretely in United States, and describe approaches to reduce it. Araújo et al.<sup>109</sup> propose CARTIM, a proposal to reduce traffic congestion by localising it through a fuzzy-logic system. Meneguette et al.<sup>107</sup> also mention that one of the consequences of the traffic congestion is economical, but it also weakens the quality of life of the citizens. They propose a smart traffic system called UNCODES, based on inter-vehicle communication. The outcome of their simulation is that the system reduces the travel time, CO<sub>2</sub> emission and fuel consumption. Similarly, De Souza et al.<sup>110</sup> and De Souza and Villas<sup>111</sup> also use the inter-vehicle communication in their approach to reduce the greenhouse emissions. They state that, in 2012, a 28% of these emissions in the United States came from transport.

**Tourism.** More and more cities are embracing ICTs by starting SC initiatives. Although one the main objective of SCs is to improve the quality of life of their citizens, this paradigm also impacts other industries that focus on offer services to people that do not reside in that city, such as tourists. In Buhalis and Amaranggana,<sup>114</sup> they introduce the concept of *smart tourist destinations*, in which SC services and amenities can enrich the experiences of traditional tourism and, therefore, can attract more tourist.

In addition, they review the literature of SCs focused on tourism, where they gather a list of smart tourism oriented applications. In Gretzel et al.,<sup>116</sup> they go deeper into the domain by defining smart tourism as a whole. They identify three main components within that concept: (1) smart destinations, which are cities that integrate ICTs to improve not only the quality of life of their residents but also the visitors' one too; (2) *smart business ecosystem* that promotes the collaboration between public and private organisations for data sharing; and (3) *smart experience* enhancement from real-time monitoring for demand forecasting and

resource coordination to interactive services that are personalised and context-aware. Another tourism-related application is the implementation of the smart kiosks. These are a kind of urban furniture that link the city and their citizens, aiming to open the city to visitors<sup>118</sup> and constitute an appropriate mean of providing event-aware and localised information to the right audience.<sup>119</sup> Smart kiosk platforms offer improved and contextual aware services for the cities, features enabling services as route finding, city guide or local events information to support travellers.<sup>115,117</sup> A successful case of smart kiosk, the first of its kind, was implemented to replace all payphones in the five boroughs in New York.<sup>120</sup>

### *Environment-related domains*

Following Yin et al.,<sup>4</sup> the following subcategories are included inside this domain: building, housing, pollution control, public space, renewable energy, smart grid, waste management and water management. We review proposals done in each subdomain one by one.

**Building.** In the last few years, there has been a big investment in experimentation to create services that match with SCs. This experimentation lead to isolated services and experiments because of the lack of planning to create a standardised experiments to create a homogeneous city. This situation is described by Cugurullo<sup>125</sup> with the example of two cities that had failed in their strategy of creating an eco-friendlier SC. The author describes this phenomenon as Frankenstein urbanism for the relation that it has with the monster created in the book written by Mary Shelley. To avoid this, Rathore et al.<sup>123</sup> propose an architecture based on IoT and Big Data for urban planning and building in SCs. The authors state that the use of a set of interconnected devices to acquire data from the city and its analysis would be useful for future urban decision-making. For example, the data collected from water-related sensors would be useful to create new dams or to prevent future damage by floods. Regarding the buildings that populate cities, there is a research line that tries to make them sustainable by converting them in zero energy buildings (ZEB), which produce zero carbon emissions in the period of 1 year. In Kylili and Fokaides,<sup>122</sup> the authors demonstrate that ZEB contribute to energy efficiency, conservation and generation of renewable energy. Marszal et al.<sup>121</sup> present a review of the definitions given to ZEB over time and propose a standard framework to calculate their efficiency. The paper concludes stating that the most important issues to have into account are (1) the connection to the energy infrastructure, (2) energy efficiency, (3) the indoor climate and (4) the building-grid

interaction. In order to create more self-sustainable buildings and focusing in the grid of the building, Kumar et al.<sup>124</sup> propose an architecture based on nano-grids for buildings. The presented architecture generates energy from renewable sources as photovoltaic panels and wind. The idea of nano-grid is that every building is capable of fulfilling its energy requirements and, in the worst condition, the energy would be taken from the city grid.

**Housing.** The other types of buildings that, mostly, populate the cities are the dwellings. Homes have seen their capabilities increased since the creation of IoT devices, improving the quality of life of the inhabitants. In Raisul Alam et al.,<sup>126</sup> a smart home is defined as an application of ubiquitous or pervasive computing applied in a home environment. This review explains the present taxonomies for the devices that could be included in smart homes, as well as the communication protocol and technologies used. In terms of a less technological view of smart homes, Risteska Stojkoska and Trivodaliev<sup>127</sup> expose the possibility of adding renewable energy generators to households in order to make them eco-friendlier and more efficient. They also discussed the lack of a unified framework for all the IoT devices that could be added to a home. Thus, the authors propose a cloud-based framework that unifies all the information gathered from the IoT devices to add value to them. Specifying more the possible applications that the smart homes could have, Tan et al.<sup>128</sup> propose an algorithm that monitors and classifies the events that occur in the front door of a smart home, this application is very useful for people who suffer from dementia or are developing it. Thanks to this algorithm, it is possible to detect when a person forgets something inside the house by monitoring the activities identified in the front door and, therefore, it can be used to recognise early-stage dementia. In Chen et al.,<sup>129</sup> they propose another concept for smart homes which allows users to interconnect appliances with indoor crops. The authors explain how raising houseplant can help people to improve physical and mental health. Therefore, they propose an architecture to create a cloud-based platform to manage and visualise the interaction between inhabitants and plants.

**Pollution control.** Due to the increase on the number of vehicles and the population derived from it, cities have seen their air quality degraded. There are several SC research studies that have proposed different approaches to have more control over the air quality and, thus, keep citizens informed of its condition. In Mehta et al.,<sup>130</sup> they propose an architecture based on sensor and video analytic to measure the emissions produced by traffic. Moreover, Peng et al.<sup>131</sup> focus their

work on air and water pollution by employing air and humidity sensors. Furthermore, they propose a video monitoring system equipped with an image recognition system in order to detect fires and quickly notify the firefighters when this occurs. Dutta et al.<sup>132</sup> propose an architecture called *AirSense* that involves citizens more actively in the evaluation of air quality. Their system is based on a portable device called *Air Quality Monitoring Device* that collects air composition in order to determine the air quality. These devices are carried by volunteers that, connected through their phones, send the data to the *AirSense* project. Finally, these data are received by all the citizens that access their platform.

**Public space.** Apart from buildings, cities have to develop green zones as they bring benefits to both citizens and the environment. To foment this, the European Commission has awarded cities that have consistent actions in reducing environmental impact with a title and a prize ([http://ec.europa.eu/environment/europeangreencapital/index\\_en.htm](http://ec.europa.eu/environment/europeangreencapital/index_en.htm)) since 2010. Cömertler<sup>134</sup> reviews the different green areas in the awarded cities, which even after being awarded, continue with the project of becoming friendlier with the environment. For example, Vitoria-Gasteiz, located in the north of Spain, received the award in 2012. The city has 32.67% of its area covered by green zones and it is surrounded by a set of parks called the Green Belt, which is connected with the centre of the city and highly contributes to reduce the environmental impact. Filipponi et al.<sup>133</sup> explain a unified system that adds technology to public spaces for their inspection and management. Furthermore, the authors introduce a use case in a subway station, where explanations on how to use the proposed system are given, instead of an older one in which devices are not interconnected, enhances communication of emergencies to passengers and operators. As Lau et al.<sup>135</sup> state, farther from knowing if something unusual is happening in a public space, it is also important to know the usage that the public spaces have. In this research, the authors propose a data processing model for public spaces based on sound and motion sensors. The manuscript explains how the model works in an experiment done within a public park and in different weather conditions. They also conclude that this system allows public administration to know if a public space needs changes to offer a better service to citizens.

**Renewable energy.** Energy generated by renewable energies is increasing rapidly and reached the 29% of all the energy generated in the European Union. However, the fossil fuels are still the biggest contributors to the power grid, being the 42% of the energy generated, as

collected in a study (<https://www.eea.europa.eu/data-and-maps/indicators/overview-of-the-electricity-production-2/assessment>) written in 2017. Mathiesen et al.<sup>136</sup> focus in the actual energy generation methods and how the fuel consumed by different elements in those scenarios is used. Throughout the manuscript the authors explain the improvement that the introduction of renewable energies in the energy production cycle can make and the decrease of fuel needs for the same electricity generation. Following this work, Connolly et al.<sup>137</sup> present a study about the impact that the consumption of 100% renewable energy would have in the European Union and a transition plan to a smart energy system is proposed in it. The authors focus in the urge of decreasing nuclear energy until getting rid of it, the importance of heat savings and the electric vehicles. For the transition to a complete renewable model, there are multiple fields to consider: (1) energy generation, (2) storage transportation, (3) consumption and (4) the models that SCs should implement. These categories, called intervention areas, are defined by Calvillo et al.<sup>138</sup> Apart from the fields cited, the authors propose three more layers that are transversal to them: hardware, communication and intelligence. Throughout the manuscript, the different intervention areas are studied and a summary of different technologies is done. Finally, Kammen<sup>139</sup> states that as the consumers of the 75% of the created energies are the cities, there is a need of introducing renewable energies inside the components that build cities in order to make them energetically sustainable.

**Smart grid.** Since cities are increasing in size, the need for better and more efficient grids has arisen. In several countries, the actual grid infrastructure is still unidirectional. This entails a great loss of energy because of the wastage in the distribution and the problem of energy retention. Moreover, this old system suffers from high maintenance costs and scalability problems. Hence, the development of the Smart Grid (SG) will bring several benefits to SCs as stated by Farhangi.<sup>140</sup> In order to develop better grid infrastructures, Fadel et al.<sup>142</sup> review the most popular wireless sensor and communication protocols. In the manuscript, the authors propose a roadmap for gradually implementing SG in cities. They propose the integration of existing services in modern platforms to generate new services for citizens and energy consumers. One of those services is proposed by Moon and Lee,<sup>143</sup> the authors developed an algorithm to create a bidirectional communication between houses and general grid in order to lower the power consumption, achieved through the demand response model. This model incentive using the most energy consuming devices during the time the energy demand is lower so that large energy demand peaks are

avoided. Mwasilu et al.<sup>141</sup> research the impact and interaction that electric cars have with the smart grid. The authors expose that cars can actuate as regulators for voltage and frequency in SGs. In fact, the reviewed architecture called vehicle-to-grid creates a bidirectional energy flow between cars and SG in order to fulfil the consumption and demand needs of both of them.

**Waste management.** Cities are growing in population and size and so is doing the waste generated by citizens. The daily collection of this waste generates traffic problem in crowded cities due to the slowness of the garbage collection process. Anagnostopoulos et al.<sup>146</sup> discuss about this problem and present the different approaches taken by several SCs to cut down this problem. Among these, most of the models use sensors installed in the containers to check for their status and trigger collections or repairs if necessary. Aazam et al.<sup>144</sup> propose an infrastructure to create smart containers capable of detecting their filling status and notifying the trash collectors when they are nearly full. Moreover, through some screens, these containers show the filling status to citizens, making them take part in recycling and showing them which are the containers that still have space. Furthermore, the data generated by the containers and trash collectors are sent to the public administrations to be used in the process of optimisation of these processes and to reduce the environmental impact. However, in cities, not all the waste generated can be collected with a collection truck; large wastes such as home appliances or furniture are discarded by citizens every day. Król et al.<sup>145</sup> propose a model for minimising and creating more efficient routes in large waste collection processes. Their solution is based on genetic algorithms, and these algorithms are used for route creation and web-based communication for the citizens to notify the collection service of new drop points.

**Water management.** Water has always been one of the most important resources for cities, that is why many of them have established and grown next to rivers or seas. The use of this important resource has to be managed and controlled in order to make a sustainable use of it. Parra et al.<sup>147</sup> present a sensor able to monitor the salinisation of water in aquifers. This utility allows us to know when the fresh water is becoming salty water and which are the causes. In addition to the water salinisation problem, cities and industrialised zones have experimented the leakage of heavy metals, which present a serious health problem for the live beings, including humans. To face this problem, Lin et al.<sup>149</sup> have developed a cheap sensor that can identify the presence

of a variety of heavy metals in fresh water. As important as the water contamination detection is where the contamination is detected. Zhao et al.<sup>148</sup> study about optimal sensor placement, with the main purpose of managing the water distribution properly so the contaminated water consumption is reduced.

### Government-related domains

As defined in Yin et al.,<sup>4</sup> the category comprises the following subdomains: city monitoring, e-government, emergency response, public safety, public service and transparent government. We review proposals done in each subdomain one by one.

**City monitoring.** It is the task of local governments to monitor behaviour and activities to ensure the proper functioning of the city. Monitoring government-enabled services is responsibility of the local governance and is tightly related to other domains presented in this survey. Batty et al.<sup>150</sup> tackle monitoring *water management* and *electrical grid* to improve the efficiency, equity and quality of life for its citizens in real time. Filipponi et al.<sup>133</sup> introduce an event-driven architecture for monitoring public spaces with heterogeneous sensors. Kitchin<sup>151</sup> state the following:

pervasive and ubiquitous computing and digitally instrumented devices built into the very fabric of urban environments (e.g., fixed and wireless telecommunication networks, digitally controlled utility services and transport infrastructure, sensor and camera networks, building management systems, and so on) that are used to monitor, manage and regulate city flows and processes, often in real-time, and mobile computing (e.g., smart phones) used by many urban citizens to engage with and navigate the city which themselves produce data about their users. Hence, city monitoring is done by capturing data from digital devices located within the city. Properly processing this data is a key factor for better decision making and automated control of SCs.

**E-government.** E-government (short for electronic government) is the use of electronic communications devices, computers and the Internet to provide public services to citizens and other people in a country or a region. In Gil-García and Pardo,<sup>153</sup> success factors for e-governments are presented. The authors identify risk understanding and management as significant properties for successful e-government initiatives. Bonsón et al.<sup>154</sup> introduce the concept of *open government* and provide principles, functions and technological enablers to achieve this participatory model of e-government. Bernardo<sup>155</sup> and Pereira et al.<sup>152</sup> start to address the concept of *smart governance* which goes beyond e-

government. This refers to a model of governance which enables city stakeholders, particularly citizens, to efficiently participate in decision-making processes that improve the quality of life in cities.

