*smart cities*

*Review*

# Role of Internet of Things (IoT) and Crowdsourcing in Smart City Projects

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**Abstract:** This paper presents and discusses the role of the Internet of Things (IoT) and crowdsourcing in constructing smart cities. The literature review shows an important and increasing concern of the scientific community for these three issues and their association as support for urban development. Based on an extensive literature review, the paper first presents the smart city concept, emphasizing smart city architecture and the role of data in smart city solutions. The second part presents the Internet of Things, focusing on IoT technology, the use of IoT in smart city applications, and security. Finally, the paper presents crowdsourcing with particular attention to mobile crowdsourcing and its role in smart cities. The paper shows that IoT and crowdsourcing have a crucial role in two fundamental layers of smart city applications, namely, the data collection and services layers. Since these two layers ensure the connection between the physical and digital worlds, they constitute the central pillars of smart city projects. The literature review also shows that the smart city development still requires stronger cooperation between the smart city technology-centered research, mainly based on the IoT, and the smart city citizens-centered research, mainly based on crowdsourcing. This cooperation could beneficiate in recent developments in the field of crowdsensing that combines IoT and crowdsourcing.

**Keywords:** crowdsourcing; IoT; mobile; monitoring; security; sensors; smart city; smart services



**Citation:** Shahrour, I.; Xie, X. Role of Internet of Things (IoT) and Crowdsourcing in Smart City Projects. *Smart Cities* **2021**, *4*, 1276–1292. https://doi.org/10.3390/smartcities4040068

Received: 23 July 2021
Accepted: 22 September 2021
Published: 1 October 2021



## 1. Introduction

This paper presents an analysis of research conducted in the Smart City, focusing on data, which constitutes the backbone of the smart city [1–5]. The contribution of this paper is threefold. The first one consists of the analysis of the evolution of research in the field of the smart city and two related technologies, namely, the IoT and crowdsourcing. This analysis provides a clear picture of the historical development of the research in these areas. The second contribution concerns an analysis of the research combining (i) the smart city and the IoT, (ii) the smart city and crowdsourcing, and finally, (iii) the smart city, the IoT, and crowdsourcing. Based on this analysis, we argue that, although significant research has been conducted on the smart city and the IoT and the smart city and crowdsourcing, research combining the smart city, the IoT, and crowdsourcing is still in the early stage. This analysis shows the necessity for stronger cooperation between the smart city technology-centered research, mainly based on the IoT, and the smart city citizens-centered research, mainly based on crowdsourcing. This cooperation is a must in developing comprehensive smart city solutions that combine both technology and citizens' participation. Furthermore, this cooperation could beneficiate in recent developments in the field of crowdsensing that combines IoT and crowdsourcing [6–9].

The last objective of this paper consists of discussing significant developments in the smart city, the IoT, and crowdsourcing with a focus on the technology, challenges, and latest developments related to the smart city.

In the past two decades, the smart city concept has emerged as a major disruptive ICT (Information and Communication Technology) innovation to improve cities' efficiency and quality of life and cope with environmental, social, and economic urban challenges. This concept has been spreading very quickly throughout the world. For example, the European Union launched several initiatives in this area intending to "bring together cities, industry, and citizens to improve urban life through more sustainable integrated solutions" (EIP-SCC) [10]. China started an ambitious smart city program with the objective of 500 smart city pilot projects (Deloitte 2018, Hu 2019) [11,12]. India has also initiated an important smart city program to develop 100 smart city projects (India Smart city, 2015) [13].

Since the smart city concept is tightly related to data collection and analysis, its development has been driven by and serves as a driver for the developments in two areas, namely, the Internet of Things (IoT) and crowdsourcing. The former is extensively used in smart city applications in sensing, data transmission, and system control. At the same time, the latter enables citizens' involvement in smart city projects through their active and passive participation in data collection about the city's functioning, services, quality of life, and environment.

The development in the field of the smart city, the IoT, and crowdsourcing has been supported by extensive academic activity. Figure 1 shows the variation of the annual number of the Web of Science indexed papers in these three fields during the period from 2010 to 2021. While Table 1 summarizes the total number of papers for the same period. We observe a great concern of scholars in the field of the IoT and the smart city, with a total number of papers of 57,311 and 21,459, respectively. In the early 2000s, the number of papers was low; then, it increased very quickly. In 2020, the number of papers about the IoT and the smart city was equal to 11,820 and 3831, respectively. Publication in crowdsourcing started in 2010, then increased with an inflection point in 2015. The number of papers in 2020 was about 1127, which also shows an increasing concern of scholars in this scientific area.

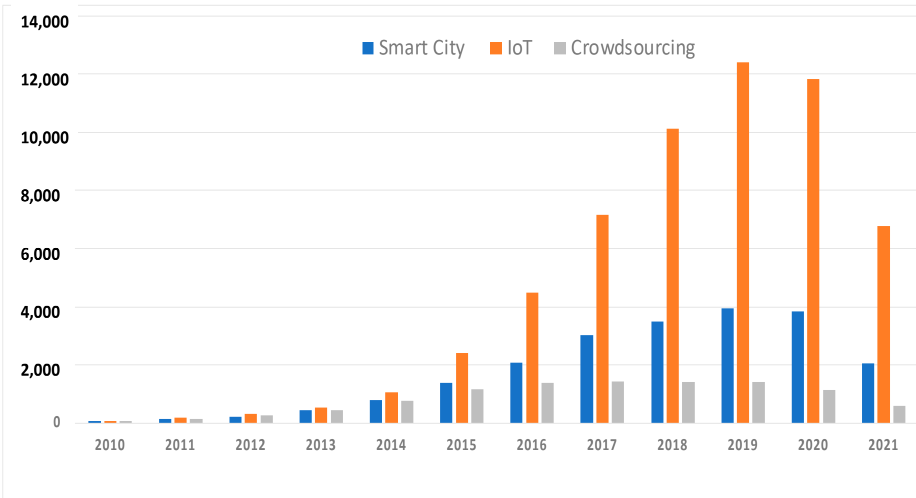


**Figure 1.** Number of papers indexed in the Web of Science in the field of smart city, IoT, and crowdsourcing (period January 2010–September 2021).

