Validation and Extension of the Smart City Ontology

Petr Štěpánek and Mouzhi Ge
Faculty of Informatics, Masaryk University, Botanicka 68a, 602 00 Brno, Czech Republic

Keywords: Smart City Ontology, Smart City Definition, Concept Validation.

Abstract: Over the last decade, the concept of the Smart City has been extensively studied with the development of modern societies. However, due to the complexity of Smart City, there does not exist a widely accepted definition for the Smart City. More recently, Ramaprasad et al. in 2017 have proposed a Smart City ontology that connects its relevant concepts with specified relations. This ontology thus can offer various paths by which theory and practice contribute to the development and understanding of a Smart City. However, this ontology is still lacking practical validations to verify its applicability, Therefore, in this paper, we select a set of critical Smart City papers and validate this ontology by fitting the papers into this ontology. Based on the validations, we also further propose and discuss the possible extensions and consolidations for this Smart City Ontology.

1 INTRODUCTION

With the rapid development of urbanization, there have been a variety of challenges that are proposed to meet the demand of modern societies to ensure the quality of life, sustainability, and economic growth. The works that tend to address these challenges with new technologies are usually associated with the term Smart City. This term was initially developed in the 1990s, when there appeared different needs from the cities e.g. to encompass sustainability by avoiding environmental pollution, efficient use of energy and materials, and life cycle engineering (Hall et al., 2000). Different smart services have been developed to offer a better satisfaction for stakeholders' needs. Thus, Smart City can be explained in terms of a complex of services exchanged by a network of actors interconnected in order to share knowledge, resources, competencies, and capabilities to perform better solution.

Even though there has been an extensive Smart City research over the last decade, there does not exist a shared definition of the Smart City concept. For example, some definitions are focused on citizens and stakeholders, "A Smart City is a city well performing in a forward-looking way in 6 characteristics built on the smart combination of endowments and activities of self-decisive, independent and aware citizens." (Giffinger et al., 2007), other definitions have a technical focus such as "Smart City is defined by IBM as the use of information and communication technology to sense, analyze and integrate the key information of core systems in running cities." (Cocchia, 2014), or to promote certain specific technologies such as the Internet of Things (IoT) – "Smart City is the product of Digital City combined with the Internet of Things." (Su et al., 2011). As far as we have reviewed, those Smart City definitions are not contradictory, rather complementary with each other. As Cocchia (Cocchia, 2014) claimed, the reason is that definitions were derived from real Smart City projects that were driven by technological innovation and its application to specific urban areas. Since the projects' environment was different, the process of Smart City implementation varied. There are therefore many definitions of Smart Cities using different division of city domains and city services.

In order to unify different Smart City Concepts, Ramaprasad et al. in 2017 (Ramaprasad et al., 2017) have proposed a Smart City ontology that connects different sets of Smart City concepts with specific relations, which thus can offer a roadmap to go through the Smart City designs and assess the Smart City services from different perspectives. We also consider this ontology can be a better way to organize the Smart City concepts rather than just a single definition. However, although this ontology follows a proper design, it is not yet validated with Smart City works. We, therefore, consider that it is valuable to conduct further validation to assess the applicability of this ontology.

This paper, therefore, aims to validate the Smart City ontology by fitting different Smart City papers into this ontology. The contribution of this paper is

Štěpánek, P. and Ge, M.
Validation and Extension of the Smart City Ontology.
DOI: 10.5220/0006818304060413
In *Proceedings of the 20th International Conference on Enterprise Information Systems (ICEIS 2018)*, pages 406-413
ISBN: 978-989-758-298-1