**Emergency response.** This subdomain comprises the proposals of organisation and management of the resources and responsibilities for dealing with all humanitarian aspects of emergencies. The aim is to reduce the harmful effects of all hazards, including natural disasters. Local governments need to assist emergency services and assess their appropriate functioning. As previous subdomains, emergency response covers a wide spectre of applications. In Dimakis et al.,<sup>156</sup> a simulation tool for smart emergency response scenarios is described. This tool addresses unique needs for emergency situations where appropriate decision making can save many people's life. Other approaches, such as the one of Djahel et al.,<sup>157</sup> engage road traffic issues such as congestion or accidents and give a solution to reduce the latency of emergency services for vehicles like ambulances and police cars when responding to emergency calls. Health and emergency-care for the elderly has also been studied by Hussain et al.<sup>97</sup> They state that a SC should be able to efficiently deal with emergency scenarios and elderly need special attention.

**Public safety.** Public safety consists in protecting citizens, people, organisations and institutions against possible threats to their well-being. A desirable characteristic for SCs is the capacity of providing ICT-powered high-quality safety measures for citizens. Various cities have already started partnerships with companies like IBM to work on different fields, with urban safety management among them.<sup>159</sup> Cities may apply ICTs to enhance public safety in several manners and domains, for instance Barba et al.<sup>158</sup> suggest ad hoc networks to facilitate communication between vehicles and the city infrastructure to increase safety. In Jin et al.,<sup>160</sup> a framework to create SCs through IoT is proposed. One of the strengths of the framework is the ability to continuously monitor the city environment to ensure appropriate environmental health and safety standards.

**Public service.** Public services are those provided by local governments to people living in the cities they manage. Those services can be directly provided through public infrastructure already established in the city or injecting money into developing and providing new services for citizens. ICTs are crucial for the development of a SC. In public services, as stated in Hollands,<sup>69</sup> Nam and Pardo<sup>161</sup> and Su et al.,<sup>10</sup> the introduction of technology within this services enhances them towards SC. For instance, Emaldi et al.<sup>162</sup> introduce the co-creation of

urban apps based on the collaboration of different stakeholders (citizens, private companies, research institutes and public administrations), whereas Aguilera et al.<sup>163</sup> create an open platform for the generation of user-oriented Internet services making use of the data generated by users' smartphones and from the different cities' open data platforms. Therefore, users act as producers, producers and consumers of the data.

**Transparent government.** Transparent government holds that citizens have the right to access documents and proceedings of governance for public supervision. According to Nam and Pardo,<sup>161</sup> transparency and accountability are significant factors for institution and SCs. In the review from Paskaleva,<sup>164</sup> the importance of communication between the different stakeholders of the city is addressed. A proper and continuous communication is necessary for greater transparency and decision making. In fact, in recent years many governments have worked to increase openness and transparency in their actions to reduce corruption. To address this challenge, the authors from Bertot et al.<sup>165</sup> present the transparent government as an open and anti-corruption tool. An overview of the technologies available for transparency in SCs and lessons learned from case studies are reported in Johannessen and Berntzen.<sup>166</sup> Furthermore, political discourse analysis approaches could be used in order to analyse politicians' priorities Bilbao-Jayo and Almeida.<sup>167</sup>

## Case studies

During the last decade, many cities have tried to transform from a traditional metropolitan area to a SC. However, in many cases, those attempts have been in vain even though there has been a considerable amount of both private and public investments. In this section, we are going to focus on those cities where the SC paradigm has been successfully applied or have a clear idea of which steps have to be followed to become one (summary in Table 5).

### Bilbao

Bilbao (Spain) has focused its efforts to grow as SC in the following domains: citizens, environment and government.

For the purpose of promoting a sustainable transportation system, Bilbao has deployed a network of electric bicycles with 40 pick up points (<https://www.elcorreo.com/bizkaia/bicicletas-electricas-alquiler-20180913225311-nt.html>) and have bought two electric buses (<https://www.europapress.es/euskadi/noticia-ayuntamiento-bilbao-destina-12-millones-compra-dos-autobuses-electricos-20161201162640.html>).

**Table 5.** Summary of the selected cities, analysing if each city has a roadmap designed, a specific department dedicated exclusively to the evolution of the city as SC and the SC domains the city covers.

City name	Roadmap designed	SC Department	Domains			
			Business	Citizen	Environment	Government
Bilbao	No	No	Yes	Yes	Yes	Yes
Birmingham	Yes	Yes	No	Yes	No	Yes
Bristol	Yes	Yes	Yes	Yes	Yes	Yes
Cape Town	No	No	No	Yes	Yes	Yes
Cleveland	Yes	No	No	Yes	Yes	Yes
Copenhagen	Yes	Yes	Yes	Yes	Yes	Yes
Fujisawa	Yes	Yes	Yes	Yes	Yes	Yes
Melbourne	No	No	No	Yes	No	Yes
Ottawa	Yes	Yes	Yes	Yes	Yes	Yes
Santander	No	No	No	Yes	No	Yes
Seattle	Yes	Yes	Yes	Yes	Yes	Yes
Seoul	Yes	Yes	No	Yes	No	Yes
Singapore	Yes	No	Yes	Yes	No	Yes
Stockholm	Yes	Yes	Yes	Yes	Yes	Yes
Toronto	Yes	No	No	Yes	Yes	Yes

SC: smart city.

In addition, the Bilbao City Council has an Open Data portal (<https://www.bilbao.eus/opendata/es/ini cio>) with around 120 datasets published in several formats. Moreover, four applications have been developed and are maintained by the Bilbao City Council (<https://www.bilbao.eus/opendata/es/aplicaciones>): *GeoBilbao* (shows real-time information about the status of parkings, traffic cameras, traffic status and so on.); *iBilbobus* (information regarding bus stops, schedules and status); *InfoBilbao* (shows information and news related to the city and City Council); and *Presupuestos Municipales* (graphic representation of the City Council’s budget).

Moreover, Bilbao has a portal of electronic administration for both citizens and businesses (<https://www.bilbao.eus/misTramites/ciudadano/preInicioCiudadano.do?lang=es>) where a considerable amount of administrative procedures with the City Council can be made. In addition, there are free Wi-Fi access points through all the city.

Finally, it is noteworthy that Bilbao has four buildings called *AuzoFactory* where people or companies with innovative ideas can work and interchange ideas (<http://bilbaogazte.bilbao.eus/es/espacio/auzofactory/>).

### Birmingham

For the last years, Digital Birmingham (<http://digitalbirmingham.co.uk/about/>), part of Birmingham City Council’s Strategic Services Directorate, has been in charge of the development of Birmingham as a SC. To do so, Digital Birmingham has acted as the bridge between the City Council and its external partners to

create new opportunities for the development of Birmingham (UK) as a SC.

So far, Digital Birmingham has developed the following services:

- They have supported citizens’ digital inclusion through various projects such as *Computers in the Home* (<http://digitalbirmingham.co.uk/project/computers-in-the-home/>) project, which consisted in providing a computer and Internet connection access to over 700 families to transform them into computer literates; or *Keeping IT in the Family* (<http://digitalbirmingham.co.uk/project/keeping-it-in-the-family/>), where an educational comic-book was used to help children teach their families IT skills.
- Open Data Portal (<https://data.birmingham.gov.uk/>): A collection of 80 datasets available in several data formats.
- Birmingham Civic Dashboard (<http://digitalbirmingham.co.uk/project/birmingham-civic-dashboard/>): an open platform where citizens can place information about incidences in the city using their smartphone.
- Free Wi-Fi is available in public buildings and in several points throughout the city.

In addition, they are currently working with a roadmap designed by the City Council to achieve a smarter Birmingham. According to the roadmap ([http://s3-eu-west-1.amazonaws.com/digitalbirmingham/resources/Birmingham\\_Smart\\_City\\_Roadmap\\_revised-Nov-2014.pdf](http://s3-eu-west-1.amazonaws.com/digitalbirmingham/resources/Birmingham_Smart_City_Roadmap_revised-Nov-2014.pdf)), this new Birmingham will focus on three fundamental axes:

- Technology and Places: providing affordable and reliable digital connectivity from anywhere in the city, investing in digital infrastructure such as fibre optic cabling or sensors.
- Economy: building an energy efficient city using energy smart metres to control energy consumption and smart grids, along with a city where the mobility is accessible to anyone, through an improved journey planning to reduce traffic congestion and pollution city.
- People: promoting digital inclusion, building a city where every citizen has the advantages of being online. To do so, people and companies must work together to design innovative solutions.

### Bristol

Awarded as the leading SC in the United Kingdom by the *UK SCs Index 2017* ([https://e.huawei.com/uk/special\\_topic/solution/smart\\_cities\\_index\\_2017](https://e.huawei.com/uk/special_topic/solution/smart_cities_index_2017)). Three different initiatives are being carried out in Bristol (UK):

- SC Research and Development—*Bristol is Open* (<https://www.bristolisopen.com>): a joint effort between Bristol City Council and the University of Bristol, resulting in a platform of multiple communications technologies installed all around the city. Furthermore, as it is stated in *Bristol Is Open* website, Bristol currently offers three different types of networks which are integrated through software controls: fibre in the ground, wireless het-net and a radio frequency mesh network. Moreover, this communication platform can be used by companies to test their innovations in a real-world scenario instead of inside a laboratory.
- City Operations Centre: this operations centre handles the traffic management and control, Close Circuit Television (CCTV) monitoring for safety and security, tele-care services and alarm monitoring. Moreover, the data are available in the Open Data platform of the city itself.
- Citizen-Centric Solutions: to do so, they have created *The Bristol Approach Program* to promote people to work together to create new opportunities. In addition, they are carrying out some projects to develop smart districts to help citizens to be energy efficient, use new ways of transportation or assist citizens to measure and combat damp problems.

### Cape Town

Even though their development as SC is in a very early stage, they have already several initiatives that could

define Cape Town (South Africa) as a SC while they encourage people to propose new initiatives (<https://www.iol.co.za/business-report/technology/cape-town-needs-your-ideas-to-become-a-smart-city-12869012>). Some of these initiatives are (<http://ventureburn.com/2017/10/heres-cape-town-using-iot-smarter-safer-sustainable/>):

- Open Data portal: the Open Data portal has datasets about budgets, tourist routes, tenders, air quality and damp levels. However, others could be available on request.
- Gunshot detection system: this real-time gunshot detection system has been able to reduce gun crimes (<https://www.cbsnews.com/news/africa-watch-gunshot-detection-system-helping-police->).
- Cape Town FMS: a free service that informs about traffic flows on some roads.
- CCTV: Cape Town has a large number of CCTV cameras all over the city.
- Public Wi-Fi: more than 500 Wi-Fi zones with 100MB of free data (<https://www.news24.com/SouthAfrica/Local/Peoples-Post/connecting-the-city-through-wi-fi-20170313>).
- Water Map: due to the water crisis, Cape Town City Council launched *Water Map* which marks residential areas with different colours depending on the expenditure of water (<https://citymaps.capetown.gov.za/waterviewer/>).

### Cleveland

In 2016, Cleveland (USA) participated in the *Beyond Traffic: The SC Challenge* with a an ambitious proposal. However, Cleveland did not win the challenge and most of their ideas have not been applied yet (for instance, there is not an Open Data portal yet).

Nevertheless, Cleveland has carried out two small SC projects:

- Safe Smart CLE (<https://clecityhall.com/2018/04/26/mayor-jacksons-safe-smart-cle-will-upgrade-citys-technology->): this initiative consists in installing energy-efficient LEDs and cameras in 61,000 streetlights in order to be more energy efficient and provide neighbourhoods a better monitoring system that will send images directly to the police department.
- Infrared cameras to detect and warn the connected buses if a pedestrian or another vehicle enters their lanes (<https://statescoop.com/cleveland-buses-test-infrared-cameras-to-improve-pedestrian->).

## Copenhagen

According to the Easy Park's 2017 SC Index (<https://easyparkgroup.com/smart-cities-index/>) Copenhagen (Denmark) was ranked in 2017 as the best SC in the world. As it is stated in Hashem et al.,<sup>168</sup> the objective of Copenhagen is to become the world's first zero carbon footprint capital by 2025. To do so, they have started to implement a variety of innovative projects related to transport, waste, water, heating and alternative energy sources.

One of the biggest entities related to this success is the Copenhagen Solutions Lab (<https://cphsolution.slab.dk/>). According to their website, Copenhagen Solutions Labs is the bridge between external companies and the Municipality of Copenhagen when it comes to initiatives linked to the development of Copenhagen as SC.

The Lab has divided their work in four different topics:

- **People and Flows:** their goal is to create the best urban spaces based on the data gathered about how people use the city (such as movement data from pedestrians and cyclists). Nowadays, they support the prioritisation of traffic for pedestrians and cyclists and provide a smart planning of physical initiatives in the city.
- **Digital Services:** they provide Wi-Fi and information screens in urban areas. Moreover, they have also developed digital services to guide citizens and visitors through the city.
- **Data-Driven Operation and Supervision:** the aim of this process is to collect information about city maintenance tasks, which are performed manually to search for potential opportunities where new services could be designed in order to facilitate those manual processes. For instance, they are currently finding new ways of catching rats above ground or searching for new procedures to improve the supervision of roads and signage.
- **Environment and Climate:** as it has been previously mentioned, Copenhagen has ambitious inspirations when it comes to city sustainability. Some of the solutions Copenhagen Solutions Lab is currently working on are: prioritising traffic and managing rainwater.

Furthermore, Copenhagen has an Open Data platform, an innovation challenge to design new IoT platform for cities and three urban laboratories where new SC solutions can be tested in a real environment.

## Fujisawa Smart Town

The Fujisawa Smart Town (a residence area inside Fujisawa City in Japan) is a SC joint project between the private and public sectors (Fujisawa's City Council) (<https://fujisawasst.com/EN/project/>). Its goal is to build a sustainable and lifestyle-based smart town. To do so, they have focused on improving the following domains: environment, government and citizens.

Every house in the Fujisawa Smart Town has a solar power generation system and storage batteries. Moreover, the energy consumption is managed by a system named Smart HEMS (Home Energy Management System). Furthermore, since the energy consumption of each of the houses is managed, in order to promote energy efficiency and sustainability, support is provided to those houses which use an excessive amount of energy.

With respect to actions related to the governance of the town, they are working with several initiatives such as disaster prevention push notification TV system, surveillance cameras, lights, and human patrols in order to ensure the security of the town. Moreover, sensor LED street lights are installed in the town. These lights regulate their brightness if a passer-by or a car is detected.

Regarding the initiatives related to citizens, Fujisawa smart town provides the *Wellness Square* to promote social interaction. In this area, several services such as pharmacies, clinics, nursery centres, libraries, after school care centres or a place where resident can exchange knowledge are available. Moreover, a community platform named SOY LINK is used in order to communicate with other members of the town.