**Table 1.** Number of papers indexed in the Web of Science in the field of smart city, IoT, and crowdsourcing (period January 2010–September 2021).

| Subject | Number of Papers Indexed in Web of Science (2010–2019) |
|---|---|
| IoT | 57,311 |
| smart city | 21,459 |
| crowdsourcing | 10,177 |

Table 2 shows the variation in the period 2010–2021 of the annual number of the Web of Science indexed papers that combined the smart city, the IoT, and crowdsourcing. The total number of papers combing "IoT" and "smart city" is equal to 4504, to be compared to 264 and 34 for papers combining "smart city and IoT" and "Smart city, IoT and crowdsourcing", respectively. It could be seen that (i) papers combining the smart city and the IoT started in 2011, with an inflection point in 2015 and 997 studies were published in 2020, (ii) papers combining smart city and crowdsourcing also started in 2011 with an inflection point in 2015 but published only 34 in 2020, which is very low compared to papers combining both the smart city and the IoT, (iii) papers combining smart city, IoT, and crowdsourcing started in 2015, but stayed at a low annual rate (inferior to 10). These results show that the smart city development still requires stronger cooperation between the smart city technology-centered research, mainly based on the IoT, and the smart city citizens-centered research, mainly based on crowdsourcing [5,14–16]. This cooperation could beneficiate from recent developments in the field of crowdsensing that combines IoT and crowdsourcing [6–9].

**Table 2.** Number of papers indexed in the Web of Science combining smart city, IoT, and crowdsourcing (period January 2010–September 2021).

| Year | Smart City and IoT | Smart City and Crowdsourcing | Smart City and IoT and Crowdsourcing |
|---|---|---|---|
| 2010 | 0 | 0 | 0 |
| 2011 | 1 | 1 | 0 |
| 2012 | 8 | 0 | 0 |
| 2013 | 28 | 4 | 0 |
| 2014 | 68 | 19 | 0 |
| 2015 | 155 | 26 | 1 |
| 2016 | 310 | 35 | 2 |
| 2017 | 546 | 40 | 6 |
| 2018 | 841 | 52 | 9 |
| 2019 | 1004 | 40 | 7 |
| 2020 | 997 | 34 | 7 |
| 2021 | 546 | 13 | 2 |
| Total | 4504 | 264 | 34 |

In the following section, the paper analyzes the scientific developments in the smart city, IoT, and crowdsourcing fields to explore the potential and perspectives of their combination for urban development. The paper is structured as follows. The first part presents the methodology used in this research. The second is dedicated to analyzing the state of the art of the smart city, focusing on the smart city concept, role of data, and architecture. The third part presents the IoT technology, its place in the application of smart cities, and security requirements. Finally, the last part presents crowdsourcing, emphasizing mobile crowdsourcing and its role in smart city projects.

## 2. Materials and Methods

This research aims at presenting a synthesis of the relevant literature about data collection in smart city projects. It is motivated by the vital role of data in smart city projects. The paper focuses on the IoT and crowdsourcing, which constitute significant tools for data collection in smart city projects. The quantitative literature analysis presented in the introduction (Table 2) showed (i) a high number of papers combining the smart city and the IoT (997 in 2020), (ii) a moderate number of papers combining the smart city and crowdsourcing (34 in 2020), and (iii) a deficient number of papers combining the smart city, the IoT, and crowdsourcing (7 in 2020). This quantitative analysis highlights a real need to combine smart city technology-centered research, mainly based on the IoT, and the smart city citizens-centered research, mainly based on crowdsourcing.

Following the quantitative analysis, the Web of Science research engine was used to identify papers about the following topics: smart city, IoT, and Crowdsourcing and their combinations. This research resulted in a high number of papers. Then, about 100 papers were manually selected. Paper selection was based on the authors' experiences in the field of education, research, and implementing smart city projects. It aimed at answering a set of core questions for smart city applications. The first set of questions concerned the smart city, emphasizing the following major sub-questions: the smart city concept, the role of data, and smart city architecture. The second set of questions concerned the IoT, focusing on the IoT technology, its contribution to smart city applications, and the hot question about cybersecurity. Finally, the last set of questions was about crowdsourcing, focusing on its role in the smart city and the emergence of mobile crowdsourcing. In our opinion, this literature review is helpful for scholars, students, and professionals working in the field of smart city.

## 3. Smart City

### *3.1. Concepts and Frameworks*

Various concepts and definitions have been proposed for the smart city. Some of these concepts are holistic. They are based on the use of ICT and social innovation to improve the quality of life and services in the city. Other papers focused on specific topics of the smart city, such as governance, sustainability, urbanization, infrastructures, energy, and water. The following sections present a synthesis of significant papers in the field of smart cities.

In one of the first papers on smart cities, Hall (2000) [17] described the smart city by its capacity to monitor and integrate critical infrastructures related to transport, water, energy, communication, and buildings to optimize resource use and to improve the maintenance, security, and urban services. Sharipo (2003) and Komninos (2006) [18,19] highlighted the role of the smart city in boosting innovation, knowledge-based management, and creative human activity. Thus, the smart city was mainly seen as a booster of urban innovation and human capital. Giffinger et al. (2007) [20] focused on the role of the smart city on economic development, governance, mobility, and quality of life. Hollands (2008) [21] defined the smartness of a city by its capacity to adapt urban infrastructures to reduce resources consumption and improve urban services and security. Paskaleva (2009) [22] highlighted the importance of digital collaborations to promote transparency for urban governance and business competitiveness. Toppeta (2010) [23] discussed the role of the smart city in improving urban livability through the use of ICT to dematerialize and ameliorate administrative services and invent new solutions for citizens-centered city management.