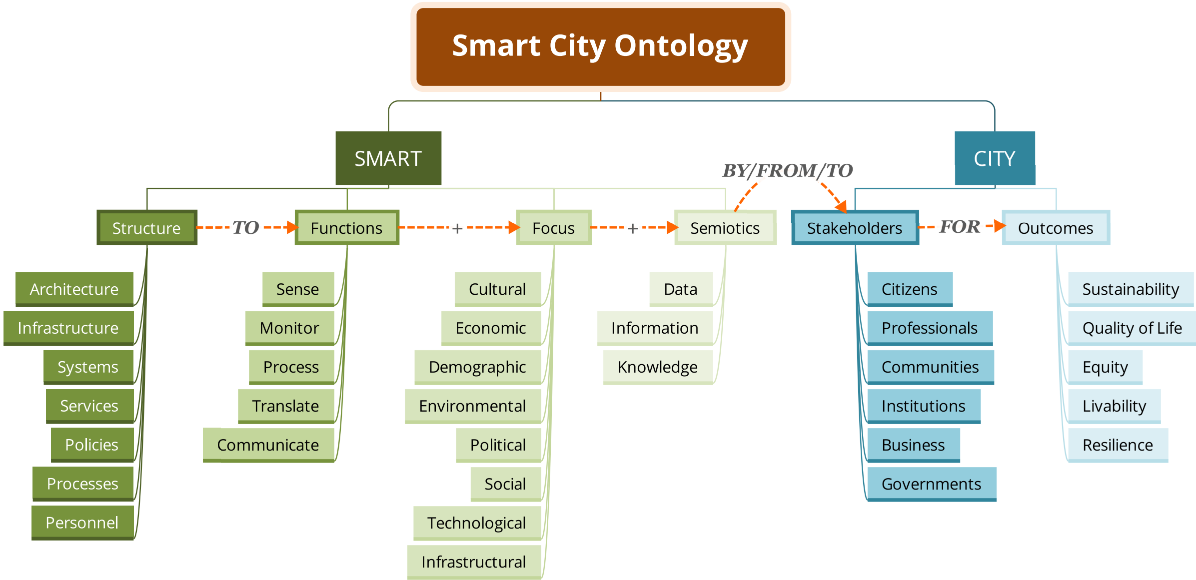

Figure 1: Smart City ontology redrawn to a mind map.

two-fold: (1) we have conducted a practical validation for Smart City ontology by verifying whether different papers follow respective routes along the ontology, (2) we have further developed and extended the ontology based on elements used in papers and missing in the ontology, elements having alternatives in papers and the ontology and finally in papers not used elements.

The remainder of the paper is organized as follows. Section 2 revisits the Smart City ontology and summarizes the ontology into Figure 1. Based on the ontology, section 3 uses a set of Smart City papers to validate the ontology in practice. From the validation, section 4 discusses the results and possible extensions of the Smart City ontology. Finally, section 5 concludes the paper and outlines the future work.

2 SMART CITY ONTOLOGY

There can be found more than 36 distinct definitions of the Smart City concept in a current scientific literature that make this research field ambiguous. The core of the problem lies mainly in the word Smart that can be perceived in many ways. At the beginning of the Smart City field, the word Smart meant to use an IT anywhere in a city. Lately, the focus of the term moved from using IT to city goals. It is connected to the realization that a city is a living organism and it needs to fulfill specific goals for the city to preserve its existence. Then, city functions were identified for a Smart City evaluation in the last few years.

In (Ramaprasad et al., 2017), the authors studied Smart City definitions and other relevant scientific studies from different fields with the intention to unify a view of the Smart City concept. They came up with a Smart City Ontology (see Figure 1) that integrates 36 Smart City definitions and other Smart City publications.

This ontology defines Smart City concept as a function of two main parameters, which are Smart and City. For each parameter, there is a function that explains the dimensions of the parameter. The concept Smart contains Structure, Function, Focus, and Semiotics. The City consists of Stakeholders and Outcomes.