## Melbourne

Melbourne's (Australia) City Council is currently carrying out several SC related initiatives:

- **CityLab:** consists in a community space for devising and testing new services in the city (re-designing council services for instance). Their design is focused on human centred design in order to maximise community's involvement.
- **Open data:** Melbourne's Open Data platform has around 100 datasets (data related to parking bays, accessibility needs, sensor feeds from across the city, census, commercial and residential development, Melbourne's environment and park, employment projections, population forecasts, traffic and so on).
- **Free Wi-Fi:** 250 MB per device a day.

- 24-h pedestrian counting system in order to know which are the busiest locations at any given time.

### Ottawa

Ottawa (Canada) has an extensive history of SC initiatives:

- Salt management system: the salt spreaders are managed by an automated salt management system which takes into account several factors (ambient and road temperature or weather forecast) (<https://cira.ca/blog/state-Internet/canadians-connected-sneak-peek-smart-communities-panel>).
- Water metering system: the system consists of 210,000 smart water flow meters in order to have real time access to water consumption data, leaks or consumption patterns (<https://www.smart-energy.com/regional-news/north-america/city-of-ottawa-selects-iron-s-smart-water-meter-technology/>).

However, they are currently implementing their Ottawa SC 2.0 strategy approved by the City Council ([https://documents.ottawa.ca/sites/default/files/smart\\_city\\_strategy\\_en.pdf](https://documents.ottawa.ca/sites/default/files/smart_city_strategy_en.pdf)). The later has designed a roadmap to promote new SC initiatives in the city in collaboration with other local organisations such as Invest Ottawa or Hydro, which have been historically involved in the creation of SC initiatives in other cities. Their strategy has three goals:

- Connected city: in order to promote a city where all the business and citizens are connected, several solutions are being implemented: (1) a fibre broadband strategy with industry stakeholders, (2) promoting community pilots to evaluate new initiatives and their consequences, (3) expanding their sensor deployment, (4) improving their LED lighting system and (5) exploring new initiatives related to data analytics.
- Smart Economy: stimulating local entrepreneurs and start-ups through innovation centres, marketing efforts to promote Ottawa as a destination for investments and establishing the city as a precision agriculture node.
- Innovative Government: continuous improvement of the Open Data program, enable online channels such as mobile apps or websites to have an easy access to city information and procedures.

### Santander

From 2012 to 2014, one of the most ambitious SC research projects was conducted in Santander (Spain) by Cheng et al.<sup>40</sup> During this project, around 2000 sensors for environmental monitoring and 400 parking sensors; 2000 RFID tags and QR codes; and 60 devices for traffic monitoring were installed to be analysed in real time in Santander (<http://www.smartsantander.eu/index.php/testbeds/item/132-santander-summary>). This project promoted new SC initiatives which are currently being applied in the city of Santander.

- Santander City Brain (<https://www.santandercitybrain.com/>): an open platform where citizens can place their ideas or rate and comment other citizens' suggestions to improve the city. This way, Santander City Council encourages the participation of its citizens.
- Santander Open Data Portal (<http://datos.santander.es/>): it contains 90 datasets in several formats. The portal also promotes the creation of applications, advertising those which take advantage of the offered data.
- *Pulso de la Ciudad* (<http://maps.smartsantander.eu/#page3>): an open platform where citizens can place information about incidences in the city using their smartphone. Those incidences that require an intervention from the City Council are transferred to the appropriate department.
- Portal of Electronic Administration (<https://sede.santander.es/>)

### Seattle

Since 2016, Seattle's (USA) efforts to become a SC have been centralised in the Seattle Information Technology Department (Seattle IT) (<https://www.seattle.gov/tech/about/publications/2017-18-strategic-agenda>).

Regarding how the transportation has changed in Seattle to become smarter, two main initiatives have been applied:

- Bike-sharing service: there are three different companies providing bike-sharing services through smartphone apps (<https://www.geekwire.com/2017/hello-yellow-bikes-testing-fo-third-bike-sharing-service-hit-seattles-streets/>).
- Improving traffic flow using external data such as highway vehicle volumes or travel times to adjust traffic lights (<https://w3.usa.siemens.com/mobility/us/en/road-solutions/traffic-management/Documents/>)

NextGeneration\_ITS\_Seattle\_Flyer.pdf, [https://www.seattletimes.com/seattle-news/transportation/new-software-to-help-seattle-streets-respond-to-traffic/?utm\\_source=The + Seattle + Times&utm\\_campaign=43f7c02a26-Morning\\_Brief\\_5\\_17\\_2016&utm\\_medium=email&utm\\_term=0\\_5beb38b61e-43f7c02a26-121055389](https://www.seattletimes.com/seattle-news/transportation/new-software-to-help-seattle-streets-respond-to-traffic/?utm_source=The+Seattle+Times&utm_campaign=43f7c02a26-Morning_Brief_5_17_2016&utm_medium=email&utm_term=0_5beb38b61e-43f7c02a26-121055389)).

Regarding Open Data and its use, Seattle also has an Open Data portal (<https://data.seattle.gov/>) with more than 1300 datasets and the possibility to request new datasets. Moreover, since 2017, Seattle's City Council is promoting the use of Open Data by both public administration and private companies to develop new solutions that could improve citizens' quality of life (e.g. fight crime, reduce greenhouse gases, foster economic development, reduce traffic congestion and so on).

It is also remarkable how Seattle's City Council is trying to earn citizens trust in how they collect and use information with the development of a Privacy Program (<http://www.seattle.gov/Documents/Departments/SeattleIT/DigitalEngagement/OpenData/FPF-Open-Data-Risk-Assessment-for-City-of-Seattle.pdf>) in collaboration with universities. Moreover, they made public a list of surveillance technologies which are currently in use (<http://www.seattle.gov/tech/initiatives/privacy/surveillance-technologies>) (e.g. emergency scene, traffic or hazmat cameras, license plate readers and so on) with their correspondent Surveillance Impact Reports.

Finally, it is worth noting the city council's efforts to achieve a Digital Equity offering citizens opportunities to gain technological skills, improving Internet availability and connectivity and discounts in computer and smartphones.

### Seoul

Created by the Seoul (South Korea) Metropolitan Government in 2016, Seoul Digital Foundation is responsible for the development of Seoul as SC (<http://sdf.seoul.kr/eng/about/greeting.jsp>). According to its director, Seoul has five pillars as SC ([https://oascities.org/wp-content/uploads/2018/01/Seoul-Smart-City-Initiatives-Cases-\\_Dr.-Jungwoo-Lee.pdf](https://oascities.org/wp-content/uploads/2018/01/Seoul-Smart-City-Initiatives-Cases-_Dr.-Jungwoo-Lee.pdf)): (1) ICT infrastructures, which connect and empower citizens; (2) an Open Government focused on communication, participation and sharing; (3) promotion of public-private partnership for sustainable development; (4) the use of latest technologies (Big Data, IoT, GIS or Cloud) to solve city problems; and (5) to share the developed solutions.

Among the available services we can highlight the following initiatives:

- Open Data Plaza: more than 4700 open datasets in formats such as spreadsheets, visualisations or Open API.
- Set up late night bus routers after analysing 3 billion taxi-call data.
- IoT Pilot Project: using IoTs to resolve several challenges (e.g. fire prevention, garbage collection, share parking lot, safety and so on) through the cooperation of public-private entities. By 2020, the project will be implemented in 50 places throughout Seoul.
- Direct communication between citizens and government through e-platforms such as a smartphone app for city-wide voting on municipal issues or to ask for ideas or receive feedback from citizens (<https://www.clc.gov.sg/docs/default-source/commentaries/smart-city.pdf>).

### Singapore

Nowadays, Singapore is following the milestones set by Smart Nation Initiative in 2014. This initiative has led Singapore to win several prizes such as the second position on Easy Park's 2017 Smarty City Index (<https://easyparkgroup.com/smart-cities-index/>) or the sixth place in the IESE Cities in Motion Index (<https://www.ieseinsight.com/doc.aspx?id=2124&ar=&idi=2&idioma=2>).

The Singapore Smart Nation Initiative consists of five strategic projects (<https://www.smartnation.sg/why-Smart-Nation/transforming-singapore>) and each of them has several milestones which are distributed over 3 years:

- National Digital Identity (NDI): the NDI is a digital identity system for Singapore's citizens and businesses so that they can perform online transactions with the government or other private companies. In order to use the NDI, Singapore has developed the SingPass authentication system with a mobile application. Moreover, the NDI system gives developers the opportunity to use SignPass as login option in their applications.
- E-payments: the project provides an open, accessible, secure and simple e-payments structure for citizens and businesses. To do so, they have created the PayNow platform where both citizens and businesses can transfer money to other citizens, businesses or administrations. Moreover, Singapore government has also launched the Singapore Quick Response Code to perform payments scanning QR codes.
- Smart Nation Sensor Platform (SNSP): the SNSP is an integrated nation-wide sensor platform whose goal is to use sensor's data to

improve aspects such as urban planning, public transport or public security. So far, they have launched three different trials: (1) a wireless sensor network, which is being used by over 500 sensors to transmit water usage data and promote water saving; (2) drowning detection system at swimming pools using computer vision; and (3) a personal alert or help button for elderly people. In 2019 a new trial will start; its objective is to place different type of sensors in lamp posts.

- **Smart Urban Mobility:** this project's goal is to enhance the comfort and reliability of Singapore's public transport analysing anonymised data collected from commuting cards or using hands-free ticketing technology. Smart Nation Singapore claims that they have been able to achieve a 92% reduction in the number of bus services with crowding issues or decrease the average waiting time (<https://www.smartnation.sg/what-is-smart-nation/initiatives/Transport/open-data-and-analytics-for-urban-transportation-1>). For 2019 they are planning trials with autonomous buses.
- **Moments of life:** this project attempts to deliver the services and information that citizens need as soon as possible and through a single platform. One of the life moments that has been already tested in a real scenario is the case of a couple that has a new child and a large list of administrative processes have to be carried out. This first trial has been very successful among parents (<https://www.smartnation.sg/what-is-smart-nation/initiatives/Strategic-National-Projects/moments-of-life>). Moreover, this application is being created taking into account citizens' suggestions.

### Stockholm

In 2017, Stockholm (Sweden) City Council approved a roadmap for the further development of Stockholm as SC, having as final goal becoming the world's smartest city by 2040 (<https://international.stockholm.se/governance/smart-and-connected-city/>). The roadmap has three main goals: (1) security for the elderly, (2) efficient mobility and (3) accessible clean water. To do so, the Digital Demo Stockholm partnership has been created, where actors from public sector, academia and industry are working to fulfil the roadmap.

However, even before this roadmap was approved, Stockholm had already taken the path of SC with initiatives such as (<https://international.stockholm.se/governance/smart-and-connected-city/how-the-smart-city-develops/>):

- **Smart Bins:** solar powered bins that report when they are about to get fully charged. Moreover, the bins are capable of packing the waste.
- **Make a suggestion app:** a smartphone application where citizens can directly report any incident related to traffic or town planning that are found in the city.
- **Smart street lights:** street lights with LED technology and motion sensors able to adjust light intensity.
- **Promotion of public transport controlling traffic lights:** buses are able to send requests to the TMS in order to have priority at traffic light when they are behind schedule.
- **Open data portal** (<http://dataportalen.stockholm.se/dataportalen/>).

### Toronto

Currently, the city of Toronto (Canada) has several smart initiatives working (<https://www.toronto.ca/city-government/accountability-operations-customer-service/city-administration/city-managers-office/key-initiatives/smart-cities-challenge-2/>):

- **MyWaterToronto:** an online website where users can view their total and average water use per day, month or year. Moreover, users are able to detect leaks using this platform.
- **Smart traffic signal technology trial:** these smart traffic signals can be adjusted at any time in order to avoid traffic congestions.
- **DineSafe:** the platform displays in a map all the establishments serving and preparing food with their corresponding inspection results (pass, conditional pass or closed).
- **Partnership with a private company owner of a navigation app:** they have access to each other's real-time data, providing motorists the best routes to navigate the city depending on the traffic.
- **Open data portal** (<https://portal0.cf.opendata.inter.sandbox-toronto.ca/>): a recently renovated portal with 30 datasets in several formats.

Toronto has also sent a proposal to the Canadian SCs Challenge (<http://www.infrastructure.gc.ca/cities-villes/index-eng.html>) in which they aim to reduce poverty among children empowering their families with the necessary tools to reduce the digital divide.

### Open challenges

Due to the intrinsic multidisciplinary nature of the SCs, several research challenges arise. In this section, a

literature review of open challenges is done. As some authors focus their work on a specific domain, we have divided this section into two parts: (1) in the Review of open challenges we made a literature review of the different challenges or taxonomies of challenges and (2) in the Domain-specific challenges we only review proposals that focus on a specific domain, such as government, traffic and so forth.

### *Review of open challenges*

Chourabi et al.<sup>72</sup> separate the challenges into eight categories, providing challenges inside each of them and some separate strategies to tackle them:

1. Managerial and organisational challenges: including project size; managers attitude and behaviour; users or organisational diversity; lack of alignment of organisational goals and projects; multiple or conflicting goals; resistance to change; and turf and conflicts.
2. Technological challenges: including IT skills (lack of employees with integration skills) and organisation-related challenges (lack of cross-sectoral cooperation and inter-departmental coordination, unclear vision of IT management, politics and culture issues).
3. Government: including collaboration; leadership and champion; participation and partnership; communication; data exchange; service and application integration; accountability; and transparency.
4. Policy context: including challenges related to the integration of the ICT with political and institutional components, as each one has its own agenda.
5. People and communities: including digital divides; information and community gatekeepers; participation and partnership; communication; education; quality of life; and accessibility.
6. Economy: including factors around economic competitiveness such as innovation, entrepreneurship, productivity and so on.
7. Built infrastructure: including IT infrastructure (internal systems restrictions; lack of knowledge regarding interoperability; availability and compatibility of software systems and applications); security and privacy (threats from viruses, worms and Trojans; privacy and personal data); and operational cost (high cost of IT, IT professionals and consultancies; cost of installation and maintenance).
8. Natural environment: including all the challenges related to the sustainability of the introduction of the ICT.

Monzon<sup>19</sup> define challenges according to the geographical position where the city is. They categorise them within the following taxonomy: governance, economy, mobility, environment, people and living.

