Advancing Cognitive Cities with the Web of Things

Sara D'Onofrio, Simone Franzelli and Edy Portmann

Abstract Currently, the Internet of Things (IoT) is employed to establish connections among smart things as well as between smart things and individuals. It is used in various applications for smart cities. However, the IoT has several drawbacks, such as a lack of common standards, which would be required if as many things as possible are to be connected. The Web of Things (WoT) (i.e., the IoT extended using Web standards) possesses common standards and has many other advantages over the IoT. This article elaborates on both approaches, compares them, and summarizes the potential uses of the WoT in cognitive cities. With the WoT, processes in cognitive cities can be simplified and living standards improved. Thus, the WoT is suitable for addressing the challenges faced by today's cities.

Keywords Cognitive city • Cognitive computing • Collective intelligence • Internet of things • Smart city • Soft computing • Web of Things

1 Introduction

The number of available data in a city is becoming so large that it is difficult to efficiently process these data (cf. big data [1]). To use such a quantity of data on behalf of urban residents and improve their user experience, cities must recognize, collect, and analyze these data [2]. A solution to this challenge is to develop information and communications technologies (ICT) that can assist in the management of urban data.

S. D'Onofrio (✉) · S. Franzelli · E. Portmann
Institute of Information Systems, University of Bern, Bern, Switzerland
e-mail: sara.donofrio@iwi.unibe.ch

S. Franzelli
e-mail: simone.franzelli@iwi.unibe.ch

E. Portmann
e-mail: edy.portmann@iwi.unibe.ch

R.R. Yager and J. Pascual Espada (eds.), *New Advances in the Internet of Things*,
Studies in Computational Intelligence 715, DOI 10.1007/978-3-319-58190-3_5

Smart city refers to the use of ICT (e.g., Web-based services) in a city when accessing, processing, and using information to socially, ecologically, and efficiently develop the city and to improve living standards [3]. In this context, the Internet of Things (IoT) plays an important role because the introduction of innovative services improves the experiences of residents and thus their quality of life [4].

By embedding short-range mobile transceivers in a wide array of everyday items (e.g., mobile telephones), new forms of interaction between residents and smart things and between smart things can be established. In this manner, the IoT is created, and the ubiquity of the Internet is increased [5]. Enabling things to communicate with one another through a highly distributed network of devices enables a city to collect data in all types of situation and to share these data with its residents when they can be useful (e.g., data on traffic disturbances, weather alerts) [2, 5]. Particularly in the context of big data, it is crucial not only to be able to collect large amounts of raw data (e.g., through sensors) but also to convert the collected data into practical information for residents [6].

The IoT only represents the starting point of this development. In the future, as a result of the rapid development of the Web, a Web of Things (WoT) will probably connect residents with their cities. To date, the WoT has no clear definition. However, a small number of researchers (e.g., [7–9]) have attempted to establish one. In particular, Guinard and Trifa [10] have promoted this effort and defined the WoT as a specialization of the IoT that uses what made the Web so successful: global information access [11]. Thus far, the physical world and the Web have been separated. As an interface, a person is required, who connects the two realms by finding, integrating, and using information and services from both in a meaningful way [12]. The evolution of the Web makes it possible to connect smart things to the Web and to a large number of developers to effectively construct interactive, innovative applications that mimic reality (i.e., a blend of the physical and digital realms) [9].

The application of the WoT can influence city development (i.e., from smart to cognitive cities). The cognitive city is understood as an enhancement of the smart cities [13] by adding cognitive computing as well as cognition and learning theories, such as connectivism [14]. Connectivism describes a constant learning process with a simultaneous nurturing of connections. Not only humans but also other knowledge carriers (e.g., computer systems) can access data knowledge from other knowledge carriers. Thus, the acquisition and maintenance of knowledge is expanded from the personal dimension to multi-agent dimensions (e.g., human to human, computer system to computer system, human to computer system, computer system to human) [15]. By applying ICT, a city can use the knowledge, which has been shared with its knowledge carriers, to understand and learn from its residents. In this way, a city can recognize and react to changes in resident behavior [16]. Through the mutual communication, systems and residents learn from one another and build their common knowledge (cf. collective intelligence [17] and urban intelligence [18]). Therefore, Web standards, such as the WoT, are becoming more important because they facilitate the connection between urban systems and devices and thus optimize the interaction between residents and the city.