Harrison and Donnelly (2011) [24] highlighted the role of the smart city in establishing collective intelligence through connecting physical, ICT, social, and business infrastructures. Caragliu et al. (2011) [25] attributed the smartness of a city to the investments in human capital, urban infrastructures, ICT, sustainable economic growth, and participatory governance. Harison and Donnelly (2011) [24] discussed the role of digital technology in smart cities to "make the invisible visible" and to build a framework based on the level of individual actions rather than on statistical abstractions. They proposed structuring urban data in five layers: natural environment, urban infrastructures, resources, services, and social systems.

According to Dameri (2012) [26], the smart city combines cooperation among ICT, urban infrastructures, and social inclusion to create social benefits in terms of well-being, eco-friendly environment, and intelligent development. Chourabi et al. (2012) [27] proposed a comprehensive framework for the smart city based on the use of the following factors: management, organization, technology, governance, policy, people, communities, economy, built infrastructures, and natural environment.

Kitchin (2014) [28] discussed the central role of governance in the smart city to promote decision making based on data and transparency. Neirotti et al. (2014) [29] considered culture a focal point in the smart city. Finally, Anthopoulos (2015) [30] highlighted the role of interdisciplinarity in the smart city concept through the combination of technical, social, and environmental issues to develop knowledge-based urban management.

Hiremath et al. (2013) and Neuman et al. (2015) [31,32] highlighted the importance of indicators for the evaluation of smart and sustainable city projects. These indicators allow policymakers to measure progress in implementing smart and sustainable city projects, evaluate their impact, and strengthen strategic planning. Indicators should be citizen-centered and focus on the evaluation of the quality of life. Furthermore, they should consider the diversity of the urban context by identifying homogeneous areas, which hold significant and specific features in urban services and environmental quality.

Zdraveski et al. (2017) [33] proposed a platform for smart cities including two categories of indicators. The first category, called "low-resolution indicators", concerns static or slow-changing indicators. This category includes the ISO4City indicators (ISO Std. 37120:2014) [34], which are organized in 17 topics related to the quality of life and urban services such as governance, finance, health, education, economy, safety, urban planning, transportation, emergency response, environment, energy, solid waste, wastewater, drinking water, and sanitation. The second category is called "high-resolution indicators"; it concerns dynamic temporal, spatial, and personal data such as traffic, noise, air pollution, and data from social media. Allam and Newman (2018) [35] proposed a framework for the smart city, which combines metabolism, culture, and governance. Metabolism enables understanding the role of smart technology in addressing environmental challenges and improving urban livability. Smart culture supports creative productions and activities as well as their diffusion. Finally, smart governance endorses creating a governance system based on transparency, inclusion, and public participation.

Dameri (2017) [36] concluded that smart city initiatives were heterogeneous, unfocused, less effective, and poorly funded based on an extensive analysis of smart projects in Europe. In a recent literature review, Mora et al. (2017) [37] attributed the fragmentation and confusion in the smart city literature to a lack of intellectual exchange and a disagreement in the smart city's conceptualization. They also argued that technical approaches dominated the scientific production in the field of smart cities. Yigitcanlar et al. (2018) [38] confirmed the conclusion of Mora et al. (2017) [37] concerning the fragmentation of research and the lack of conceptualization in the field of the smart city. They highlighted the necessity to develop a balanced and sustainable strategy for smart city projects, considering technology as a means, not as an end.

This literature review shows that most of the academic papers focused on the smart city concept and framework and the role of the smart city in improving the quality of life, urban services, governance, infrastructures efficiency, resources preservation, and the urban environment. Some papers criticized ICT-centered smart city concepts and highlighted the necessity of embracing citizen-centered approaches. The literature review shows a significant lack of feedback and data-based research from real smart city projects. This lack could be attributed to different factors, particularly the youngness and fragmentation of the majority of the smart city projects, the difficulty to access comprehensive data about smart city projects, and the lack of cooperation among cities, corporations, and academics. Recent papers focused on the application of the smart city in the fields of urban mobility [39], urban sustainability and resilience [40–42], energy efficiency [43], cybersecurity [44], and health [45,46].

### 3.2. Smart City Data

Smart city projects are based on the use of data related to the city components, such as urban infrastructures, the urban environment, urban services, city stakeholders, and socioeconomic activities (Table 3).

**Table 3.** Data for the smart city.

| Urban System | Source | Data |
|---|---|---|
| Urban infrastructures | The city administration, urban services providers, facility managers | Digital model including geo-referenced data for architectures and components (GIS, BIM, . . . , functioning data (traffic, congestion, consumptions, flow, pressure, quality, tension, frequency, temperature, humidity, accessibility |
| Urban environment | The city administration, environmental and weather agencies, NGO, urban services providers, citizens, public authorities | Indicators concerning air pollution, quality of water and soils, biodiversity including green areas, biological species, public health indicators as well as safety and security |
| Urban services | The city administration, urban services' providers (transport, water, energy, municipal wastes), citizens, companies | Indicators concerning the quality, availability, affordability, risk, of urban services (mobility, energy, and water supply, telecommunication, municipal wastes, sanitation, health, education, cultural, sportive, and artistic activities, . . . ) |
| City stakeholders | citizens, policymakers, urban services providers, and socioeconomic actors. | Data for citizens concerning urban indicators (urban services, strategies, significant projects, impact analysis, finance, . . . ).<br>Data from citizens, including feedback and evaluation about urban services, city functioning, quality of life, as well as improvement suggestions. |
| Socio-economic activities | The city administration, public authorities, social activity managers and providers, economic actors | Indicators concerning type and distribution of socio-economic activities, buildings capacity, industrial innovative capacity, city attractiveness, availability and use of cultural and sportive facilities, availability of commercial and industrial land, labor availability. |

Urban infrastructures concern the built environment, including (i) transport infrastructures such as roads, bridges, tunnels, parking, and walking areas; (ii) water infrastructures used for water supply, sanitation, and stormwater; (iii) energy infrastructures used for electrical, gas, and district heating supply, as well as for public lighting; (iv) infrastructures for municipal waste collection and treatment; and (v) public buildings such as those used for sport, art, culture, education, health, and administration. Data should include the digital model of urban infrastructures using digital tools such as GIS (Geographic Information System) and BIM (Building Information Modelling) with geo-referenced data concerning infrastructures' architecture, components, and maintenance. Data should also include dynamic data related to infrastructures functioning such as fluid consumption, flow, pressure, fluid quality, electrical tension, current frequency, temperature, and humidity.