1. In European Cities, the governance models should become more flexible while the economy must become resilient to downturns (especially after an economic crisis due to the past focus on only one economical sector). The mobility inside the city has to move towards a more sustainable, inclusive and efficient system. For this aim and to preserve the environment, the author argues that cities should avoid urban sprawl and become more dense and liveable cities. This would reduce the need of a car and, thus, the pollution and CO<sub>2</sub> emissions. Finally, three major challenges in this setting are related to the supply of housing, health conditions and crime rate situation.
2. South and East Mediterranean cities, due to their conditions and being highly urbanised areas, should focus on providing basic services to their inhabitants. Moreover, they also face some critical challenges: scarcity of resources, such as fresh water and food supply; poverty; urban insecurity; government instability and even high levels of violence and corruption. All these affect the economy too. In order to move towards a better urban future, these concerns must be addressed. In addition, Southern countries have a lower amount of smartphone users compared with European cities and more technology-illiterate people, which can delay the integration of the ICT in the cities.

Yin et al.<sup>4</sup> review three major challenges in SCs: (1) city traffic, (2) citizen behaviour and (3) city planning.

1. *City traffic*. There are a variety of sources of data (such as GPS or GIST data) and also a challenge in the algorithms to efficiently use all of them. This includes real-time processing of data or analysis of traffic conditions and traffic behaviour.
2. *Citizen behaviour*. Research in mathematical models to understand the human behaviour is reviewed. In addition, with the introduction of the ICT, new ways to analyse the behaviour have arisen, such as the use of mobile phones and the GPS system.
3. *City planning*. Another major challenge is how to guide the urban development and construction based on data, as there is not a specific function to do this. Some researchers first separate the different urban areas in categories, such

as residential area, industrial area and administrative area; although this is not adequate for large cities.

Van den Bergh and Viaene<sup>169</sup> explore some challenges that cities are facing in order to transform into a SC. Based on extensive interviews, six challenges were identified: (1) defining the city administrations ecosystem position; (2) having an expert team lead the SC growth; (3) establishing an internal coordination mechanism (as there was no structure to discuss about SC projects); (4) managing the relation between IT and business; (5) the need for motivated workers that have a forward-thinking attitude is a prerequisite for a SC; and (6) going from the experimental phase (in which SC projects get stuck) to a real implementation.

Pierce and Andersson<sup>170</sup> propose a taxonomy for SC challenges focusing on the municipal decision making, in which they analyse them from both theoretical background and based on interviews they made. They organised the challenges as non-technical, which include (1) collaboration, (2) financial, (3) governance, (4) awareness and technical issues as (5) interoperability and (6) privacy.

1. *Collaboration*. Includes weak collaboration with external stakeholders.
2. *Financial*. Includes challenges with limited funds for SC initiatives, large up-front investment, lack of business model and difficulties in monetisation SC investments.
3. *Governance*. Challenges that surge from outdated rules and regulations that interfere with SC initiatives.
4. *Awareness*. Includes challenges regarding the lack of knowledge and experience in SC-related technologies.
5. *Interoperability*. Includes challenges regarding SC integration.
6. *Privacy*. Includes the problematic of big data while at the same time preserving citizen privacy.

Centred in the Indian situation, Anand and Anand<sup>171</sup> analyse various domains where challenges for the implementation of SCs arise. In the water sector, they do not have enough drinkable water and lack of a system to collect rain water. In the energy sector, they also fail to provide electricity in all urban areas and do not have enough hydrocarbon even though they are largely consumed. In waste and sanitation sector, there is not an efficient waste collection system, an open defecation issue, not all houses are connected to the sewerage and there is not citizen participation in the management and segregation of waste. In the mobility sector, there is an inadequate public transport

system which makes the citizens rely on private transport, and this is even worse considering that the road infrastructure has not been adapted for congestions. In the built environment sector, house prices have increased leading an underprivileged part of the population to be unable to own a house (the consequence is the creation of informal dwellings without basic services) and cities have not updated their infrastructure with the growth of the population. In the education sector, India falls behind in literacy rate compared to other countries in Asia and, even though the enrolment in schools has increased, the quality of the education is still poor and there is a large gap between the level of the school and the industry. Moreover, little funding is given to research, making researchers leave India to be able to continue their career. In the healthcare sector, there is a lack of public and private services, a small percentage of the population is covered with a health insurance and the cost of it is very high, and the government does not promote preventive health and wellness programmes. Most of these challenges could be extrapolated to other cities in developing nations. Therefore, all these challenges must be addressed in order to be closer to the SC paradigm where citizens have their basic needs satisfied.

More recently, Silva et al.<sup>172</sup> describe 10 concerns in designing a realistic SC: (1) connectivity, (2) big data, (3) waste management, (4) performance, (5) sustainability, (6) heterogeneity, (7) cost operation, (8) information security, (9) system failures and (10) carbon footprints. A major challenge is the cost of deploying the city (the lower the cost, the higher the chances of implementing it in the real world) and the maintenance cost (again, the lower the cost, the higher the probability of being sustainable). Other critical issues between these 10 concerns are the ability to integrate the heterogeneous software and hardware together (interoperability) and environmental concerns such as waste management, minimising the carbon footprint and the introduction of renewable energies.

### Domain-specific challenges

*Agriculture*. The agricultural sector has recently advanced forward thanks to the development of new systems and machinery but still poses some problems when it comes to fitting it into the SCs. Among these problems is that cities are occupying land that was previously fertile, so they should be responsible for generating food that could have been received from the land. In addition, the shipment of imported foods from the places where they are produced spend more quantities of resources than they nutritionally provide (<https://blogs.scientificamerican.com/plugged-in/10-calories-in-1-calorie-out-the-energy-we-spend-on-food/>). Vertical farming ([https://en.wikipedia.org/wiki/Vertical\\_farming](https://en.wikipedia.org/wiki/Vertical_farming))

is a paradigm that tries to tackle these problems through crops inside buildings. Al-Chalabi<sup>173</sup> conducted a study evaluating the viability of different architectures for buildings dedicated to vertical farming. The consumption of light and water and the size of the buildings are some of the main challenges when creating these buildings due to the search for an ecological solution. Riffat et al.<sup>174</sup> make a review through the farms that already exist nowadays in the world. In the manuscript, authors explain how cities with farms are using them to help solving other challenges. For example, in Vancouver they have developed a project that recovers minerals from waste water to create soil fertiliser (<http://ostara.com/about/>).

**Citizen.** In order to optimally achieve SCs' objectives, the engagement or participation of citizens is pivotal. This way, the city can satisfy their needs following their feedback and/or including them as active agents in the city. In fact, Simonofski et al.<sup>175</sup> identify three ways in which citizens can be involved in the city: (1) as democratic participants, (2) as co-creators and (3) as ICT users. In the first case, for example, Irvin and Stansbury<sup>176</sup> analyse the advantages and disadvantages of including citizens in the decision-making process of the city. As stated by Arnstein,<sup>177</sup> this participation can consist on: (1), (2) and (3). Research done in Emaldi et al.<sup>162</sup> bet on the citizens as co-creators of the city (second case), that is, they are not anymore passive agents but crucial stakeholders to develop ideas, tools and so on. They also provide citizens (as ICT users, third case) with open data to allow them to create apps to offer new services for the city.

**Education.** Education is always changing and being adapted to the necessities of society. As the concept of SCs evolves, Zhu et al.<sup>178</sup> state that it will create new challenges on how to extend and interconnect the learning services that smart education provides with other contextual aware systems of the SCs. In addition, they also foresee new technologies in smart learning environments will introduce new challenges to the foundations of education itself that will require adapt and introduce topics such as: (1) new pedagogical theories, (2) educational technology leadership, (3) learning leadership of teachers, (4) educational structures and (5) educational ideology.

Apart from the education of the future generations, there are also some challenges regarding the education of the grown-up citizens already interacting with the services that SCs provide. As some authors state,<sup>84,179</sup> SCs are creating and providing new services and platforms for users to take part into cities life. These services are based on ICTs and therefore we must educate the citizens in two different tasks: (1) change the way

we interact with the city and become proactive citizens and (2) learn to use the tools that governments have to take part in the decisions of the cities.

**Energy.** Energy efficiency is also a major challenge, there is a need to motivate and involve citizens in reducing the energy intensity in order to achieve energy efficiency and, thus, a sustainable growth.<sup>180</sup> In the domestic sphere of the SCs, the integration of ICTs may be energetically unsustainable and not available for all the citizens.<sup>181</sup> This stresses the importance of considering the energy consumption when introducing ICTs in the SCs.

From the smart micro-grids perspective, Yoldas et al.<sup>182</sup> identify two main challenges: regulation, which prevent the proper usage of micro-grids, and technical challenges. For the later, they distinguish the following issues: (1) operation, (2) components and compatibility, (3) integration of renewable generation and (4) protection.

**Environment.** Concerning the environmental challenges, Colding and Barthel<sup>183</sup> offer an urban-ecology viewpoint of various issues of SCs: (1) the resiliency and cyber-security of the paradigm itself in order to avoid unwanted surprises and, specially, safeguarding basic human needs (food, energy and water security); (2) an analysis of benefiteres and losers within the paradigm, as the SCs may create a segregated part of the population which are technologically marginalised; and (3) that SCs may disconnect humans from the nature, as our ties to physical places shape our pro-environmental behaviour. Thus, new tools to let humans reconnect with nature are needed.

Due to the rapid growth of some countries such as China, the need to expand the urban area has become increasingly more important. Thus, former industrial areas have been adapted for living, causing health risks due to the contamination of those areas. A major environmental challenge is readopting those places to be safe for living.<sup>184</sup> In addition, new pollutants are emerging and, therefore, a strategic plan to assess their consequences must be created. According to Gavrilesco et al.,<sup>185</sup> the research challenges in order to biomonitorise and assess the risk of the emerging pollutants are (1) identification and preparation of comprehensive lists of emerging contaminants; (2) characterisation of the consequences of the chemicals or biological emerging pollutants in ecosystems (e.g. soil and water); and (3) assess the water or soil system with the presence of the emerging pollutants (Table 6).

The creation of green public spaces is challenging to implement without benefitting an affluent community and causing the gentrification of a neighbourhood (due to the increase of the housing costs and the

**Table 6.** Literature review of domain-specific challenges.

Domain	Challenge	Related work
Agriculture Citizen	Include farming inside cities	173
	Engaging citizens in decision-making processes	175–177
	Engaging citizens as co-creators	162,
Education	Engaging citizens as ICT users	162, 175
	New education necessities	178
	Continuous education for all citizens	84, 179
Energy	Achieve lower energy consumption	180, 181
	Micro-grids regulation and technical challenges	182
Environment	Taking into account an urban-ecology viewpoint	186
	Re-adapting contaminated areas for new urban spaces	184, 185
	Protect the social sustainability alongside the ecological sustainability	162, 175
Government	E-government challenges	153
	IoT-based governance challenges	187
Healthcare	Health monitoring challenges	188, 189
Internet of Things	Taxonomies of challenges related to IoT	190
	Resilience among interdependent infrastructure	191
	Challenges with autonomous IoT wearable devices	192
Security	Data storage-related privacy	193
	Security threads	194, 195
Sustainability	Sustainable growth of cities taking the ICT into account	196
Traffic	Technical issues with Traffic Management Systems	112
	Challenges related to the smartness of roads	197
Waste management	Lack of resources to implement a waste management system	198
	Not having e-waste recycling culture	199

IoT: Internet of Things; ICT: Information and Communication Technologies.

displacement of the residents). Therefore, whenever green spaces are created, they must take into account the protection of the social sustainability in addition to the ecological sustainability.<sup>186</sup>

**Government.** In the domain of government, centred in e-government, Gil-García and Pardo<sup>153</sup> propose a taxonomy for the challenges of government initiatives: (1) information and data, (2) information technology, (3) organisational and managerial, (4) legal and regulatory and (5) environmental and institutional. AlEnezi et al.<sup>187</sup> present three challenges related to IoT-based governance: (1) mindscaping or the process of convincing entities to change, as administration systems tend to be rigid; (2) investment in ICT; and (3) security and privacy in order to safely implement a smart government.

**Healthcare.** Concerning health monitoring, Chen et al.<sup>188</sup> focus on challenges of wearable sensors. They identify the following main issues to overcome: (1) bionic smart cloth fabrication, (2) health big data, (3) control system design for multimodal body sensors, (4) intra-body area network communication, (5) impact of body human interference and (6) contextual data interpretation. Mshali et al.<sup>189</sup> review the challenges of

homes as a smart environment for health monitoring. They distinguish the following main issues: (1) monitoring accuracy, (2) context-awareness, (3) human factors, (4) heterogeneity, (5) availability and reliability, (6) data transmission, (7) security and privacy, (8) intrusiveness and (9) power consumption.

**IoT.** IoT-based Smart city introduces a paradigm in which all the devices are connected. This means that all the critical infrastructure we rely on, such as electric grids, healthcare or home automation, are connected to a single and global network. This exposure to the Internet and the interconnection of infrastructure introduces the risk that a failure of single infrastructure could bring down the whole network. To mitigate this problem, it is essential to incorporate resilience mechanisms to the modelling of SC IoT architectures to ensure resilience among interdependent infrastructure. Sterbenz<sup>191</sup> identifies the main challenges of modelling as (1) abstracting the architecture complexity for tractable graph-theoretic analysis and (2) the availability of model simulations that include all the protocols used on SCs.

Ahmed et al.<sup>190</sup> review the challenges of the IoT-based SCs as: (1) big data, (2) compatibility, (3) investment, (4) precision and (5) security and privacy. In

addition, Mehmood et al.<sup>200</sup> also contemplate the following research challenges: (6) risk management, (7) low-power and low-cost communication, (8) connectivity and (9) trust.

Balsamo et al.<sup>192</sup> focus on the challenges of autonomous IoT wearable devices for IoT-based SCs. They address the following perspectives: (1) IoT wireless communication infrastructure and reliability; (2) energy management; (3) wearable electronic fabrication, interconnection and reliability in day life and washing; and (4) smart software design that can handle redundant or unwanted noise, encourage participation and achieves situation awareness.

**Security.** Regarding security of a SC, Elmaghraby and Losavio<sup>193</sup> point out the major issues related to privacy with the stored data, such as the location (GPS data can provide information about daily itinerary or home address), contact lists and messages. Baig et al.<sup>194</sup> summarise the challenges for the SC data landscape as (1) smart grids, (2) building automation systems, (3) unmanned aerial vehicles, (4) smart vehicles, (5) IoT sensors and (6) cloud, in which they list the data sources and security threads. Zhang et al.<sup>195</sup> identify three security challenges: (1) the crowdsensing (using sensing devices of local residents) requires to incentive or motivate citizens to participate but also taking into consideration the trustworthiness and their privacy; (2) identifying false data injections; and (3) due to the new era of big data, there is a need for new policies of data privacy, availability and management.