In this article, we compare the IoT with the WoT and demonstrate how the WoT can help smart cities evolve into cognitive cities. This article represents an outline of the current state of work-in-process and is in line with design science research [19]. The article is structured as follows: The transition from smart city to cognitive city is outlined in Sect. 2. Section 3 introduces the IoT, while Sect. 4 presents the WoT. Section 5 compares the IoT and the WoT in the context of smart and cognitive cities. Section 6 concludes the article.

2 From Smart City to Cognitive City

Although smart city is a frequently used term, a clear, consistent understanding of the concept among practitioners and scientists is lacking [2]. According to Portmann and Finger [3], a smart city is characterized by various concepts (e.g., smart democracy, smart mobility, smart work) that facilitate the interconnection of residents and modern technologies. Therefore, to enable such interconnection and the development of a city into a smart city, well-functioning ICT is required. Here, applications in many areas (e.g., health care, logistics, security) are imaginable (cf. [2]). Using such applications and thus interacting and sharing information with their city, residents become smart while further developing and shaping their city [3]. Newly developed systems (e.g., cloud-based social feedback, crowdsourcing, predictive analytics) improve the interaction between the smart resident and the city. The more input that residents have in shaping a system (i.e., a smart city), the higher their satisfaction (i.e., the better their user experience) [2]. Thus, the smart city can be understood as a sociotechnical system that aims to maintain a balance between efficiency and technology on the one hand and the happiness of its residents on the other hand [3].

A city's smartness can be described in terms of understanding, learning, and self-awareness. That is, a city can understand its own processes and learn from and reflect on them. It is important that the smart city collaborates with many disciplines (e.g., architecture, computer sciences, politics, business) and involves them in its development [2, 3]. Collectively, residents and cities can act in such a way that they behave more intelligently than they would individually, and in this manner, urban intelligence (i.e., collective intelligence [17] in a smart city) is achieved [18]. To improve the relationship between a city and its residents, it is crucial that the city understand resident needs. In this context, connectivism [14] is a significant concept. Here, not only personal experiences and perceptions but also those of others are important. Using advanced ICT to share these experiences and perceptions, the city can retrieve relevant information from its residents. Learning algorithms included in the underlying urban processes enable the city to extract patterns [20] and to understand and learn from these patterns. This learning concept is a basic principle of cognitive computing.

Cognitive computing represents an enhancement of semantic computing (which emerged from the Semantic Web [21]). Semantic computing simplifies and automates processes through definitions, models, and queries to extract the meaning of the data, while cognitive computing refers to the ability of systems to reason.

Cognitive systems can act consciously, critically, and logically to extract knowledge [22]. The application of cognitive computing and additional, new components (i.e., cognition and the related cognitive systems) support the further development of smart cities and optimize their urban processes [13]. The underlying cognitive systems can cope with natural language and perceptions and learn from the user's (i.e., the resident's) past behavior [2]. That is, these systems recognize changes in behavior and can react to them [16].

Therefore, using the advantages of cognitive computing, the city can successfully respond to challenging situations, particularly those that involve imprecise language and perceptions using cognitive systems [2, 13]. The interaction between residents and advanced ICT is optimized, which enlarges the knowledge base inside a city [3]. Because of the increased knowledge—based on the experiences and behavior of the system user (i.e., the resident)—urban processes can be performed more realistically and efficiently [16], provide more opportunities for residents to develop themselves and increase the city's attractiveness [2].

Several companies (e.g., Accenture, IBM, Microsoft) have begun applying cognitive computing in business and IT services to generate higher revenues, solve problems more efficiently, make better decisions, and improve the efficiency of applications [2]. Thus, the application of cognitive computing in urban development is of substantial interest.

3 Internet of Things

This section introduces the IoT, describes several of its technical aspects, and presents examples of IoT applications in cities.