For a deeper understanding of the ontology, every dimension from Smart and City functions is defined as a set of components (or classes). The class of Structure is constructed by Architecture, Infrastructure, Systems, Services, Policies, Processes, and Personnel elements. The Function class contains Sense, Monitor, Process, Translate and Communicate elements. The Focus dimension contains Cultural, Economic, Demographic, Environmental, Political, Social, Technological and Infrastructural elements. For Semiotics, there are Data, Information, and Knowledge elements. For the two classes in the City, Stakeholders include Citizens, Professionals, Communities, Institutions, Business, and Governments elements, while Outcomes are constructed by Sustainability, Quality of Life, Equity, Livability, and Resilience elements. The presented ontology is more a proposal than a unified definition. As authors themselves stated, it can be expanded or reduced depending on a context of its use. There are different possible applications for the ontology such as assessing the level of smartness of their cities from many perspectives at different levels of complexity, providing a roadmap for new smart city designs, and guiding cooperative thinking among government agencies and other stakeholders.

2.1 Alignment of Smart City Ontology

In order to further explain the Smart City ontology, we have aligned three typical papers to this ontology, indicating which paper follows which path according their contexts. For example, (Babar and Arif, 2017) proposes and tests a generic Smart City architecture which aims at efficient planning and decision making for Smart Cities. Its intended parameters are inclusivity and elasticity and it is built upon IoT and Big Data analytics. The architecture consists of three main parts each with its own purpose. The essential part takes care of data acquisition & aggregation using mainly IoT elements. The second part of the architecture pre-processes data, which means it checks the validity, normalizes it, scales it and filters useful data that are stored. The last part of the architecture uses the pre-processed data for making intelligent decisions and communicating events to citizens. We can translate the idea of the paper into the following function aligned with the Smart City ontology:

$$\begin{aligned}(BabarandArif, 2017) = {} & f(f(architecture + (monitor,\ process,\\ & translate,\ communicate) + urban + data)\\ & + f(citizens + quality\ Of\ Life))\end{aligned} \tag{1}$$

The paper (Uribe-Perez and Pous, 2017) proposes a solution to problems of communication within the Smart City. More specifically, the paper says that the ICT plays a key role in every Smart City and this ICT needs to be efficient and valuable for the city. A city using ICT doesn't need to be smart. For the ICT to be more efficient and valuable for the city, the interconnection and mutual communication are one of the parameters. Therefore, authors of the paper propose a communication architecture inspired by a human nervous system. The architecture is composed of (1) a sensing layer containing a sensor network, (2) an access layer with Smart GateWays to process a low-level information and act consequently, (3) data layer with 3 types of databases to store data, (4) a platform layer to supervise and manage the city and the last, (5) application layer to provide services. This proposed communication architecture should be dynamic and scalable with ensuring a fast response when a not complex event appears. Let us transform the idea of the paper to fit in the ontology function:

$$\begin{aligned}(Uribe - PerezandPous, 2017) = {} &\\ & (f(architecture + (sense,\ monitor,\\ & translate,\ communicate) + urban\\ & + (data,\ information))\\ & + f(stakeholders + resilience))\end{aligned} \tag{2}$$

Another paper (Chen et al., 2016) describes an automotive sensing platform used in the city to obtain data from different parts of the city by cars equipped with sensors. In general, an automotive sensing has two main advantages. The sensors can be powered by a car battery. It solves energetic constraints that are usually present. The second advantage is a size and a weight of the sensors which is not that restrictive as for instance in case of mobile phone sensors. The study describes a sensing platform built upon garbage collecting trucks equipped with sensors to sense data and send it to servers where can be converted to the required format and processed further. In the words of ontology function:

$$\begin{aligned}(Chenet\ al., 2016) = {} &\\ & f(f(platform + (monitor,\ process,\\ & communicate) + data))\end{aligned} \tag{3}$$

3 VALIDATION OF THE SMART CITY ONTOLOGY

In order to validate the Smart City ontology, we have selected several Smart City papers by searching academic databases and well-known publishers such as ScienceDirect, Scopus, as well as general Google search with keywords like Smart City or Smart Service. We limited the search to up-to-date papers from 2010 to 2017. The search resulted in papers that contain a process that describes how the services and solutions in Smart City are designed for a certain purpose and we gave a special preference on the papers with higher citations. Therefore, we selected 22 Smart City papers. Based on the selected papers, we validated the Smart City ontology by matching the paper to different dimensions of the ontology.