**Sustainability.** The sustainability in SCs is an underdeveloped concept which requires to solve several challenges. Höjer and Wangel<sup>196</sup> present five issues to address: (1) strategic assessment of the indicators to define the importance of a SC and help to define priorities; (2) mitigate the effect of the ICT in the improvement of the infrastructure, as their benefits also come with a deterioration of the ecosystems; (3) products, services and systems that are created by big companies may monopolise and harm the sustainability of the city while the ones managed by small initiatives are difficult to take them to the next level in order to create a big change; (4) cities ICT knowledge must be increased in order to equal big companies and be able to make adequate ICT requests; and (5) a specialised group to assess the investment in ICT should be created to aid the city government in order to focus on a sustainable growth.

**Traffic.** In the domain of smart traffic, concerning the TMS, Djahel et al.<sup>112</sup> observe some open challenges. There is a critical challenge in the synchronisation of

the information gathered, as it is difficult to correlate information from different sources. Some steps towards the standardisation have been taken, but its application is still very limited. The storage is also a challenge related to the gathering of data. In addition, the amount and complexity of data is exponentially increasing, which poses another challenge. In fact, the exchange of the data and its processing are also part of the problem. A domain inside smart traffic is the smartness of the roads, for example for automatically detecting incidents. Some challenges in these approaches are the natural contingencies such as glare, snow, rain and shadow.<sup>197</sup>

**Waste management.** In underdeveloped or developing countries, waste management is still an issue to be addressed. However, various gaps make difficult to implement waste management programmes. For example, for the case of India, Joshi and Ahmed<sup>198</sup> point out the following gaps: (1) there is not an organised or scientifically planned segregation of the waste at household and community bin level; (2) collection strategies should be improved, as community bins are used by households and the surrounding commercial sector; (3) recycling is impossible as all the waste goes to the same bin, even though the material could be reused to create new products; (4) the available transportation systems is not adequate to cover the whole system and is not efficient; (5) they follow unscientific disposal of waste, some of it may get lost in the cities without ever reaching the dumping site; and (6) public private partnership usually does not fulfil both sides' goals and aspirations with their stakeholders.

With respect to electronic waste (e-waste), in India they started talking about this topic in 2011 and nowadays there are still some challenges to tackle in order to fully implement the e-waste management:<sup>199</sup> (1) lack of infrastructure, (2) the rules for e-waste management must be changed, (3) eco-awareness training for citizens, (4) poor people in India cannot be engaged in waste management when they are more worried about money, (5) people in India are not willing to hand over obsolete electronic equipment, (6) waste management programmes are an additional cost for the budget of India and (7) products have a longer life time due to all the reparations done, even though those products may be polluting the environment.

## Discussion

Throughout this document, we have reviewed the main components of a SC: (1) starting with the different definitions given to the concept of SC in the 'Definitions of smart city' section; then (2) the technological pipelines and data flows of the literature in the 'Smart city

architectures' section; after that, (3) an overview of the different domains of applications used in the literature is provided in the 'Application domains' section; (4) the 'Case studies' section presents an updated summary of the implementations of SCs around the world; followed by (5) the review of open research challenges and issues that are delaying the SCs to become a reality in the 'Open challenges' section.

Even though the SCs are getting popular and more real-world implementations are being developed, there is still a lack of a proper basis; starting from standardising a formal definition of what a SC is. From the literature review of definitions, it is clear that there is not a consensus on the requirements or attributes that characterise the *smartness* that those cities strive to achieve. Therefore, a major advance in the field would be given by applying the same definition for every research in order to follow the same direction.

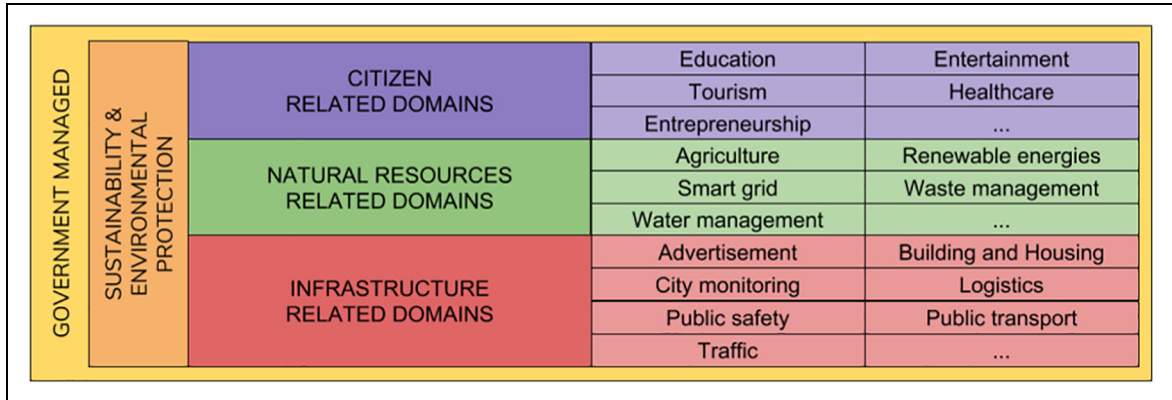
As an effort to provide a first approach, we can argue that the first issue is to consider if the introduction of the ICTs is what makes a city smart or the technology is a key addition but not the basis. Authors who support technology-based definitions of SCs (1) use the ICTs as tools to improve their performance in various domains or (2) argue that the use of ICTs inherently makes the city smart. In the former, the technology is used as a support rather than as the main driver of the smartness while, in the latter, the essence is rooted in the ICTs. Despite the benefits of the ICTs, solely the introduction of technology does not make a city secure and safe, it does not provide food, water, electricity and other basic needs and it does not protect the environment by itself (this can be seen in Monzon,<sup>19</sup> in which it is stated that specific regions suffer from this issue). For example, even though the entire traffic system may be monitored and the data may be shared with the citizens, basic needs and services might not be provided by the government. Can a city like that be considered a SC?

The point is that the technology is a major tool to make a city smart, but it does not create a SC only by itself. However, it does help to improve services such as education, healthcare, security and so forth, as seen in the 'Application domains' section, and also to connect the city and its citizens. Therefore, a definition of a SC needs to include the requirements of (1) the satisfaction of the basic needs (water, food, electricity and so on) and (2) the introduction of the ICTs to make a significant improvement in several areas. Nevertheless, both elements are not separable: without the basic needs satisfied, the technology is useless; and without the technology, even though citizens may be fully satisfied, the city is not smart. To summarise, the integration of the ICTs and the fulfilment of basic needs and services as a whole, without separation, create the basis for a SC.

By the literature review done in the 'Definitions of smart city' section, it is clear that the technology-based definitions or the ones that focus on the data or the integration of systems do not fit our cosmivision of SCs, as they focus on the technology rather than the satisfaction of basic needs. The domain-based definitions are closer to our definition proposal, taking into account citizens' needs and their well-being. The definition given by Caragliu et al.<sup>13</sup> would be the most promising one following our proposal: one of the main goals is promoting the quality of life and the technology is used alongside the human and social capital to achieve that goal.

Moreover, whenever a city plans to become smart, it must tackle the issues arising from the definition itself. The literature mentions a wide range of challenges, divided by domains. However, there must be a priority assigned to each challenge. First of all, following our definition proposal, a city must cover its inhabitants' needs and provide basic services. For underdeveloped or developing countries this should be the top priority. Second, following our definition of a SC, the next step should be the introduction of the ICTs. Nonetheless, this may be a mistake in some cases, as there may be a challenge to tackle before taking this step: training the technologically illiterate citizens. Otherwise, the ICTs are going to be an obstacle rather than a helpful tool. These people are usually the elderly or people from underdeveloped countries where the access to technology is limited.<sup>19</sup> Even though some cities have started to address this issue (as mentioned in the 'Case studies' section), this challenge is not widely covered in the literature and should be addressed better.<sup>201</sup>

In addition, the introduction of the ICTs comes domain-wise, that is, they are applied to specific domains (healthcare, transport, education and so forth). Based on the taxonomies of the literature, some applications can be assigned to multiple domains, which would be interesting to avoid. A solution we propose here is establishing a hierarchy of domains in order to avoid the issue (see Figure 2). The atomic domains would be citizen-related domains (entertainment, tourism or healthcare, among others), natural resources-related domains (water and waste management, food waste management, smart grids, renewable energies and so on) and infrastructure (building, housing, public spaces and so forth). These depend on the government of the city, which manages them. We argue that these domains must be considered from the viewpoint of sustainability and the protection and promotion of the environment. In the majority of taxonomies proposed in the literature, the environment protection and sustainability are considered as specific categories. However, other domains also take into account environmental measures, which creates the problem of multiple possible assignments of a subdomain to various



**Figure 2.** Our proposed domain taxonomy, grouping atomic domains within categories (purple, green and red boxes), to avoid the multiple assignment of domains to various categories. Examples of atomic categories are given in the right part of the figure. The orange box shows the requirement of sustainability and environmental protection that affects all three categories and their domains. Then, the yellow box includes all the previous domains and requirements inside as the government is the one on charge of managing them.

categories. Nonetheless, if both sustainability and environmental protection are considered requirements and not domains, the multiple assignment issue is no longer a challenge. Furthermore, all the challenges arising in the literature should be ordered by priorities; future work should cover how to address this task and provide guidelines to go from a basic city which covers basic needs and services to a SC.

After planning the process to become a SC, a question arises: is it possible to optimise the pipeline? In the ‘Common architectures’ section, we have presented the most common architectures and paradigms to build an IoT-based SC. However, depending on the cities, the architectures are modified to adapt it to their specific needs and requirements. However, we believe that defining the architecture and protocols that a smart city will use before starting with projects and works for its implementation will help reduce costs and problems in the future.

To tackle this challenge, there are various potential solutions which can be used to standardise the architecture. First, the creation of a committee to set up the best practices to implement the basic technical structure in each city<sup>196</sup> and provide the basic tools to gather data from different IoT devices and exploit it. This committee would create a convention to unify the communication interoperability between IoT devices, sensors, actuators and so on forth with the storage layer as presented by Kafle et al.<sup>202</sup> Second, an agreement between different hardware companies to create a unified communication system to consolidate the process of data extraction and storage. This agreement would be critical to ensure that different devices are capable

of sending information and storing it in the same way, providing a unified data representation format. Third, the definition of the data exploitation, making decisions about the granularity of the data that it is possible to consume based on different roles, for example, governments, companies and researchers. This would ensure that the proposed third-party solutions would exclusively use the data that they have been granted access to.

Regarding how the SC paradigm is being implemented nowadays, after analysing several cities, we consider it is worth noticing that most of the cities have not been able to go further than creating an open data portal yet, providing free Wi-Fi and some smartphone applications to receive feedback from citizens. Thus, very few cities have been able to use their own data to offer new utilities to the city and its citizens by their own means or through private companies. Therefore, we believe that SCs should be able to successfully use all the collected data to offer innovative services to their citizens. This could be promoted either using public investment or encouraging private companies through incentives to use publicly available data or infrastructures to create smart city utilities.

Furthermore, we also believe that it is very important for cities to define a SC roadmap where future steps that the city should take are clearly planned and designed. There are some cities which have carried out some interesting initiatives unrelated with each other and without long-term planning. However, these approaches do not allow a long-term maintenance of the initiatives and prevent any collaboration between the different groups working on them.

Therefore, one of the main conclusions drawn from this article is that those cities aiming to become a SC should design a long-term roadmap and create a specific department assigned to coordinate that task, as previously mentioned in this section.

### **Best practices**

For the sake of designing better roadmaps, an analysis of the best practices in implementing SCs should be taken into account. For example, in the case of data privacy: the development of SCs involves the acquisition, processing and analysis of data from the activities that people carry out in cities. How all the gathered data by public and private companies is used is a raising concern in our society. These data contain any kind of sensitive information of people's daily habits and routines. Public and private entities could misuse the collected citizens' data on their favour, going against data protection laws ([https://www.google.com/url?q=https://informationisbeautiful.net/visualizations/worlds-biggest-data-breaches-hacks/&sa=D&source=hangouts&ust=1544702056223000&usg=AFQjCNE5vYGuF8YpWIAFVCvz\\_SDo0cTedw](https://www.google.com/url?q=https://informationisbeautiful.net/visualizations/worlds-biggest-data-breaches-hacks/&sa=D&source=hangouts&ust=1544702056223000&usg=AFQjCNE5vYGuF8YpWIAFVCvz_SDo0cTedw)). For instance, cities could use the gathered data to create a social control condition in which these data are used to monitor citizens and restrict their freedom. We believe that this approach is not ethically correct, as it transgresses against the privacy of people, a right recognised in the Universal Declaration of Human Rights (<http://www.un.org/en/universal-declaration-human-rights/>).

However, the data privacy problem is not an issue that has been widely addressed in most of the cities we have analysed in the 'Case studies' section with the exception of Seattle, where this concern is being addressed in a very interesting way. Seattle's privacy programme obliges to analyse, from a privacy standpoint, any proposed dataset to become public.

Moreover, Seattle publishes a report of each and every one of their surveillance technologies. In these reports, questions such as how and when the data are gathered and used, how and where is the data stored and deleted or who can use the data are answered. In addition, each of these technologies is presented in public meetings where any citizen can ask questions or express their concerns regarding the technology.

Therefore, we believe that programmes such as the one proposed by Seattle's City Council are much needed to promote transparency and facilitate citizens information about how these technologies work, reducing the possibilities of the misuse of the information by third parties. In fact, promoting transparency in procedures, technology and data is key to gain the trust of the citizens in the SC.

Another major best practice is creating specific programmes for the inclusion of immigrants, individuals

who lack housing and people in risk of exclusion. There should not exist second-class citizens and the government of the city must take responsibility for them. Moreover, the ICTs may ease or difficult the accessibility to move around the city or access its infrastructure. For example, buildings with no lifts, ramps and so on; applications not prepared for people with health conditions or impairments; and so forth. This should be taken into account within the inclusion programmes as pivotal practices and, besides, they should be considered too in the urban planning of the city.

The constantly changing employers' needs and demands require re-thinking the education. As stated by Zhu et al.,<sup>178</sup> education will have to cope with the evolving technology, this includes preparing the population for the rapidly growing demands of the market in terms of technologies such as the IoTs or the Artificial Intelligence. Even though it is a challenging task, it is necessary to connect the education with the evolution of the technology. Building a bridge between both worlds is a task that has to be addressed in a SC roadmap.