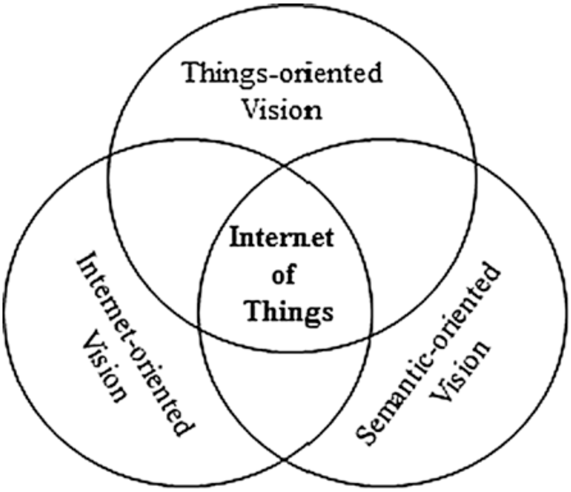
3.1 Definition

The Internet, which is a global system of interconnected computer networks, uses the standard Internet protocol suite (TCP/IP) to link numerous devices worldwide to carry a substantial amount of data or information. The IoT functions in the same manner as the Internet (i.e., collects and shares information) by combining networks of various physical objects using network connectivity [6, 10].

The IoT's evolution can be viewed as a movement from the current Internet to a network of interconnected (smart) things. The IoT is based on interoperable ICT, which not only gathers information from the environment (i.e., through sensing) and interacts with the physical world (i.e., actuation) but also uses existing Internet standards to provide services for information transfer, analytics, and communications [23, 24].

The main characteristic of IoT is the integration of several technologies and communications solutions (e.g., identification and tracking technologies, wired and wireless sensors, actuator networks) to improve interaction and cooperation among

Fig. 1 Three visions of IoT



users, for example, through devices (e.g., mobile telephones, sensors), and thus to achieve common knowledge [5].

According to Atzori et al. [5], in the IoT, the following three visions converge: Internet-oriented (i.e., middleware), things-oriented (i.e., sensors), and semantic-oriented (i.e., knowledge) (Fig. 1).

The Internet-oriented vision refers to the idea of reducing the number of Internet protocols (IPs). By implementing IoT using simplified IPs, objects are made addressable and reachable from any location [5, 6]. The things-oriented vision is based on several simple items (e.g., RFID, smart items) and basic components (e.g., NFC, wireless sensors), which are applied using interfaces to connect the real world with modern ICT. The semantic-oriented vision addresses the challenge of extracting information from the increasing number of items in the Internet. In this context, the primary task is to aggregate and represent knowledge (cf. [5, 6, 25]).

From a system-level view, the IoT is a highly dynamic network system that consists of a large number of (smart) things that produce and consume information. Capable of connecting the physical realm with the digital realm and translating the data into human-readable information, the IoT opens a new era of knowledge-building [6].

3.2 Architecture

Generally, the IoT can be divided into the following 3 layers: the perception/sensing layer, the network/transmission layer, and the application layer (Fig. 2) [26, 27].