The urban environment covers different issues such as air pollution, water quality, and biodiversity, including green areas and species evolution.

Urban services concern the availability, continuity, affordability, and quality of services to citizens such as the dematerialization of administrative procedures, mobility services (public transport, congestion, parking lots, bikes, walking areas, carpooling, multimodal transportation, transition areas, . . . ), water and energy supply, and telecommunication services including access to a high-speed internet connection, 4G/5G coverage, and free Wi-Fi. They also concern access to health, education, cultural, and sports services.

City stakeholders include citizens, policymakers, urban services providers, as well as socioeconomic actors. Their involvement in local development and activities constitutes a key success factor of the smart city. In smart city projects, each stakeholder is a potential holder of static and dynamic data, and at the same time, he is in demand for data from other stakeholders. It is then necessary to organize data collection and data sharing among stakeholders through security procedures that ensure data security, integrity, and access rights protection. Data constitute a focal point in participatory governance. Indeed, on the one hand, active and aware citizens' participation should be based on relevant information about the city policy, projects, decision-making process, resources, and expenses, and the city projects and their impacts.

On the other hand, the city decisions should be based on data concerning citizens' feedback and evaluation. Citizens also constitute a major source for smart city data through crowdsourcing. This issue will be discussed in Section 5.

Data quality constitutes a major issue in smart city projects. Barnaghi et al. (2015) and Mahdavinejad et al. (2018) [47,48] highlighted the necessity to control the quality of smart city data through an assessment of the following factors: measurements error and precision, devices' noise, discrete observation, and data transmission. Different solutions could be used to improve data quality, such as selecting trustworthy sources, combining and crossing data from multiple sources, increasing the frequency and density of sampling, and semantic data annotation.

### *3.3. Smart City Architecture*

Digital platforms are used for the coordination of the digital tasks related to smart city management. The platform architecture includes different layers (Aguilera et al., 2017, MASKED FOR REVIEW, Silva et al., 2018, Alvear et al., 2018) [7,49–51]. For example, Figure 2 shows a smart city architecture, which includes six layers.

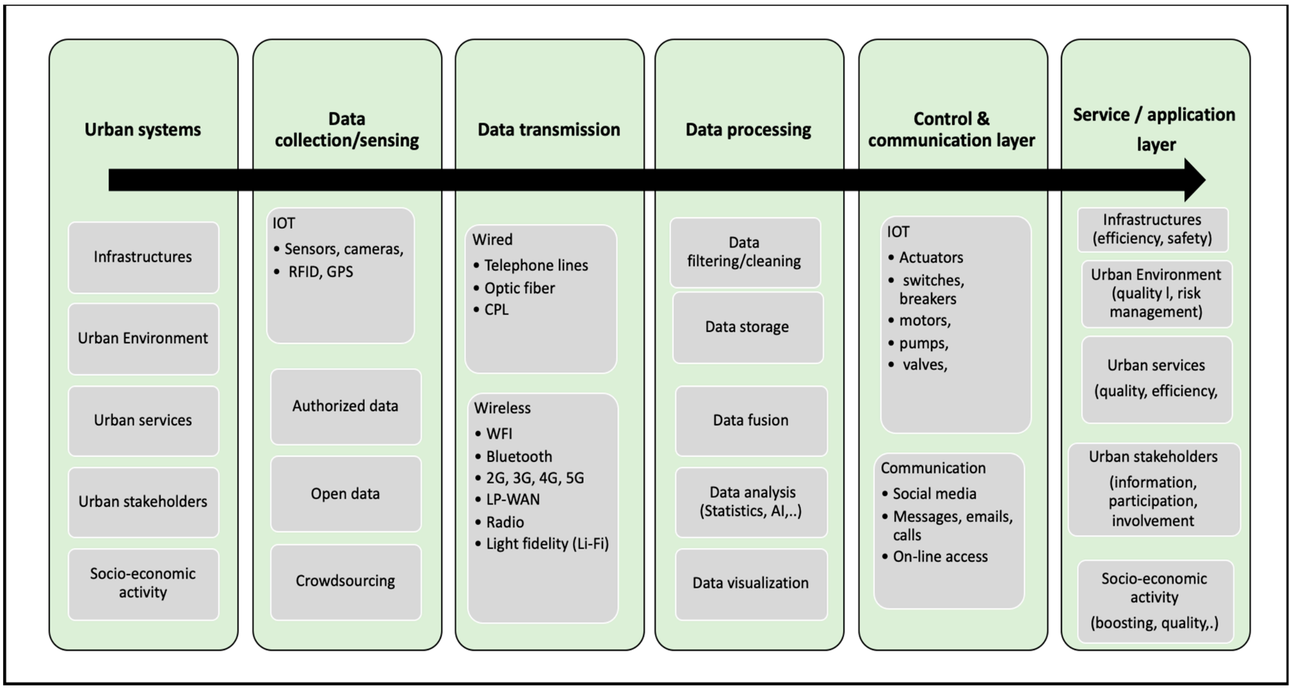


**Figure 2.** Smart city architecture including six layers.

The first layer concerns the physical components of the city, which constitute the data sources: urban environment, urban services, urban stakeholders, and socioeconomic activity (Table 2).