Regarding the architecture and infrastructure to develop a SC, cities should start by designing the architecture and the standards that projects and applications implemented in the city will use. This plan will help to implement future projects and services in a quicker and easier way. This plan should include the communication standards and requirements that new infrastructures should have. Thanks to the standardisation and planning of the SC architecture new projects will have some guidelines to meet in their development and the implementation will be smoother.

### **Research opportunities**

Given the knowledge acquired through the literature review, we are presenting now the research opportunities that we believe that are promising and relevant in the area. As the list of pending research lines have been proposed taking into account the references shown in this article, we are not providing specific references as it is content created by merging all the ideas presented here. In fact, other authors have also discussed research opportunities in the area. For example, Lim et al.<sup>203</sup> state there is a need of (1) policy development and ICTs application towards developing smart cities with big data; (2) more reference models of applications with big data, challenges and considerations should be identified based on other analysis and projects; and (3) more review papers that integrate the existing studies. The following paragraphs show the lines of research that still need more analysis and development.

Even though more actions should be taken towards the better management of sensible information, more research should be done in techniques (such as AI) that

can handle encrypted information without any loss in terms of performance with respect to the original data. For example, using encrypted images from surveillance cameras would alleviate the feeling of being monitored. In fact, edge and fog computing (discussed in the ‘Smart city architectures’ section) can also help to solve this problem by keeping all the computations done locally, preventing data to be leaked to a third person. Furthermore, there is a new technology that was devised to build trust between different stakeholders, Blockchain. In this regard, Blockchain is also a potential technology for solving privacy and data management issues in the context of SCs. However, most of the Blockchain implementations are not conceived for SCs and citizens’ data management. Besides, to the best of our knowledge, no development providing a framework to integrate Blockchain with other SC services has been proposed. This is a whole area where researchers can contribute working on frameworks, standards and theoretical approaches.

Moreover, there is some research to be done in the field of education. SCs are continuously adding new services and applications for citizens to use. However, some citizens may not have the training to use these ICT-enabled services and applications. Therefore, an opportunity to research would be to look for an effective way in which cities could train their citizens and teach them how to use and understand the new concepts.

It is possible that the most relevant research effort is done in the healthcare domain, as knowledge fields such as bioinformatics and biomedical image analysis are becoming increasingly popular. ICTs are planned to be steadily included in this domain in order to improve services in clinics and hospitals, but more research is needed to improve the performance and accuracy of that technology in order to be fully accepted by patients and normalise the introduction of ICTs in the domain. In fact, research done in the field of human–computer interaction can be helpful to ease the acceptance of technology.

Computer Vision research is quite important in the healthcare domain but can be applied in other domains such as smart traffic (to improve TMSs), city monitoring (for safety purposes, taking into account the issue of privacy), logistics and advertisement. Pushing this field forward and applying new techniques within SCs could be a major improvement.

Other major research lines involve food and water management around the globe. Regarding the latter, there is some research done in the field of water management and its control in places where it is a common resource but few of them have focus in the management and its storage in places with difficult access to it. In

the field of food, as we stated in the ‘Business-related domains’ section, there has been some research conducted in the field of vertical farming. This field has not been very well explored yet, so it is possible to advance along this line in several areas (construction of buildings, crop management, transgenic research, and so on).

In conclusion, the implementation of SCs is still lacking some basis: the definition of the concept and the standardisation of its pipeline; addressing the biggest challenges (such as providing basic needs and services and promoting the sustainability and environmental protection) and following a roadmap which satisfies a best practice guideline that is still not settled in the field of SCs. This article has comprised the information extracted from the state of the art in order to answer the above issues and to be a helpful resource for the scientific community.

### Acknowledgements

We gratefully acknowledge the support of the Basque Governments Department of Education for the predoctoral funding of some of the authors.

### Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

### Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work has been supported by the Spanish Government under the FuturAAL-Ego project: RTI2018-101045-A-C22 and by the Basque Government under the Deustek project: IT-1078-16-D.

### ORCID iD

Ruben Sánchez-Corcuera  <https://orcid.org/0000-0002-6361-0901>

### References

1. DESAP U. *World urbanization prospects: the 2014 revision highlights (ST/ESA/SER. A/352)*. New York: Population Division, Department of Economic and Social Affairs, United Nations, 2014.
2. Cocchia A. Smart and digital city: a systematic literature review. In: Dameri R (ed.) *Smart city*. Cham: Springer, 2014, pp.13–43.
3. Javidroozi V, Shah H, Amini A, et al. Smart city as an integrated enterprise: a business process centric framework addressing challenges in systems integration. In:

- Proceedings of 3rd international conference on smart systems, devices and technologies*, Paris, 20–24 July 2014, pp.55–59. Wilmington, DE: IARIA.
4. Yin C, Xiong Z, Chen H, et al. A literature survey on smart cities. *Sci China Inform Sci* 2015; 58(10): 1–18.
  5. Coe A, Paquet G and Roy J. E-governance and smart communities: a social learning challenge. *Soc Sci Comput Rev* 2001; 19(1): 80–93.
  6. Palmisano SJ. A smarter planet: the next leadership agenda. *IBM* 2008; 6: 1–8.
  7. Washburn D, Sindhu U, Balaouras S, et al. Helping CIOs understand smart city initiatives. *Growth* 2009; 17(2): 1–17.
  8. Hall RE, Bowerman B, Braverman J, et al. The vision of a smart city. Technical report, Brookhaven National Lab, Upton, NY, 2000.
  9. Harrison C, Eckman B, Hamilton R, et al. Foundations for smarter cities. *IBM J Res Develop* 2010; 54(4): 1–16.
  10. Su K, Li J and Fu H. Smart city and the applications. In: *International conference on electronics, communications and control (ICECC)*, Ningbo, China, 9–11 September 2011, pp.1028–1031. New York: IEEE.
  11. Harrison C and Donnelly IA. A theory of smart cities. In: *Proceedings of the 55th annual meeting of the ISSS*, Hull, 17–22 July 2011, vol. 55, pp.1–15. New York: Curran Associates.
  12. Odendaal N. Information and communication technology and local governance: understanding the difference between cities in developed and emerging economies. *Comput Environ Urban Syst* 2003; 27(6): 585–607.
  13. Caragliu A, Del Bo C and Nijkamp P. Smart cities in Europe. *J Urban Technol* 2011; 18(2): 65–82.
  14. Lazaroiu GC and Roscia M. Definition methodology for the smart cities model. *Energy* 2012; 47(1): 326–332.
  15. Giffinger R, Fertner C, Kramar H, et al. City-ranking of European medium-sized cities, 2007, <http://www.srf.tu.wien.ac.at/kramar/publikationen/IFHP2007.pdf>
  16. Cook DJ and Youngblood M. Smart homes. In: Bainbridge WS (ed.) *Berkshire encyclopedia of human-computer interaction*. Great Barrington, MA: Berkshire Publishing Group, 2004, pp.623–626.
  17. Moss Kanter R and Litow SS. Informed and interconnected: a manifesto for smarter cities, 2009, <https://hbswk.hbs.edu/item/informed-and-interconnected-a-manifesto-for-smarter-cities>
  18. Dameri RP. Searching for smart city definition: a comprehensive proposal. *Int J Comput Technol* 2013; 11(5): 2544–2551.
  19. Monzon A. Smart cities concept and challenges: bases for the assessment of smart city projects. In: *International conference on smart cities and green ICT systems (SMARTGREENS)*, Lisbon, 20–22 May 2015, pp.1–11. New York: IEEE.
  20. Petrolo R, Loscri V and Mitton N. Towards a smart city based on cloud of things, a survey on the smart city vision and paradigms. *Trans Emerg Telecommun Technol* 2017; 28(1): e2931.
  21. Al-Hader M, Rodzi A, Sharif AR, et al. Smart city components architecture. In: *International conference on computational intelligence, modelling and simulation*, Brno, 7–9 September 2009, pp.93–97. New York: IEEE.
  22. Yamamoto S, Matsumoto S and Nakamura M. Using cloud technologies for large-scale house data in smart city. In: *International conference on cloud computing technology and science proceedings*, Taipei, Taiwan, 3–6 December 2012, pp.141–148. New York: IEEE.
  23. Longo F, Puliafito A and Rana O. Guest editors introduction to the special issue on fog, edge, and cloud integration for smart environments. *ACM Trans Internet Technol* 2019; 19(2): 17.
  24. Almeida A, Mulero R, Rametta P, et al. A critical analysis of an IoT-aware AAL system for elderly monitoring. *Future Gener Comput Syst* 2019; 97: 598–619.
  25. Mell P and Grance T. *The NIST definition of cloud computing* (NIST special publication 800–145). National Institute of Standards and Technology, Gaithersburg, MD, 2011.
  26. Kaur MJ and Maheshwari P. Building smart cities applications using IoT and cloud-based architectures. In: *International conference on industrial informatics and computer systems (CIICS)*, Sharjah, United Arab Emirates, 13–15 March 2016, pp.1–5. New York: IEEE.
  27. Biswas K and Muthukkumarasamy V. Securing smart cities using blockchain technology. In: *Proceedings of the 18th international conference on high performance computing and communications; 14th international conference on smart city; 2nd international conference on data science and systems (HPCC/SmariCity/DSS)*, Sydney, NSW, Australia, 12–14 December 2016, pp.1392–1393. New York: IEEE.
  28. Mazza D, Tarchi D and Corazza GE. A unified urban mobile cloud computing offloading mechanism for smart cities. *IEEE Commun Mag* 2017; 55(3): 30–37.
  29. Khanna A and Anand R. IoT based smart parking system. In: *International Conference on Internet of Things and applications (IOTA)*, Pune, India, 22–24 January 2016, pp.266–270. New York: IEEE.
  30. Bar-Magen Numhauser J. *Fog computing introduction to a new cloud evolution*. Alcalá de Henares: University of Alcalá, 2012.
  31. Bruneo D, Distefano S, Longo F, et al. Stack4Things as a fog computing platform for smart city applications. In: *Conference on computer communications workshops (INFOCOM WKSHPS)*, San Francisco, CA, 10–14 April 2016, pp.848–853. New York: IEEE.
  32. Chen N, Chen Y, You Y, et al. Dynamic urban surveillance video stream processing using fog computing. In: *Proceedings of the 2nd international conference on multimedia big data (BigMM)*, Taipei, Taiwan, 20–22 April 2016, pp.105–112. New York: IEEE.
  33. Santos J, Wauters T, Volckaert B, et al. Fog computing: enabling the management and orchestration of smart city applications in 5G networks. *Entropy* 2017; 20(1): 4.
  34. Barik RK, Dubey H, Samaddar AB, et al. FogGIS: fog computing for geospatial big data analytics. In: *Uttar Pradesh section international conference on electrical, computer and electronics engineering (UPCON)*, Varanasi, India, 9–11 December 2016, pp.613–618. New York: IEEE.

35. Shi W, Cao J, Zhang Q, et al. Edge computing: vision and challenges. *IEEE Internet Things J* 2016; 3(5): 637–646.
36. Taleb T, Dutta S, Ksentini A, et al. Mobile edge computing potential in making cities smarter. *IEEE Commun Mag* 2017; 55: 38–43.
37. Wang X, Yang LT, Xie X, et al. A cloud-edge computing framework for cyber-physical-social services. *IEEE Commun Mag* 2017; 55(11): 80–85.
38. Ji Z, Ganchev I, O'Droma M, et al. A cloud-based car parking middleware for IoT-based smart cities: design and implementation. *Sensors* 2014; 14(12): 22372–22393.
39. Patti E and Acquaviva A. IoT platform for smart cities: requirements and implementation case studies. In: *Proceedings of the 2nd international forum on research and technologies for society and industry leveraging a better tomorrow (RTSI)*, Bologna, 7–9 September 2016, pp.1–6. New York: IEEE.
40. Cheng B, Longo S, Cirillo F, et al. Building a big data platform for smart cities: experience and lessons from Santander. In: *International congress on big data (Bigdata Congress)*, New York, 27 June–2 July 2015, pp.592–599. New York: IEEE.
41. Petrolo R, Loscri V and Mitton N. Towards a smart city based on cloud of things. In: *Proceedings of the 2014 ACM international workshop on Wireless and mobile technologies for smart cities*, Philadelphia, PA, 11 August 2014, pp.61–66. New York: ACM.
42. Lea R and Blackstock M. City hub: a cloud based IoT platform for smart cities. In: *Proceedings of the 6th international conference on cloud computing technology and science*, Singapore, 15–18 December 2014. New York: IEEE.
43. Mitton N, Papavassiliou S, Puliafito A, et al. Combining cloud and sensors in a smart city environment. *J Wireless Commun Netw* 2012; 2012: 247.
44. Fox GC, Kamburugamuve S and Hartman RD. Architecture and measured characteristics of a cloud based Internet of Things. In: *International conference on collaboration technologies and systems (CTS)*, Denver, CO, 21–25 May 2012, pp.6–12. New York: IEEE.
45. Mulero R, Almeida A, Azkune G, et al. An IoT-aware approach for elderly-friendly cities. *IEEE Acc* 2018; 6: 7941–7957.
46. Helbostad JL, Vereijken B, Becker C, et al. Mobile health applications to promote active and healthy ageing. *Sensors* 2017; 17(3): 622.
47. Stavrotheodoros S, Kaklanis N, Votis K, et al. A smart-home IoT infrastructure for the support of independent living of older adults. In: *IFIP international conference on artificial intelligence applications and innovations*, Rhodes, 25–27 May 2018, pp.238–249. Cham: Springer.
48. Djaja-Josko V and Kolakowski J. UWB positioning system for elderly persons monitoring. In: *Proceedings of the 23rd telecommunications forum Telfor (TELFOR)*, Belgrade, 24–26 November 2015, pp.169–172. New York: IEEE.
49. Bonino D, Alizo MTD, Alapetite A, et al. ALMANAC: Internet of Things for smart cities. In: *Proceedings of the 3rd international conference on future Internet of Things and cloud*, Rome, 24–26 August 2015, pp.309–316. New York: IEEE.
50. Psomakelis E, Aisopos F, Litke A, et al. Big IoT and social networking data for smart cities: algorithmic improvements on big data analysis in the context of radical city applications, 2016, <https://arxiv.org/abs/1607.00509>
51. Zheng Y, Liu T, Wang Y, et al. Diagnosing New York City's noises with ubiquitous data. In: *Proceedings of the international joint conference on pervasive and ubiquitous computing*, Seattle, WA, 13–17 September 2014, pp.715–725. New York: ACM.
52. Longo F, Bruneo D, Distefano S, et al. Stack4Things: a sensing-and-actuation-as-a-service framework for IoT and cloud integration. *Ann Telecommun* 2017; 72(1–2): 53–70.
53. Tang B, Chen Z, Hefferman G, et al. A hierarchical distributed fog computing architecture for big data analysis in smart cities. In: *proceedings of the ASE BigData & socialinformatics*, Kaohsiung, Taiwan, 7–9 October 2015, p.28. New York: ACM.
54. Giffinger R and Gudrun H. Smart cities ranking: an effective instrument for the positioning of the cities? *ACE* 2010; 4(12): 7–26.
55. Neirotti P, De Marco A, Cagliano AC, et al. Current trends in smart city initiatives: some stylised facts. *Cities* 2014; 38: 25–36.
56. Liu P and Peng Z. China's smart city pilots: a progress report. *Computer* 2014; 47(10): 72–81.
57. Lombardi P, Giordano S, Farouh H, et al. Modelling the smart city performance. *Innovation* 2012; 25(2): 137–149.
58. Albino V, Berardi U and Dangelico RM. Smart cities: definitions, dimensions, performance, and initiatives. *J Urban Technol* 2015; 22(1): 3–21.
59. Gharaibeh A, Salahuddin MA, Hussini SJ, et al. Smart cities: a survey on data management, security, and enabling technologies. *IEEE Commun Surv Tutor* 2017; 19(4): 2456–2501.
60. Salo J. The success factors of mobile advertising value chain. *Bus Rev* 2004; 4(1): 93–97.
61. Shiva G and Raajan N. Augmented reality: the future tense of 3D advertisement. In: *International conference on computer communication and informatics*, Coimbatore, India, 4–6 January 2013, pp.1–4. New York: IEEE.
62. Yang B, Kim Y and Yoo C. The integrated mobile advertising model: the effects of technology-and emotion-based evaluations. *J Business Res* 2013; 66(9): 1345–1352.
63. Finn RL and Wadhwa K. The ethics of smart advertising and regulatory initiatives in the consumer intelligence industry. *INFO* 2014; 16(3): 22–39.
64. Carter-Harris L, Ellis RB, Warrick A, et al. Beyond traditional newspaper advertisement: leveraging Facebook-targeted advertisement to recruit long-term smokers for research. *J Med Internet Res* 2016; 18: e117.
65. Lipper L, Thornton P, Campbell BM, et al. Climate-smart agriculture for food security. *Nature Climate Change* 2014; 4(12): 1068.
66. Baranwal T, Nitika and Pateriya PK. Development of IoT based smart security and monitoring devices for agriculture. In: *Proceedings of the 6th international conference on cloud system and big data engineering (Confluence)*, Noida, India, 14–15 January 2016, pp.597–602. New York: IEEE.