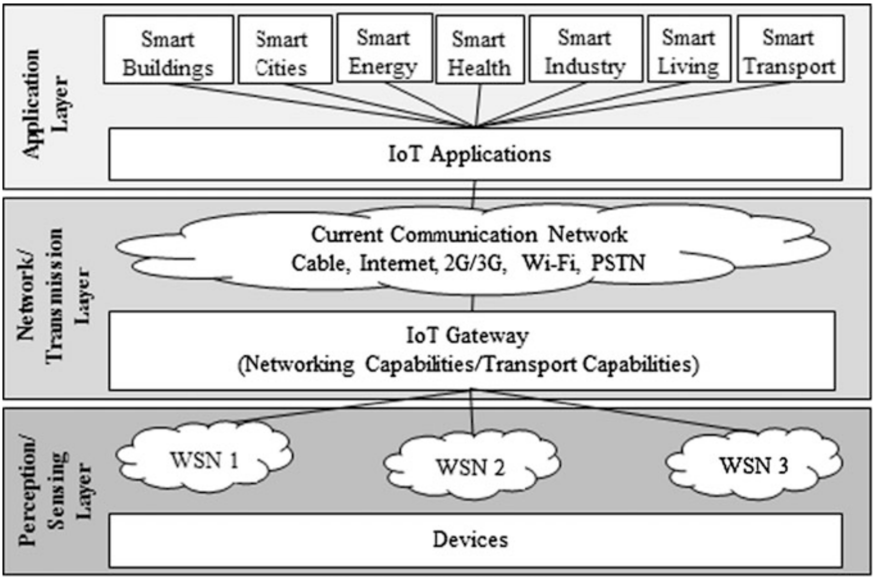


Fig. 2 IoT architecture

The primary function of the perception/sensing layer, which consists among others of two-dimensional code tags, a code reader, sensors, and sensor networks, is to perceive and identify (smart) things and to acquire and recognize information from them. The network layer (i.e., the IoT's infrastructure) is formed by all types of communication networks and the Internet. Its main parts are the IoT management center and the information center. Therefore, the network layer operates not only the network but also the information. To develop accurate application solutions, the application/transmission layer (i.e., information service system) is required that can be viewed as IoT technology combined with expertise (from industry or academia). This layer's primary task is to guarantee information sharing and information security in various areas (e.g., smart buildings, smart industry, smart transport) [26, 27]. Therefore, a typical IoT solution is characterized by many devices (i.e., smart things) that use a gateway to communicate through a network [28].

3.3 Standards and Interfaces

Standards are key for the interoperability required to improve the integration of various technologies and thus enhance the interaction between individuals and systems [29]. There are hundreds of standards from diverse organizations (e.g., IEEE,[1] NIST[2]), protocols[3] (e.g., IPv6, 6LoWPan), and IoT platforms[4] (e.g., ThingWorx, EVRYTHING, Amazon Web Services Internet of Things) to choose from [10]. Therefore, it is impossible to summarize the IoT standards.

Because there is a defined API for every standard, there are even more interfaces (API) than standards (cf. [29]). Thus, every IoT solution has its own defined API, which enables easy integration with existing applications and integration with other IoT solutions [28].

3.4 IoT Applications in Cities

Many researchers (e.g., [4, 5, 30]) have conceptualized and tested IoT applications in the urban context. A literature review, Table 1, shows examples of urban IoT applications.

Several of the studies cited in the table aim to improve urban mobility by monitoring roads and parking spaces (cf. [4, 31, 32]). Others try to decrease energy consumption and environmental pollution (cf. [5, 33, 34]). Still others collect data on buildings and infrastructure as well as general environmental data (cf. [5, 35]). There is also an application from the shopping domain (cf. [36]). In sum, these examples of urban applications indicate that the IoT has the potential to improve city development through the integration of human and machine.

4 Web of Things

This section introduces the WoT, describes several of its technical aspects, and presents examples of WoT applications used in cities.

4.1 Definition

The Web is constantly evolving (i.e., from Web 1.0 to Web 4.0 [37]). Thus, today, anyone can access Web servers from personal devices (e.g., computer, mobile telephone), and services are increasingly provided on the Internet using Web applications [8].

---

[1] cf. https://www.ieee.org/index.html.

[2] cf. https://www.nist.gov/.

[3] cf. http://www.postscapes.com/internet-of-things-protocols/.

[4] cf. http://internetofthingswiki.com/top-10-iot-platforms/634/.

Table 1 IoT applications in cities

Source	Approach	Description
[5]	City information model	The city continuously monitors the status and performance of its buildings and infrastructure (e.g., cycle paths, rail lines) and shares the information with third parties through APIs
[35]	Low carbon open data network	Using low-power, low-cost sensing equipment, environmental data are collected in real time. Open access to these data is provided to residents via online services, which means that they can develop applications based on the data
[31]	RDF stream processing	A travel planner application, which recommends the best route based on live data from traffic sensors while considering factors such as the user's transport mode, traffic congestion, and estimated arrival time
[32]	Road condition application	An application that provides road condition alerts based on data from embedded sensors in the smartphones of vehicle users
[36]	Smart shopping	A smart shopping environment that tells merchants when to inform citizens regarding shopping offers based on the analysis of city-context data (e.g., city agenda, parking data)
[33]	Energy management	The application draws data from different sources (e.g., heat and electricity meters) to improve the use of energy in commercial and residential areas
[4]	Traffic control systems	IoT technologies are applied to monitor traffic and parking spaces in cities as well as to offer traffic routing advice
[34]	Semantic framework	A framework that collects data and models them for specific IoT applications (e.g., detection of vehicle pollution) that are based on semantic and machine-learning technologies