The second layer is the sensing layer, which enables data collection and capturing from data sources. Sensing constitutes a major pillar in the smart city because it retrieves data from urban components (Alvear et al., 2018) [7]. This layer includes the following components: (i) the IoT, including sensors, cameras, RFID, and GPS (Bandyopadhyay & Sen, 2011; Mulligan & Olsson, 2013) [52,53]; (ii) authorized data sources from public authorities such as weather, air quality, traffic information, public transport, and health; (iii) open data, which are generally shared by public authorities and agencies; and (iv) crowdsourcing, which includes citizens' active and passive data.

The third layer concerns data transmission from the sensing layer to the smart city server. It combines wired and wireless communications infrastructures. The former includes phones lines, ethernet cables, fiber optic, and PLC lines (Power Line Communication). At the same time, the latter refers to various technologies such as WIFI, radio, LP-WAN (Low-Power Wide-Area Network) including LoRa and Sigfox (LoRa 2020, Sigfix 2020) [54,55], Bluetooth (Gomez et al., 2012) [56], Li-Fi (Light Fidelity), and 2G, 3G, 4G, and 5G connections (Eiaz et al., 2016) [57]. Generally, wireless technology is used at the local level to transmit data to a local DataGate, transmitting collected data to the smart city server via wired or wireless communication protocols (Figure 3).

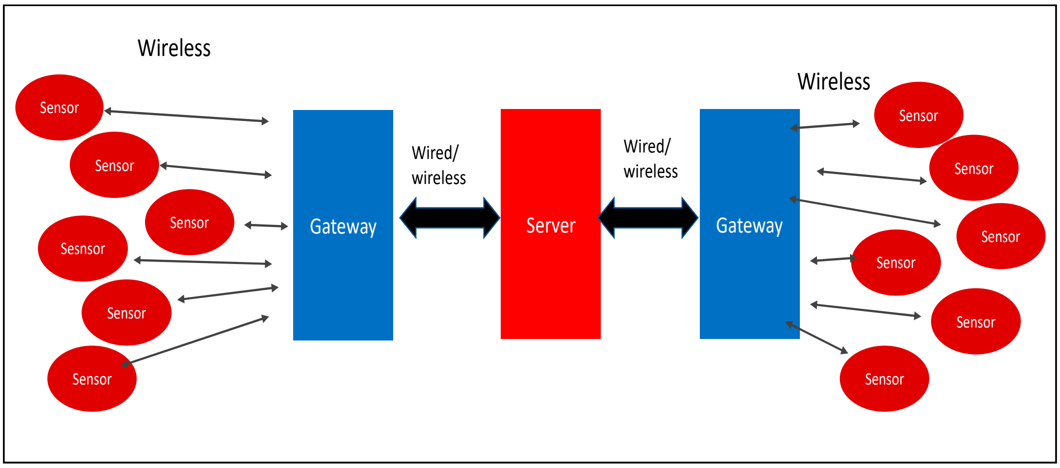


**Figure 3.** Data communication layer.

This paper presented a comprehensive management system for fire evacuation. This system is based on the combination of BIM, the smart technology for the early detection of fire events, and the FDS and ABS to optimize the evacuation route. This system permits detecting fire, collecting and analyzing environmental data, locating occupants, and guiding them to the optimal routes.

The fourth layer concerns data processing (Silva et al., 2017, 2018 [51,58]. It includes (i) data filtering to identify erroneous or corrupted data, to reduce data noises, and to conduct specific operations including alerts and data rectification; (ii) data storage in existing data sets or information systems; (iii) data fusion through data combination for cross verification or added-value analysis (Hall and Llinas, 1997, Silva et al., 2017) [58,59]; and (iv) data analysis using engineering tools, statistics, and more advanced tools such as Artificial Intelligence to convert collected data into operational information to feed the services layer. Considering the massive amount of urban data, their diversity (structured, semi-structured, or unstructured), and high flow velocity, some authors proposed the use of big data techniques in smart city applications (Mayer-Schönberger and Cukier, 2013; Chen et al., 2014, Al Nuaimi et al., 2015) [60–62].

The fifth layer is the control layer. The IoT controls urban systems such as actuators, switches, breakers, valves, and electronic motors, pumps, and locks. This layer also comprises interaction tools with citizens and other stakeholders for alerts or information diffusion using messages, emails, phone calls, and online access.

The last layer is the services or applications layers (Aguilera et al., 2017, Silva 2018) [49,51]. It includes smart city services such as (i) the optimal and safe management of urban infrastructures; (ii) the survey and control of the urban environment to detect eventual anomalies and to take appropriate actions through citizens' information or technical interventions; (iii) the improvement of urban services such as optimization of public transportation and traffic, real-time mapping of available parking places, rapid detection of water leakages or contamination [63,64], optimization of the stormwater system to reduce flood risk as well as pressure on water treatment plants [65], the detection of depredations in electrical grids, early detection of electrical outages together with efficient actions for faults confinement and grid healing, and the optimization of the public lighting system. It could also include smart tools for managing utilities hosted in a shared space [66].

This layer includes interactive tools to inform citizens and other stakeholders about the city news, projects, events, hazards, realizations, and challenges and reinforce their involvement in the participatory governance. It also provides information about socioeconomic activities, including sports, cultural, and artistic events, local social events, and economic activity such as jobs opportunities, start-up creation, the installation of new activities, innovation trends, and incentives and support opportunities for innovations and economic initiatives.

## 4. The Internet of Things (IoT)

### *4.1. Definition and Technology*

According to ISO/IEC JTC1 (2015) [67], the IoT refers to the "interconnection of uniquely identifiable embedded computing like devices within the existing Internet infrastructure". The IoT offers services in almost all daily fields through advanced connectivity of devices, systems, and services, particularly smart applications. ITU-T (2019) [68] defines the IoT as a "global infrastructure for the information society enabling advanced services by interconnecting physical and virtual things based on existing and evolving interoperable information and communication technologies". According to Hameed et al. (2019) [69], the IoT could be seen as the next generation of interconnection technology that will enable connectivity among people's devices and machines, allowing the actions to happen without human intervention.