At first, we introduce a table divided into 3 figures (see Figures 2, 3, 4) containing the data from selected papers fitting the ontology. Figure 2 and Figure 3 show information about the appearance of elements from the ontology smart dimension. As it can

Figure 2: A table showing occurrence of ontology smart terms (structure, function) in studied papers.

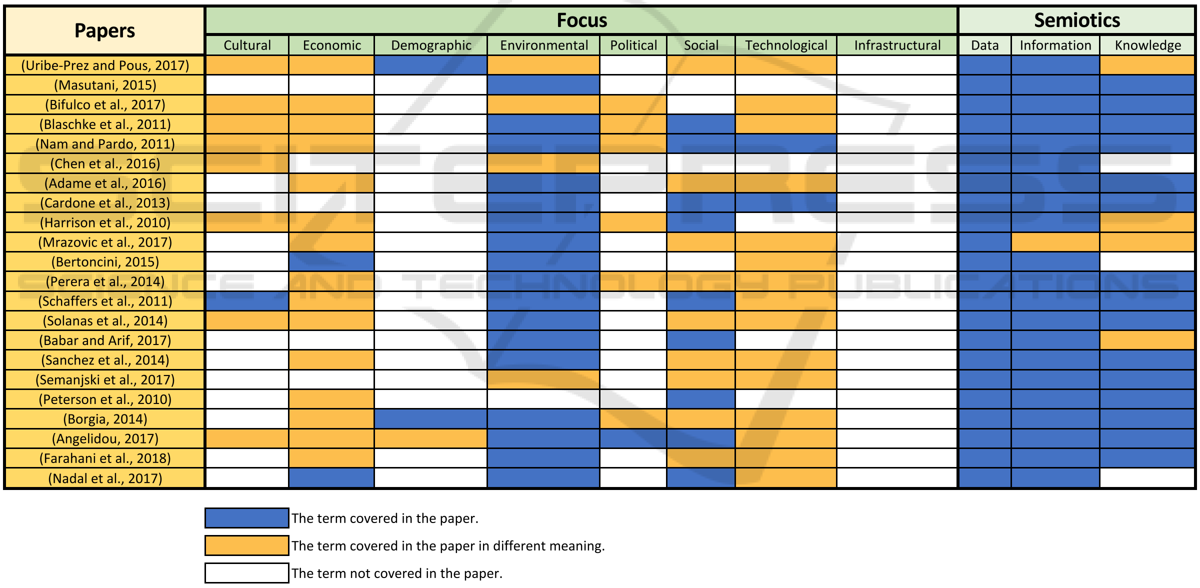

Figure 3: A table showing occurrence of ontology city terms (focus, semiotics) in studied papers.

be seen, the papers contain nearly every part of the ontology glossary. The interesting finding is that the papers do not contain infrastructural focus. The word infrastructure appears a lot, but always in a context of a structure. Less used is also focus on politics and demographics and the translate function. On the other hand, data and information are mentioned in nearly every paper.

The third figure, Figure 4, contains more white places than the previous one. It means that when papers speak about stakeholders, they, in most cases, mention citizens and governments. There is probably a less focus on other city stakeholders in this research field. Regarding the outcomes, they are mentioned quite often, but usually in a sense that Smart City should aim at their fulfillment. In a very small number of papers were outcomes directly connected to the main idea of the papers.