67. Kalantari F, Mohd Tahir O, Mahmoudi Lahijani A, et al. A review of vertical farming technology: a guide for implementation of building integrated agriculture in cities. *Adv Eng Forum* 2017; 24: 76–91.
68. Harvey D. From managerialism to entrepreneurialism: the transformation in urban governance in late capitalism. *Geografiska Annaler* 1989; 71(1): 3–17.
69. Hollands RG. Will the real smart city please stand up? Intelligent, progressive or entrepreneurial? *City* 2008; 12(3): 303–320.
70. Datta A. New urban utopias of postcolonial India: entrepreneurial urbanization in Dholera smart city, Gujarat. *Dial Hum Geograp* 2015; 5(1): 3–22.
71. Allwinkle S and Cruickshank P. Creating smart-er cities: an overview. *J Urban Technol* 2011; 18(2): 1–16.
72. Chourabi H, Nam T, Walker S, et al. Understanding smart cities: an integrative framework. In: *Proceedings of the 45th Hawaii international conference on system science (HICSS)*, Maui, HI, 4–7 January 2012, pp.2289–2297. New York: IEEE.
73. Mulligan CE and Olsson M. Architectural implications of smart city business models: an evolutionary perspective. *IEEE Commun Mag* 2013; 51(6): 80–85.
74. Kawa A. Smart logistics chain. In: *Asian conference on intelligent information and database systems*, Kaohsiung, Taiwan, 19–21 March 2012, pp.432–438. Cham: Springer.
75. Nowicka K. Smart city logistics on cloud computing model. *Proc Soc Behav Sci* 2014; 151: 266–281.
76. Pelletier S, Jabali O and Laporte G. 50th anniversary invited article – goods distribution with electric vehicles: review and research perspectives. *Transp Sci* 2016; 50(1): 3–22.
77. Nakamoto S. Bitcoin: a peer-to-peer electronic cash system, 2008, <https://bitcoin.org/bitcoin.pdf>.
78. Perera C, Zaslavsky A, Christen P, et al. Sensing as a service model for smart cities supported by Internet of Things. *Trans Emerg Telecommun Technol* 2014; 25(1): 81–93.
79. Sun J, Yan J and Zhang KZ. Blockchain-based sharing services: what blockchain technology can contribute to smart cities. *Financial Innovat* 2016; 2(1): 26.
80. Roy HE, Pocock MJ, Preston CD, et al. Understanding citizen science and environmental monitoring: final report on behalf of UK environmental observation framework, 2012, <http://nora.nerc.ac.uk/id/eprint/20679/>
81. Craglia M and Granell C. *Citizen science and smart cities*. Luxembourg: European Commission, 2014, p.54.
82. Hwang GJ. Definition, framework and research issues of smart learning environments—a context-aware ubiquitous learning perspective. *Smart Learn Environ* 2014; 1(1): 4.
83. Wolff A, Kortuem G and Cavero J. Towards smart city education. In: *Sustainable internet and ICT for sustainability*, Madrid, 14–16 April 2015, pp.1–3. New York: IEEE.
84. Zhuang R, Fang H, Zhang Y, et al. Smart learning environments for a smart city: from the perspective of lifelong and lifewide learning. *Smart Learn Environ* 2017; 4(1): 6.
85. Edirisinghe C, Nijholt A and Cheok AD. From playable to playful: the humorous city. In: *International conference on intelligent technologies for interactive entertainment*, Utrecht, 28–30 June 2016, pp.261–265. Cham: Springer.
86. Nijholt A. Playable cities: a short survey (keynote paper). In: *Proceedings of the 6th international conference on informatics, electronics and vision & 7th international symposium in computational medical and health technology (ICIEV-ISCMT)*, Himeji, Japan, 1–3 September 2017, pp.1–6. New York: IEEE.
87. Andujar M, Nijholt A and Gilbert JE. Mobile augmented games in playable cities: humorous interaction with Pokémongo. In: *Proceedings of the 5th international conference on distributed, ambient and pervasive interactions*, Vancouver, BC, Canada, 7–14 July 2017, pp.575–586. Cham: Springer.
88. Nijholt A. Mischief humor in smart and playable cities. In: Nijholt A (ed.) *Playable cities*. Cham: Springer, 2017, pp.235–253.
89. Hamari J, Malik A, Koski J, et al. Uses and gratifications of Pokémon go: why do people play mobile location-based augmented reality games? *Int J Human Comput Interact* 2018; 35: 804–819.
90. Nijholt A. Playable cities for children? In: *International conference on applied human factors and ergonomics*, Orlando, FL, 21–25 July 2018, pp.14–20. Cham: Springer.
91. Prandi C, Melis A, Prandini M, et al. Gamifying cultural experiences across the urban environment. *Multimed Tool Appl* 2018; 78: 3341–3364.
92. Chen L, Hoey J, Nugent CD, et al. Sensor-based activity recognition. *IEEE Trans Syst Man Cyber C* 2012; 42(6): 790–808.
93. Acampora G, Cook DJ, Rashidi P, et al. A survey on ambient intelligence in healthcare. *Proc IEEE* 2013; 101(12): 2470–2494.
94. Movassaghi S, Abolhasan M, Lipman J, et al. Wireless body area networks: a survey. *IEEE Commun Surv Tutor* 2014; 16(3): 1658–1686.
95. Solanas A, Patsakis C, Conti M, et al. Smart health: a context-aware health paradigm within smart cities. *IEEE Commun Mag* 2014; 52(8): 74–81.
96. Holzinger A, Röcker C and Ziefle M. From smart health to smart hospitals. In: Holzinger A, Röcker C and Ziefle M (eds) *Smart health*. Cham: Springer, 2015, pp.1–20.
97. Hussain A, Wenbi R, da Silva AL, et al. Health and emergency-care platform for the elderly and disabled people in the smart city. *J Syst Software* 2015; 110: 253–263.
98. Bilbao-Jayo A, Almeida A and Lóez-de-Ipina D. Promotion of active ageing combining sensor and social network data. *J Biomed Inform* 2016; 64: 108–115.
99. Almeida A, Fiore A, Mainetti L, et al. An IoT-aware architecture for collecting and managing data related to elderly behavior. *Wireless Commun Mobile Comput* 2017; 2017: 5051915.
100. Azkune G and Almeida A. A scalable hybrid activity recognition approach for intelligent environments. *IEEE Acc* 2018; 6: 41745–41759.
101. Blythe PT. Improving public transport ticketing through smart cards. *Proc Inst Civil Eng* 2004; 157: 47–54.
102. Bagchi M and White PR. The potential of public transport smart card data. *Transp Policy* 2005; 12(5): 464–474.
103. Agard B, Morency C and Trépanier M. Mining public transport user behaviour from smart card data. *IFAC Proc Vol* 2006; 39(3): 399–404.

104. Pelletier MP, Trépanier M and Morency C. Smart card data use in public transit: a literature review. *Transp Res C Emerg Technol* 2011; 19(4): 557–568.
105. Devillaine F, Munizaga M and Trépanier M. Detection of activities of public transport users by analyzing smart card data. *Transp Res Rec* 2012; 2276: 48–55.
106. Yonezawa T, Matranga I, Galache JA, et al. A citizen-centric approach towards global-scale smart city platform. In: *International conference on recent advances in Internet of Things (RIoT)*, Singapore, 7–9 April 2015, pp.1–6. New York: IEEE.
107. Meneguette RI, Ueyama J, Krishnamachari B, et al. Enhancing intelligence in inter-vehicle communications to detect and reduce congestion in urban centers. In: *Proceedings 20th IEEE symposium on computers and communication (ISCC)*, Larnaca, 6–9 July 2015, pp.662–667. New York: IEEE.
108. Cambridge Systematics. Traffic congestion and reliability: trends and advanced strategies for congestion mitigation. Final report, Texas Transportation Institute, 2005, [https://ops.fhwa.dot.gov/congestion\\_report/](https://ops.fhwa.dot.gov/congestion_report/)
109. Araújo GB, Queiroz MM, de LP Duarte-Figueiredo F, et al. CARTIM: a proposal toward identification and minimization of vehicular traffic congestion for VANET. In: *Symposium on computers and communications (ISCC)*, Funchal, 23–26 June 2014, pp.1–6. New York: IEEE.
110. De Souza AM, Boukerche A, Maia G, Meneguette RI, et al. Decreasing greenhouse emissions through an intelligent traffic information system based on inter-vehicle communication. In: *Proceedings of the 12th international symposium on mobility management and wireless access*, Montreal, QC, Canada, 21–26 September 2014, pp.91–98. New York: IEEE.
111. De Souza AM and Villas LA. A new solution based on inter-vehicle communication to reduce traffic jam in highway environment. *IEEE Latin Am Trans* 2015; 13(3): 721–726.
112. Djahel S, Doolan R, Muntean GM, et al. A communications-oriented perspective on traffic management systems for smart cities: challenges and innovative approaches. *IEEE Commun Surv Tutor* 2015; 17: 125–151.
113. De Souza AM, Brennand CA, Yokoyama RS, et al. Traffic management systems: a classification, review, challenges, and future perspectives. *Int J Distrib Sensor Netw* 2017; 13(4): 1550147716683612.
114. Buhalis D and Amaranggana A. Smart tourism destinations. In: Xiang Z and Tussyadiah I (eds) *Information and communication technologies in tourism 2014*. Cham: Springer, 2013, pp.553–564.
115. Kamga C, Yazici MA and Singhal A. Implementation of interactive transit information kiosks at New York City transit facilities: analysis of user utilization and lessons learned. *Transp Res C Emerg Technol* 2013; 35: 218–231.
116. Gretzel U, Sigala M, Xiang Z, et al. Smart tourism: foundations and developments. *Electron Market* 2015; 25(3): 179–188.
117. Ekşioğlu M. User experience design of a prototype Kiosk: a case for the Istanbul public transportation system. *Int J Human Comput Interact* 2016; 32(10): 802–813.
118. Amessafi H, Jourani R, Echchelh A, et al. Building a smart interactive kiosk for tourist assistance. *Trans Mach Learn Artif Intell* 2017; 5: 622–627.
119. Gómez-Carmona O, Casado-Mansilla D and López-deIpiña D. Multifunctional interactive furniture for smart cities. *Proceedings* 2018; 2: 1212.
120. Sinky H, Khalfi B, Hamdaoui B, et al. Responsive content-centric delivery in large urban communication networks: a LinkNYC use-case. *IEEE Trans Wireless Commun* 2018; 17(3): 1688–1699.
121. Marszal A, Heiselberg P, Bourrelle J, et al. Zero energy building a review of definitions and calculation methodologies. *Energy Build* 2011; 43(4): 971979.
122. Kylii A and Fokaides P. European smart cities: the role of zero energy buildings. *Sustain Cities Soc* 2015; 15: 86–95.
123. Rathore M, Paul A, Ahmad A, et al. Urban planning and building smart cities based on the Internet of Things using big data analytics. *Comput Netw* 2016; 101: 63–80.
124. Kumar N, Vasilakos A and Rodrigues J. A multi-tenant cloud-based DC nano grid for self-sustained smart buildings in smart cities. *IEEE Commun Mag* 2017; 55(3): 14–21.
125. Cugurullo F. Exposing smart cities and eco-cities: Frankenstein urbanism and the sustainability challenges of the experimental city. *Environ Plan A* 2017; 50(1): 7392.
126. Raisul Alam M, Reaz M and Mohd Ali M. A review of smart homes past, present, and future. *IEEE Trans Syst Man Cyber C* 2012; 42(6): 1190–1203.
127. Risteska Stojkoska B and Trivodaliev K. A review of Internet of Things for smart home: challenges and solutions. *J Clean Product* 2017; 140(6): 1454–1464.
128. Tan TH, Gochoo M, Jean FR, et al. Front-door event classification algorithm for elderly people living alone in smart house using wireless binary sensors. *IEEE Acc* 2017; 5: 10734–10743.
129. Chen M, Yang J, Zhu X, et al. Smart home 2.0: innovative smart home system powered by botanical IoT and emotion detection. *Mobile Netw Appl* 2017; 22(6): 1159–1169.
130. Mehta Y, Pai MM, Mallisery S, et al. Cloud enabled air quality detection, analysis and prediction—a smart city application for smart health. In: *Proceedings of the 3rd MEC international conference on big data and smart city (ICBDSC)*, Muscat, Oman, 15–16 March 2016, pp.1–7. New York: IEEE.
131. Peng H, Bohong Z and Qinpei K. Smart city environmental pollution prevention and control design based on Internet of Things. *IOP C Ser Earth Env* 2017; 94: 012174.
132. Dutta J, Chowdhury C, Roy S, et al. Towards smart city: sensing air quality in city based on opportunistic crowd-sensing. In: *Proceedings of the 18th international conference on distributed computing and networking*, Hyderabad, India, 5–7 January 2017, pp.41:1–42:6. New York: ACM.
133. Filippini L, Vitaletti A, Landi G, et al. Smart city: an event driven architecture for monitoring public spaces with heterogeneous sensors. In: *Proceedings of the 4th*