Practical use of IoT devices requires their integration in networks, including software, hardware, communication technologies, platforms, and services. Therefore, different IoT architectures have been proposed for smart applications. The three-layer architecture was firstly proposed (Yun and Yuxin 2010) [70]. It includes perception, network, and application layers, ensuring sensing, data transmission, and service tasks. The three-layer architecture was extended to a four-layer architecture by adding a layer for specific tasks such as security and management or a middleware/service layer (Guth et al., 2016, Yaqoob et al., 2017, De Gruz et al., 2018) [71–73]. The extension to a five-layer architecture aimed at adding two specific layers, namely, middleware and business layers (Mashal et al., 2015, Omoniwa et al., 2019) [74,75].

Several authors highlighted the necessity to use a service-oriented architecture (SoA) to provide digital services to users (Panetto and Cecil 2013, Wang and Xu 2012, Li et al., 2015 [76–78]). For example, Li et al. (2013) [78] proposed a generic SoA composed of four layers (Figure 4). The first layer is the "Sensing layer". It uses tags, sensors, and devices to sense the surrounding environment and exchange data among devices. The second layer is the "Network Layer", which connects IoT components via wired and wireless communication protocols to turn these data into services. The third layer, the "Service layer", provides different services by identifying users' demand, services combination, or the development of new services. Finally, the last layer, the "Interface layer", allows the easy and convivial interaction with the services layer.

### *4.2. Use of the IoT in Innovative City Applications*

The IoT has a huge potential in smart city applications such as smart buildings, smart grids, smart mobility, smart logistics, smart environmental monitoring, smart water, and smart health. The crucial role of sensors in smart cities is evident in the conceptual model of the smart city.

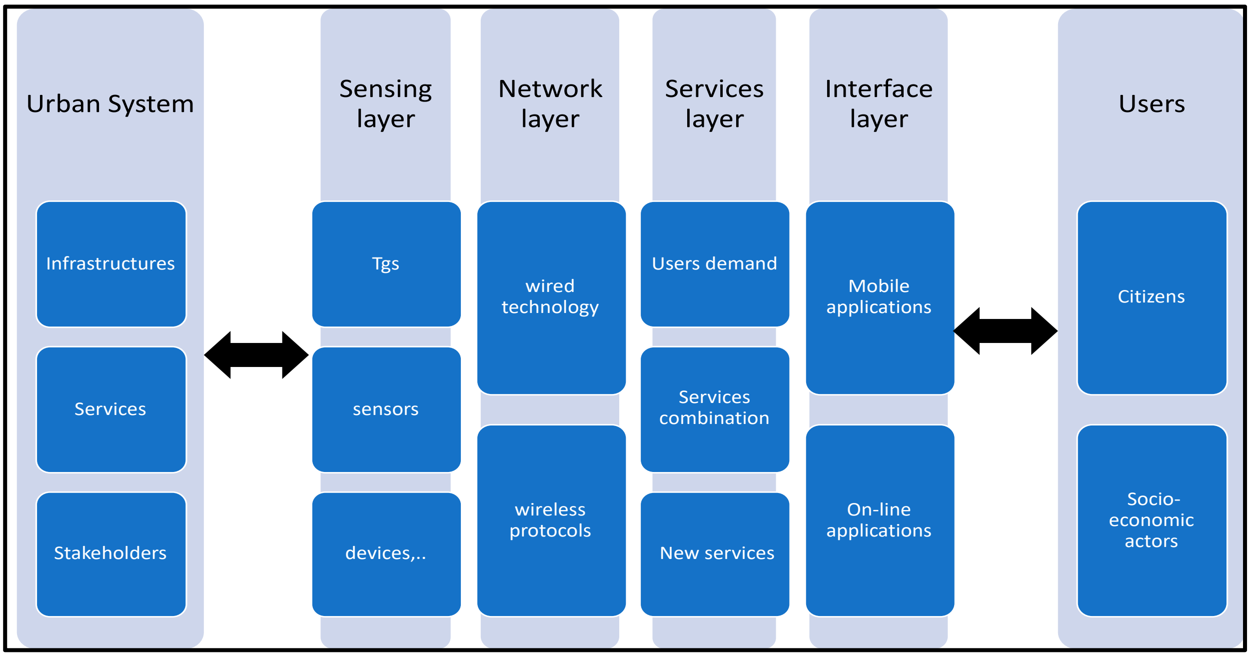


**Figure 4.** IoT service-oriented architecture.

According to Al-Fuqaha et al. (2015) and Mohindru et al. (2019) [79,80], the IoT is used in (i) public lighting for the optimization of the streetlight intensity based on weather conditions, time, and people presence; (ii) smart parking to identify free parking slots and report parking violations; (iii) waste management by transmitting information about waste containers for the optimization of the collector truck's route; (iv) optimization of energy consumption through the identification of excesses in power consumption; (v) air quality and noise monitoring by tracking the time and spatial variation of both air quality and noise together with taking adequate measurements in case of abnormal values; (vi) traffic management through the use of data from air quality and noise sensors, GPS, cameras, and smartphones for navigation advising and congestion management; (vii) health building monitoring through recording the buildings' vibrations and deformations to feed building stability assessment software.

Sagl et al. (2015) [81] classified the use of the IoT in urban sensing into three categories: in situ, remote, and human-centered sensors. The first category refers to sensing in the sensors' immediate surroundings. It includes an extensive range of sensors such as those used in monitoring air quality, air pollution, temperature, humidity, lighting intensity, fluid flow, fluid pressure, fluid consumption, traffic intensity, objects movement, occupancy, intrusion, face recognition, etc. Remote sensing refers to urban monitoring using satellite or aircraft-based sensor technologies. Finally, human-centered sensing includes many sensors used in health, comfort, safety, and navigation services.