In the following section, we intend to position the papers into the ontology, which aims to validate this ontology by checking whether the relevant Smart City papers can be classified by the ontology, if not, what

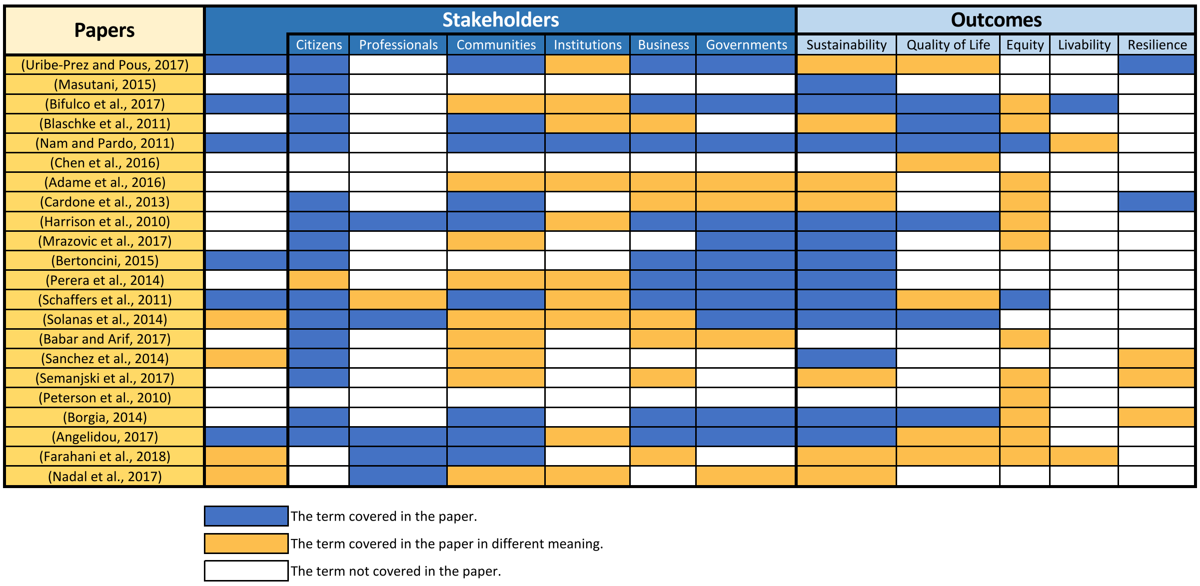

Figure 4: A table showing occurrence of ontology city terms in studied papers.

kind of extensions can be made to improve the ontology. For example, in the following validations, some terms might be out of the glossary of the Smart City ontology, they can be thus considered as the extensions to the ontology glossary. Therefore, the selected Smart City papers are used to test the validity of this ontology rather than using the ontology to classify the selected papers.

Table 1: Smart City Ontology validation by selected papers.

Paper	Ontology validation
(Uribe-Perez and Pous, 2017)	The communication architecture to sense, monitor, translate and communicate the urban data and information to stakeholders for a resilience.
(Masutani, 2015)	A route control method to enhance sensing coverage of a crowdsensing system.
(Bifulco et al., 2017)	Living Labs to develop services innovation. Living Labs to enhance citizens' engagement in urban life.
(Blaschke et al., 2011)	OGC framework to integrate remote sensing and sensor webs for decision makers to have better urban knowledge.

table continues

continued table

Paper	Ontology validation
(Nam and Pardo, 2011)	Strategic principles to strengthen human infrastructure and governance for institutional improvement and citizen engagement.
(Chen et al., 2016)	A platform to monitor, process and communicate data.
(Adame et al., 2016)	An IoT hybrid monitoring system to provide location, status, and to track patients and assets for improving healthcare environments.
(Cardone et al., 2013)	A crowd-sensing platform to profile users A crowd-sensing platform to autonomously choose people for deciding who to involve inparticipation and to quantify the performance of their sensing. A crowd-sensing platform to collect sensing data from smartphones for delivering sensing/actuation tasks to users.