- international conference on sensor technologies and applications*, Venice, 18–25 July 2010, pp.281–286. New York: IEEE.
134. Cömertler S. Greens of the European green capitals. *IOP Conf Ser-Mat Sci* 2017; 245: 052064.
  135. Lau BPL, Wijerathne N, Ng BKK, et al. Sensor fusion for public space utilization monitoring in a smart city. *IEEE Internet Things J* 2018; 5(2): 473–481.
  136. Mathiesen B, Lund H, Connolly D, et al. Smart energy systems for coherent 100% renewable energy and transport solutions. *Appl Energ* 2015; 145(1): 139–154.
  137. Connolly D, Lund H and Mathiesen B. Smart energy Europe: the technical and economic impact of one potential 100% renewable energy scenario for the European Union. *Renew Sust Energ Rev* 2016; 60(1): 16334–11653.
  138. Calvillo C, Sanchez-Miralles A and Villar J. Energy management and planning in smart cities. *Renew Sust Energ Rev* 2016; 55(1): 273–287.
  139. Kammen DM and Sunter DA. City-integrated renewable energy for urban sustainability. *Science* 2016; 352(6288): 922–928.
  140. Farhangi H. The path of the smart grid. *IEEE Power Energ Mag* 2010; 8(1): 18–28.
  141. Mwasilu F, Justo JJ, Kim E-K, et al. Electric vehicles and smart grid interaction: a review on vehicle to grid and renewable energy sources integration. *Renew Sust Energ Rev* 2014; 34(4): 501516.
  142. Fadel E, Gungor VC, Nassef L, et al. A survey on wireless sensor networks for smart grid. *Comput Commun* 2015; 70(1): 22–33.
  143. Moon S and Lee J-W. Multi-residential demand response scheduling with multi-class appliances in smart grid. *IEEE Trans Smart Grid* 2018; 9(4): 2518–2528.
  144. Aazam M, St-Hilaire M, Lung CH, et al. Cloud-based smart waste management for smart cities. In: *Proceedings of the 21st international workshop on computer aided modelling and design of communication links and networks (CAMAD)*, Toronto, ON, Canada, 23–25 October 2016, pp.188–193. New York: IEEE.
  145. Król A, Nowakowski P and Mrówczyńska B. How to improve WEEE management? novel approach in mobile collection with application of artificial intelligence. *Waste Manage* 2016; 50: 222–233.
  146. Anagnostopoulos T, Zaslavsky A, Kolomvatsos K, et al. Challenges and opportunities of waste management in IoT-enabled smart cities: a survey. *IEEE Trans Sustain Comput* 2017; 2(3): 275–289.
  147. Parra L, Sendra S, Lloret J, et al. Development of a conductivity sensor for monitoring groundwater resources to optimize water management in smart city environments. *Sensors* 2015; 15(9): 20990–21015.
  148. Zhao Y, Schwartz R, Salomons E, et al. New formulation and optimization methods for water sensor placement. *Environ Model Soft* 2016; 76: 128–136.
  149. Lin WC, Li Z and Burns MA. A drinking water sensor for lead and other heavy metals. *Anal Chem* 2017; 89(17): 8748–8756.
  150. Batty M, Axhausen KW, Giannotti F, et al. Smart cities of the future. *Euro Phys J Spec Top* 2012; 214(1): 481–518.
  151. Kitchin R. The real-time city? Big data and smart urbanism. *GeoJournal* 2014; 79(1): 1–14.
  152. Pereira GV, Parycek P, Falco E, et al. Smart governance in the context of smart cities: a literature review. *Inform Polity* 2018; 23: 143–162.
  153. Gil-García JR and Pardo TA. E-government success factors: mapping practical tools to theoretical foundations. *Govern Inf Quarter* 2005; 22(2): 187–216.
  154. Bonsón E, Torres L, Royo S, et al. Local e-government 2.0: social media and corporate transparency in municipalities. *Govern Inf Quarter* 2012; 29(2): 123–132.
  155. Bernardo MRM. Smart city governance: from e-government to smart governance. In: Carvalho LC (ed.) *Handbook of research on entrepreneurial development and innovation within smart cities*. Hershey, PA: IGI Global, 2017, pp.290–326.
  156. Dimakis N, Filippoupolitis A and Gelenbe E. Distributed building evacuation simulator for smart emergency management. *Comput J* 2010; 53(9): 1384–1400.
  157. Djahel S, Salehie M, Tal I, et al. Adaptive traffic management for secure and efficient emergency services in smart cities. In: *International conference on pervasive computing and communications workshops (PERCOM Workshops)*, San Diego, CA, 18–22 March 2013, pp.340–343. New York: IEEE.
  158. Barba CT, Mateos MA, Soto PR, et al. Smart city for VANETs using warning messages, traffic statistics and intelligent traffic lights. In: *Intelligent vehicles symposium (IV)*, Alcalá de Henares, 3–7 June 2012, pp.902–907. New York: IEEE.
  159. Vanolo A. Smartmentality: the smart city as disciplinary strategy. *Urban Stud* 2014; 51(5): 883–898.
  160. Jin J, Gubbi J, Marusic S, et al. An information framework for creating a smart city through Internet of Things. *IEEE Internet Things J* 2014; 1(2): 112–121.
  161. Nam T and Pardo TA. Conceptualizing smart city with dimensions of technology, people, and institutions. In: *Proceedings of the 12th annual international digital government research conference: digital government innovation in challenging times*, College Park, MD, 12–15 June 2011, pp.282–291. New York: IEEE.
  162. Emaldi M, Aguilera U, López-de-Ipiña D, et al. Towards citizen co-created public service apps. *Sensors* 2017; 17(6): E1265.
  163. Aguilera U, Peña O, Belmonte O, et al. Citizen-centric data services for smarter cities. *Future Gener Comput Syst* 2017; 76: 234–247.
  164. Paskaleva KA. Enabling the smart city: the progress of city e-governance in Europe. *Int J Innovat Region Develop* 2009; 1(4): 405–422.
  165. Bertot JC, Jaeger PT and Grimes JM. Using ICTs to create a culture of transparency: e-government and social media as openness and anti-corruption tools for societies. *Government Information Quarterly* 2010; 27(3): 264–271.
  166. Johannessen MR and Berntzen L. The transparent smart city. In: Rodríguez Bolívar M (eds) *Smart technologies for smart governments*. Cham: Springer, 2018, pp.67–94.
  167. Bilbao-Jayo A and Almeida A. Automatic political discourse analysis with multi-scale convolutional neural

- networks and contextual data. *Int J Distrib Sensor Netw* 2018; 14: 1550147718811827.
168. Hashem IAT, Chang V, Anuar NB, et al. The role of big data in smart city. *Int J Inf Manage* 2016; 36(5): 748–758.
  169. Van den Bergh J and Viaene S. Key challenges for the smart city: turning ambition into reality. In: *Proceedings of the 48th Hawaii international conference on system sciences*, Kauai, HI, 5–8 January 2015, pp.2385–2394. New York: IEEE.
  170. Pierce P and Andersson B. Challenges with smart cities initiatives: a municipal decision makers perspective. In: *Proceedings of the Hawaii international conference on system sciences*, 2017, pp.2804–2813. Institute of Electrical and Electronics Engineers, <https://lup.lub.lu.se/search/publication/b6702b98-e8aa-4620-9643-20c1c2bed969>
  171. Anand SK and Anand M. Smart cities: environmental challenges and green computing. *Int J Adv Res Comput Sci* 2017; 8, <http://www.ijarcs.info/index.php/ijarcs/article/view/3737>
  172. Silva BN, Khan M and Han K. Towards sustainable smart cities: a review of trends, architectures, components, and open challenges in smart cities. *Sustain Cities Soc* 2018; 38: 697–713.
  173. Al-Chalabi M. Vertical farming: skyscraper sustainability? *Sustain Cities Soc* 2015; 18: 74–77.
  174. Riffat S, Powell R and Aydin D. Future cities and environmental sustainability. *Future Cities Environ* 2016; 2(1): 1.
  175. Simonofski A, Asensio ES, De Smedt J, et al. Hearing the voice of citizens in smart city design: the citivoice framework. *Bus Inf Syst Eng*. Epub ahead of print 15 June 2018. DOI: 10.1007/s12599-018-0547-z.
  176. Irvin RA and Stansbury J. Citizen participation in decision making: is it worth the effort? *Public Admin Rev* 2004; 64(1): 55–65.
  177. Arnstein SR. A ladder of citizen participation. *J Am Inst Plan* 1969; 35(4): 216–224.
  178. Zhu ZT, Yu MH and Riezebos P. A research framework of smart education. *Smart Learn Environ* 2016; 3(1): 4.
  179. Martelli C. A point of view on new education for smart citizenship. *Future Internet* 2017; 9(1): 4.
  180. Moreno-Munoz A, Bellido-Outeirino F, Siano P, et al. Mobile social media for smart grids customer engagement: emerging trends and challenges. *Renew Sust Energy Rev* 2016; 53: 1611–1616.
  181. Herrero ST, Nicholls L and Strengers Y. Smart home technologies in everyday life: do they address key energy challenges in households? *Curr Opinion Environ Sustainabil* 2018; 31: 65–70.
  182. Yoldaş Y, Önen A, Muyeen S, et al. Enhancing smart grid with microgrids: challenges and opportunities. *Renew Sust Energy Rev* 2017; 72: 205–214.
  183. Colding J and Barthel S. An urban ecology critique on the ‘smart city’ model. *J Clean Product* 2017; 164: 95–101.
  184. Qu C, Shi W, Guo J, et al. China’s soil pollution control: choices and challenges. *Environ Sci Technol* 2016; 50: 13181–13183.
  185. Gavrilescu M, Demnerová K, Aamand J, et al. Emerging pollutants in the environment: present and future challenges in biomonitoring, ecological risks and bioremediation. *New Biotechnol* 2015; 32(1): 147–156.
  186. Wolch JR, Byrne J and Newell JP. Urban green space, public health, and environmental justice: the challenge of making cities just green enough. *Landscape Urban Plan* 2014; 125: 234–244.
  187. AlEnezi A, AlMeraj Z and Manuel P. Challenges of IoT based smart-government development. In: *Green technologies conference (GreenTech)*, Austin, TX, 4–6 April 2018, pp.155–160. New York: IEEE.
  188. Chen M, Ma Y, Song J, et al. Smart clothing: connecting human with clouds and big data for sustainable health monitoring. *Mobile Netw Appl* 2016; 21(5): 825–845.
  189. Mshali H, Lemlouma T, Moloney M, et al. A survey on health monitoring systems for health smart homes. *Int J Indus Ergonom* 2018; 66: 26–56.
  190. Ahmed E, Yaqoob I, Gani A, et al. Internet-of-things-based smart environments: state of the art, taxonomy, and open research challenges. *IEEE Wireless Commun* 2016; 23(5): 10–16.
  191. Sterbenz JP. Smart city and IoT resilience, survivability, and disruption tolerance: challenges, modelling, and a survey of research opportunities. In: *Proceedings of the 9th international workshop on resilient networks design and modeling (RNDM)*, Alghero, 4–6 September 2017, pp.1–6. New York: IEEE.
  192. Balsamo D, Merrett GV, Zaghari B, et al. Wearable and autonomous computing for future smart cities: open challenges. In: *Proceedings of the 25th international conference on software, telecommunications and computer networks (SoftCOM)*, Split, 21–23 September 2017, pp.1–5. New York: IEEE.
  193. Elmaghraby AS and Losavio MM. Cyber security challenges in smart cities: safety, security and privacy. *J Adv Res* 2014; 5(4): 491–497.
  194. Baig ZA, Szewczyk P, Valli C, et al. Future challenges for smart cities: cyber-security and digital forensics. *Digital Invest* 2017; 22: 3–13.
  195. Zhang K, Ni J, Yang K, et al. Security and privacy in smart city applications: challenges and solutions. *IEEE Commun Mag* 2017; 55(1): 122–129.
  196. Höjer M and Wangel J. Smart sustainable cities: definition and challenges. In: Hilty L and Aebischer B (eds) *ICT innovations for sustainability*. Cham: Springer, 2015, pp.333–349.
  197. Shehata MS, Cai J, Badawy WM, et al. Video-based automatic incident detection for smart roads: the outdoor environmental challenges regarding false alarms. *IEEE Trans Intell Transp Syst* 2008; 9(2): 349–359.
  198. Joshi R and Ahmed S. Status and challenges of municipal solid waste management in India: a review. *Cogent Environ Sci* 2016; 2(1): 1139434.
  199. Rathi S and Niyogi S. E-waste management: save earth. *Int J Comput Appl* 2015; 127(4): 1–4.
  200. Mehmood Y, Ahmad F, Yaqoob I, et al. Internet-of-things-based smart cities: recent advances and challenges. *IEEE Commun Mag* 2017; 55(9): 16–24.

201. Neves BB and Amaro F. Too old for technology? How the elderly of Lisbon use and perceive ICT. *J Commun Inform* 2012; 8(1): 1–12.
202. Kafle VP, Fukushima Y and Harai H. Internet of Things standardization in ITU and prospective networking technologies. *IEEE Commun Mag* 2016; 54(9): 43–49.
203. Lim C, Kim KJ and Maglio PP. Smart cities with big data: reference models, challenges, and considerations. *Cities* 2018; 82: 86–99.