According to Bibri (2018) [82], sensors can be classified according to their use into the following categories: location, optical, light, image, sound, temperature, heat, electrical, pressure, orientation, movement, bio, wearable, and identification.

In smart city applications, the IoT is located at the interface between the physical and digital parts of the smart city. In the sensing layer, the IoT conducts crucial tasks such as (i) data collection including sensing and data transmission, (ii) data sharing among authorized IoT systems, and (iii) local data treatment and eventual local actions (Sanchez et al., 2013, ISO/IEC 2015) [67,83]. Furthermore, the IoT carries out actions to manage urban infrastructures and the environment in the control layer. In smart city applications, sensors are generally deployed in large numbers, and they have to be interconnected. This raises specific challenges related to the construction of efficient and secure communication infrastructures and the temporal and spatial scales for data aggregation and the location of data processing (Hancke 2013, ISO/IEC 2015) [67,84].

### 4.3. Security and Privacy

Security and privacy constitute hot topics in the IoT use in smart city applications because of the IoT systems' vulnerability and the dramatic consequences of their hacking on urban infrastructures and services. Hammi et al. (2018) [85] reported that IoT security is considered a major obstacle to the worldwide deployment of the IoT because users' adoption of the IoT is subject to privacy security protection guarantees. Extensive research has been conducted on both IoT security and privacy with an emphasis on IoT vulnerability and the dramatic consequences of this vulnerability on critical infrastructures safety and users' privacy (Jing et al., 2014, Hui et al., 2017, Frustaci et al., 2018, Khan and Salah 2018, Kouicem et al., 2018, Sengupta et al., 2020, Meneghello et al., 2019, Waraga et al., 2020, Alladi et al., 2020) [86–94].

The review of some papers related to IoT vulnerability shows that this vulnerability is related to a multitude of factors (Li et al., 2015, Kouicem et al., 2018, Sengupta et al., 2020, Meneghello et al., 2019, Waraga et al., 2020) [78,90–93] in particular:

The limited processing capacity of smart sensors and devices does not allow installing embedded advanced security protocols in IoT devices.

The complexity of the IoT networks is related to the massive number of connected devices in smart city applications. This complexity is a serious source of IoT vulnerability because each IoT component could be used as a hacking hole. The vulnerability could also result from other sources, such as (i) the use of a large range of electronic components and related communication protocols, which results in a high heterogeneity in IoT networks with additional security and privacy challenges; (ii) the use of low-cost electronic components with a low-security level, which could seriously deteriorate the security of the global IoT network; generally, manufacturers of low-cost electronic components do not have enough expertise in advanced IoT security and could be unaware of security risks related to the use of their devices in IoT global networks; and (iii) The lack of users' security and privacy awareness, which could be used as an easy entry-point for malicious intrusion into individual data and IoT networks.

Jing et al. (2014) [86] highlighted the necessity to develop an integrated security solution for the totality of the IoT layers starting from devices and sensors used in the sensing layer, through to the protocols used in the communication layer, up to the application layer in relation with the end-users. Hui et al. (2017) [87] reported that although some IoT providers claim advanced security levels, their solutions may include vulnerable points, which could not be identified by isolated technology.

Based on a recent literature review, Hameed et al. (2019) [69] identified the following requirements to ensure IoT security: privacy, lightweight cryptography, secure routing and forwarding, resiliency, service denial, and the detection of insider attacks. They also highlighted the role of virtualization techniques and centralized management in enhancing IoT security.

Meneghello et al. (2019) [92] classified the IoT security requirements into three categories. The first category is related to the information level. It includes the following requirements: data integrity that prevents data alteration during transmission, data anonymity to third parties, data confidentiality that prevents data access by third parties, and data privacy to protect users' identities and private data. The second category refers to the access level. It includes security requirements about IoT network access, in particular, (i) control protocols that guarantee IoT access to legitimate users only, (ii) authentication procedures to check devices' rights to access the IoT network, and (iii) authorization control to ensure that only authorized users and devices could access the IoT network's services and resources. The last category concerns the functional level, which includes resiliency and self-organization requirements. Resiliency designates the capacity of the IoT network to learn from historical events and improve recovery capacity. At the same time, self-organization refers to the capacity of an IoT system to remain operational in case of a cyberattack.

Sengupta et al. (2020) [91] presented an object-based classification of IoT cyberattacks, which could help users and practitioners to identify relevant security challenges. Alladi et al. (2020) [94] proposed a set of recommendations to enhance IoT security, including static and dynamic verifications, tamper-proofing lightweight cryptographic encryption, API endpoint security, session key generation, strong password protection, secure-by-design, and symmetric key encryption. Finally, Waraga et al. (2020) [93] proposed bedtests to verify the security of the IoT sensors and devices. These bedtests aim at the verification of the IoT components before their commercialization or installation.

### *4.4. Challenges for the Use of the IoT in Smart City Applications*

Based on an extensive literature review, Hui et al. (2017) [87] identified the following major challenges for effective use of the IoT in smart city applications: (i) heterogeneity, which is related to the use of a large variety of devices and protocols; (ii) self-configurability, which is necessary to establish automatic configuration in case of any physical modification in IoT systems; (iii) extensibility, which guarantees easy extension in IoT systems to integrate new functions, configurations, and technologies; (iv) context awareness to integrate capacities to detect, understand, and react to changes in the surrounding environments; (v) usability to facilitate the use of IoT applications by non-technical users through advanced human–computer interaction tools; (vi) security and privacy to protect IoT devices and applications from malicious attacks; and (vii) intelligence to integrate capacities to learn from previous events as well as to predict future evolution.

According to Mohindru et al. (2019) [80], additional developments are yet required for the use of IoT in smart cities, in particular (i) standardization for compatibility, interoperability, operational effectiveness, efficiency, and reliability; (ii) innovation in low power, cost-effective, and efficient IoT devices and protocols; (iii) IoT distributed and cloud-integrated architectures; (iv) privacy and security against malicious attacks; (v) efficient data visualization combined with effective data analytics; and (vi) data analysis based on distributed and edge computing frameworks.