table continues

continued table

Paper	Ontology validation
(Harrison et al., 2010)	Systems to sense data to get basic information about the city or services. Systems to interconnect other systems to get better more complex information about the city or services. Systems to analyze, model, optimize, visualize operations of city services to get even more complex information about the city or services.
(Mrazovic et al., 2017)	Mobility policies to restrict points of interest and routes among them by governments for sustainable growth.
(Bertoncini, 2015)	A framework to improve a Smart City infrastructure integration for cost-efficiency, energy efficiency, and reduced carbon footprints.
(Perera et al., 2014)	Sensing as a Service model to interconnect different data to extended service providers for opportunities to build innovative value added solutions that make the decision making process efficient and effective in IoT paradigm.
(Schaffers et al., 2011)	Collaboration frameworks to integrate Future Internet testbeds &Living Lab environments for fostering innovation ecosystems.
(Solanas et al., 2014)	A smart health concept to propose complex information about patient's health and environment or trigger processes by using Smart City elements for a better quality of life.
(Babar and Arif, 2017)	The architecture to monitor, process, translate and communicate the urban data to citizens for a quality of life.
(Sanchez et al., 2014)	A deployment and experimentation architecture to provide a suitable platform for large scale experimentation and evaluation of IoT concepts under real-life conditions.

table continues

continued table

Paper	Ontology validation
(Semanjski et al., 2017)	A model to infer transport mode from mobile sensed data for better understanding people's travel behavior.
(Peterson et al., 2010)	A service to use vehicle batteries to store grid electricity generated at off-peak hours for off-vehicle use during peak hours for balancing electricity consumption.
(Borgia, 2014)	An IoT paradigm to support Smart City ideas.
(Angelidou, 2017)	Different strategies to enhance citizen participation and civic innovation.
(Farahani et al., 2018)	A holistic architecture to sense, monitor, process, translate and communicate data to doctors and citizens for better quality of life.
(Nadal et al., 2017)	An automated methodology to use airborne sensors for identifying feasibility of implementation of rooftop greenhouses in non--residential urban areas.

It can be seen that there are three types of papers. Some are very specific and they can be very easily fitted into the ontology, e.g. (Mrazovic et al., 2017). In the second category, there are papers about more high-level ideas or concepts, e.g. (Farahani et al., 2018). These papers cover more ways in the ontology (the functions of IT architecture are sensing, monitoring, processing, translating as well as communicating and they can serve to all the city stakeholders). The third category of papers contains overview and conceptual papers. They discuss less specific topics, and those papers cover a very broad area of ideas. Therefore, they may consist of a high number of elements in the Smart City ontology. Our validation is mainly focused on the first two categories of papers, rather than overview and conceptual papers.

4 DISCUSSIONS

Based on the validation results, we found that most papers are fitting into different paths in the Smart City ontology, indicating the positive validity of this Smart City ontology. We, therefore, suggest that instead of finding a unified definition for Smart City, constructing and consolidating a comprehensive Smart City ontology can be more practical to define the

Smart City research.

Our validation results also show that this ontology can be extended, for example, in the structure component, additional elements can be included such as a methodology, analysis, platform, and approach. Also, in the function component, elements such as collect, improve, extend, optimize and handle can be added to the ontology. This brings to the discussion that a set of keywords in the ontology may refer to the same element or the same operation, e.g. approach, method and methodology may refer to the same term but just with different phrasing formats. Therefore, consolidating the terms in the ontology can be considered as a foundational future work for a validated Smart City ontology.

The independence and scope of the terms proposed in the ontology glossary need to be further validated, for example, some of our selected Smart City papers use "Platform" as their structure, which is not included in the current ontology. There can be overlaps between platform and system or platform can be used to dock systems. Therefore, a set of commonly agreed terms with clear scopes should be derived for the Smart City ontology. Furthermore, some of the terms are used together such as service system, where in the ontology service and system are considered as two independent terms. Our validation can thus help to improve the ontology glossary by further clarifying independence and scope of the ontology glossary.

It can be seen that some elements in the ontology are rarely used in different works, for example, translate in the function, demographical and infrastructural in focus, professionals in stakeholders and livability in outcomes. It may indicate that some element is not in the focus of the current Smart City research, for example, professionals may not be one of the well-focused stakeholders in Smart City research. It may otherwise indicate that some elements in the ontology can be omitted or merged to other elements e.g. the professionals can be considered as part of the citizen. Thus checking the reliability and scope of the elements in the ontology is critical.

On the other hand, some elements in the ontology are widely addressed in different Smart City papers. For example, systems in the structure, monitor in the function, environmental in focus, data, and information in semiotics, citizen and government in stakeholders, and sustainability in outcomes. We may infer the up-to-date priorities in the current Smart City research. Furthermore, our validation results indicate which paths in the Smart City ontology can be considered as main research streams in a Smart City research.

We further found that inside the ontology, it is difficult to commonly agree on the scope of some elements, especially for the architecture. The Smart City ontology considers architecture as a part of the structure. Some papers, e.g. (Babar and Arif, 2017), consider architecture as one big scope that covers all the concepts in a Smart City. Therefore, we further propose to refine the scope of the elements in the Smart City ontology.

5 CONCLUSION

In this paper, we have described the Smart City ontology that is recently proposed by (Ramaprasad et al., 2017). In order to better explain this ontology, we have aligned three papers to explain the possible paths from the ontology aspect. To further validate this ontology, we have selected a total of 22 Smart City papers and verified the validity of this ontology by matching the papers to the attributes of the ontology. Based on the validation results, we found that this ontology can be further refined and extended. Given different nature of the Smart City papers, some papers may not fit into this ontology but most papers can be explained by this ontology. As future works, we plan to align the design of the Smart Service with the roadmap that is indicated by the Smart City ontology. The implementation of a Smart Service may provide further insights into the ontology.

REFERENCES

Adame, T., Bel, A., Carreras, A., Melià-Seguí, J., Oliver, M., and Pous, R. (2016). Cuidats: An rfid-wsn hybrid monitoring system for smart health care environments. 78.

Angelidou, M. (2017). The role of smart city characteristics in the plans of fifteen cities. *Journal of Urban Technology*, 24(4):3–28.

Babar, M. and Arif, F. (2017). Smart urban planning using big data analytics to contend with the interoperability in internet of things. *Future Generation Computer Systems*, 77:65–76.

Bertoncini, M. (2015). Multi-resource optimized smart management of urban energy infrastructures for improving smart city energy efficiency. In *SMARTGREENS 2015 - 4th International Conference on Smart Cities and Green ICT Systems, Proceedings*, pages 107–114. Cited By :2.

Bifulco, F., Tregua, M., and Amitrano, C. C. (2017). Cogoverning smart cities through living labs. top evidences from eu. *Transylvanian Review of Administrative Sciences*, 2017(50E):21–37. Cited By :1.

Blaschke, T., Hay, G. J., Weng, Q., and Resch, B. (2011). Collective sensing: Integrating geospatial technologies to understand urban systems-an overview. *Remote Sensing*, 3(8):1743–1776. Cited By :40.

Borgia, E. (2014). The internet of things vision: Key features, applications and open issues. *Computer Communications*, 54:1–31. Cited By :172.

Cardone, G., Foschini, L., Bellavista, P., Corradi, A., Borcea, C., Talasila, M., and Curtmola, R. (2013). Fostering participaction in smart cities: A geo-social crowdsensing platform. *IEEE Communications Magazine*, 51(6):112–119. Cited By :93.

Chen, Y., Nakazawa, J., Yonezawa, T., Kawsaki, T., and Tokuda, H. (2016). Cruisers: A public automotive sensing platform for smart cities. In *Proceedings - International Conference on Distributed Computing Systems*, volume 2016-August, pages 767–768. Cited By :3.

Cocchia, A. (2014). Smart and digital city. pages 13–43.