## 5. Crowdsourcing

### *5.1. Overview*

Crowdsourcing refers to the participation of individuals and groups through different technologies in urban data acquisition (Howe 2006, Ganti et al., 2011; Guo et al., 2015) [8,95,96]. It includes two categories. The first category is task-oriented, where individuals and groups participate in data acquisition about specific issues upon private or public requests (Howe 2006, Ma et al., 2014, Cheng et al., 2014) [95,97,98]. The second category concerns opinions crowdsourcing (Noveck 2015, Charalabidis et al., 2014 and Loukis and Charalabidis 2015) [99–101]. It includes passive and active practices. The public sector mainly uses passive crowdsourcing to collect, without any stimulation, citizens' opinions and feedback concerning urban issues. Social media constitutes the primary source of data for this type of crowdsourcing. The private sector mainly uses active crowdsourcing. In this category, data are collected through an active stimulation of citizens' feedback on specific topics to establish or improve business strategies and actions.

### *5.2. Mobile Crowdsourcing*

Combining crowdsourcing with mobile applications resulted in new, cost-effective, and high-quality crowdsourcing-based services (Alvear et al., 2018, Kong et al., 2019) [7,9]. Indeed, mobile crowdsourcing takes advantage of the mobility of citizens and sensing tools to cover large areas at a low cost. Mobile crowdsourcing also benefits from the high sensing capabilities of mobile devices, which currently incorporate various types of sensors, such as GPS, cameras, microphones, temperature, light, accelerometers, and health-monitoring sensors. In addition, external sensors could be connected to smartphones, which increases their sensing capacity. Furthermore, mobile crowdsourcing is powered by human sensing capacity, which combines sensors with human feedback and analysis (Kong et al., 2019) [9]. This advantage is particularly relevant for the evaluation by users of some urban issues such as the quality of urban services and the impact of decisions on users' quality of life. Finally, mobile crowdsourcing benefits from the possibility of involving a high number of individuals with an extensive range of diversity, which improves the monitoring quality, reliability, and significance.

### *5.3. Crowdsourcing in Smart City Applications*

Crowdsourcing contributes to three key success factors of smart city projects.

The first factor is related to data collection. As discussed in the previous section, mobile crowdsourcing provides high mobile and human sensing capacities, which allow the development of cost-effective and high-quality monitoring systems for urban infrastructures, services, and environment (Noveck et al., 2015, Alvear et al., 2018, Kong et al., 2019) [7,9,99]. Furthermore, user feedback supported by sensor data is precious to capture citizens' needs and preferences and evaluate the real impact of smart city projects on citizens' quality of life. In addition, mobile crowdsourcing allows the rapid implementation of smart city projects because it could be a valuable alternative to some monitoring devices, which require high investments, time, and operating expenses.

The second factor concerns citizens' involvement in local development and activities (Alvear et al., 2018, Kong et al., 2019) [7,9]. Through mobile crowdsourcing, local governments can access citizens' opinions and feelings about smart city projects and the real impact on citizens' lives. It also constitutes a powerful tool for the interaction with citizens, which is one of the central pillars of participatory governance.

The third factor is related to developing crowdsourcing-based smart applications such as smart navigation, real-time public transportation, carpooling, risk alerts, emergency operations, and disturbance alerts. Recent papers focused on crowdsourcing and smart cities' standardization [4], the investigation of social insights in the smart city [16], disaster management [102], urban infrastructure management [103], and finally, smart mobility and traffic congestion analysis [4,104,105].

## 6. Conclusions

This paper presented a literature analysis of the scientific developments in the fields of the smart city, the IoT, and crowdsourcing, as well as their combination for urban development. The literature review showed:

- Most academic papers about smart cities focus on the smart city concept and its role in improving the quality of life, urban governance, infrastructures efficiency, and the urban environment. Some papers criticized the ICT-centered smart city concepts and highlighted the necessity to extend these concepts to include citizen-centered concerns. However, a significant lack is observed in the feedback from real smart city projects. This lack could be attributed to the youngness and fragmentation of smart city projects and the lack of cooperation among cities, corporations, and academics.
- An impressive scientific development in the field of the IoT and a high perspective of the use of the IoT in smart city transformations, with, however the following challenges: heterogeneity of the IoT components and protocols, self-configurability for automatic configuration in case of modification or perturbation to the IoT systems, extensibility for easy extension in the IoT system to include new functions or technologies, context awareness to enhance the capability to detect and react to changes in the surrounding environment, and security to protect IoT devices and applications from malicious attacks.
- Developing the smart city still requires stronger cooperation between the smart city technology-centered research, mainly based on the IoT, and the smart city citizens-centered research, mainly based on crowdsourcing; this cooperation could benefit in re-

cent developments in the field of crowdsensing that combine the IoT and crowdsourcing.
- An excellent perspective for mobile crowdsourcing to support citizens' implication in local development and strengthen participatory governance. Mobile crowdsourcing could also accelerate the implementation of smart city projects by developing crowdsourcing-based and cost-effective monitoring systems as an alternative to conventional smart city monitoring systems.

This paper showed that the development in both the IoT and crowdsourcing constitutes a vital driver for smart city development because it directly impacts data collection, citizens' involvement, and the control and security of urban systems. Furthermore, Il also showed that the IoT and mobile applications are precious in the development of crowdsourcing. Finally, the smart city offers a vast market and a large innovation area for the IoT and crowdsourcing. Therefore, any smart city project should explore the latest development in the fields of the IoT and crowdsourcing and reserve a space for scientific and business innovation in these fields.

**Author Contributions:** Conceptualization, investigation, and analysis, I.S.; writing, review and editing, I.S. and X.X. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Conflicts of Interest:** The authors declare no conflict of interest.

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