Farahani, B., Firouzi, F., Chang, V., Badaroglu, M., Constant, N., and Mankodiya, K. (2018). Towards fog-driven iot ehealth: Promises and challenges of iot in medicine and healthcare. *Future Generation Computer Systems*, 78:659–676.

Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler-Milanović, N., and Meijers, E. (2007). *Smart cities: Ranking of European medium-sized cities*. Vienna University of Technology, Vienna.

Hall, R. H., Bowerman, B., Braverman, J., Taylor, J., Todosow, H., and von Wimmersperg, U. (2000). The vision of a smart city.

Harrison, C., Eckman, B., Hamilton, R., Hartswick, P., Kalagnanam, J., Paraszczak, J., and Williams, P. (2010). Foundations for smarter cities. *IBM Journal of Research and Development*, 54(4). Cited By :160.

Masutani, O. (2015). A sensing coverage analysis of a route control method for vehicular crowd sensing. In *2015 IEEE International Conference on Pervasive Computing and Communication Workshops, PerCom Workshops 2015*, pages 396–401. Cited By :4.

Mrazovic, P., Larriba-Pey, J. L., and Matskin, M. (2017). Improving mobility in smart cities with intelligent tourist trip planning. In *Proceedings - International Computer Software and Applications Conference*, volume 1, pages 897–907.

Nadal, A., Alamús, R., Pipia, L., Ruiz, A., Corbera, J., Cuerva, E., Rieradevall, J., and Josa, A. (2017). Urban planning and agriculture. methodology for assessing rooftop greenhouse potential of non-residential areas using airborne sensors. *Science of the Total Environment*, 601-602:493–507.

Nam, T. and Pardo, T. A. (2011). Conceptualizing smart city with dimensions of technology, people, and institutions. In *ACM International Conference Proceeding Series*, pages 282–291. Cited By :233.

Perera, C., Zaslavsky, A., Christen, P., and Georgakopoulos, D. (2014). Sensing as a service model for smart cities supported by internet of things. *Transactions on Emerging Telecommunications Technologies*, 25(1):81–93. Cited By :205.

Peterson, S. B., Whitacre, J. F., and Apt, J. (2010). The economics of using plug-in hybrid electric vehicle battery packs for grid storage. *Journal of Power Sources*, 195(8):2377–2384. Cited By :275.

Ramaprasad, A., Sánchez-Ortiz, A., and Syn, T. (2017). A unified definition of a smart city. In *Electronic Government*, pages 13–24. Springer International Publishing, Cham.

Sanchez, L., Muñoz, L., Galache, J. A., Sotres, P., Santana, J. R., Gutierrez, V., Ramdhany, R., Gluhak, A., Krco, S., Theodoridis, E., and Pfisterer, D. (2014). Smartsantander: Iot experimentation over a smart city testbed. *Computer Networks*, 61:217–238. Cited By :113.

Schaffers, H., Komninos, N., Pallot, M., Trousse, B., Nilsson, M., and Oliveira, A. (2011). *Smart cities and the future internet: Towards cooperation frameworks for open innovation*, volume 6656 of *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. Cited By :256.

Semanjski, I., Gautama, S., Ahas, R., and Witlox, F. (2017). Spatial context mining approach for transport mode recognition from mobile sensed big data. *Computers, Environment and Urban Systems*, 66:38–52.

Solanas, A., Patsakis, C., Conti, M., Vlachos, I., Ramos, V., Falcone, F., Postolache, O., Perez-Martinez, P., Pietro, R., Perrea, D., and Martinez-Balleste, A. (2014). Smart health: A context-aware health paradigm within smart cities. *IEEE Communications Magazine*, 52(8):74–81. Cited By :112.

Su, K., Li, J., and Fu, H. (2011). Smart city and the applications. In *2011 International Conference on Electronics, Communications and Control (ICECC)*, pages 1028–1031.

Uribe-Perez, N. and Pous, C. (2017). A novel communication system approach for a smart city based on the human nervous system. *Future Generation Computer Systems*, 76:314–328. Cited By :1.