The WoT is a means of accessing surrounding devices through Web applications [8]. The WoT's underlying idea is for each (smart) thing to have its own Web page and thus be available for indexing by search engines. Subsequently, one can search for the thing and access it directly from a Web browser [38]. By reusing Web standards and adapting technologies and patterns commonly used for traditional Web content, objects (i.e., things) of daily life can be connected and fully integrated into the Web [5, 39]. Therefore, the WoT is an environment in which everyday objects (e.g., buildings, traffic lights, commodities) are identifiable, recognizable, and controllable through the Internet using Semantic Web standards. Thus, a large number of things appear on the Web, which means that seamless communication between individuals and (smart) things is provided. Similar to the IoT, the WoT seeks to bridge the gap between the physical and digital realms using a common platform (i.e., the Web) that is accessible to everyone [9].

According to Trifa [40], the WoT is based on five pillars of the modern Web architecture (Fig. 3).

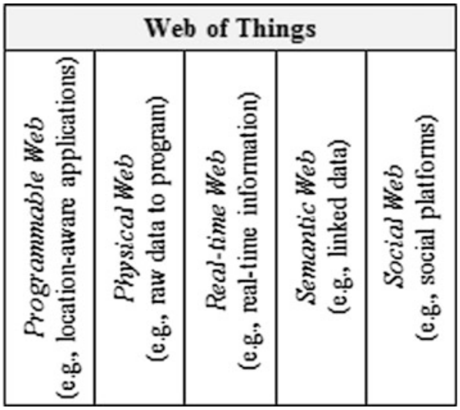


Fig. 3 WoT characteristics

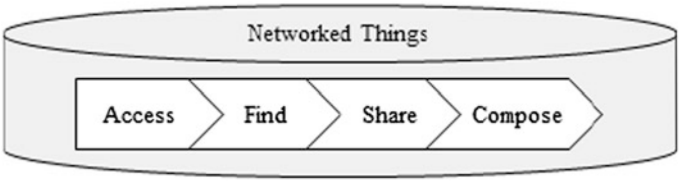


Fig. 4 WoT architecture

4.2 Architecture

The WoT has the following four layers: *Access*, *Find*, *Share*, and *Compose* (Fig. 4). These layers more thoroughly integrate (smart) things into the Web and make them more accessible for applications and individuals [10].

In *Access*, the primary task consists of transforming a (smart) thing into a programmable Web thing with which other devices can easily communicate. The layer *Find* ensures that a device is findable and automatically usable by other WoT applications. *Share* specifies how the data generated by (smart) things can be efficiently shared over the Web. Finally, *Compose* creates in a simple way applications that involve (smart) things and virtual Web services [10]. Thus, the aim is not to apply the Web as a transport infrastructure but to make devices an integral part of the Web [39].

4.3 Standards and Interfaces

The WoT does not create completely new standards. Instead, it reuses the well-known Web standards [39] used in the physical (e.g., Beacon), programmable (e.g., REST, HTTP), semantic (e.g., RDF, OWL), real-time (e.g., WebSockets), and social (e.g., profile standards) Webs [40].

Web standards ensure that data can be rapidly and easily moved across systems. HTTP and REST (cf. [41]) are the most frequently recommended Web services for offering public access to data available on the Web. With REST constraints, the interaction between the components (because each component of the system complies with those constraints) is well defined and thus predictable. Therefore, (smart) things can be smoothly integrated into the Web by making them findable for Web users through a RESTful interface (API) using HTTP [10].

4.4 WoT Applications in Cities

Although the WoT remains an emerging approach, a small number of researchers (e.g., [42–44]) have theoretically applied it in a city context. A literature review, Table 2, shows examples of WoT applications used in cities.

Table 2 WoT applications in cities

Source	Approach	Description
[42]	Traffic SenseBox	A sensor platform focused on easy accessibility via the Web, with a built-in ultrasonic sensor that can determine traffic density by counting the number of passing cars
[7]	WebIoT	A Web application framework that aims to improve the interaction among things and between things and humans
[45]	Intelligent vehicle system	Road users can apply a traffic information service, which shows road obstacles and congestion levels and is personalized through WoT-API for their requirements
[39]	Energie visible	This project provides a Web dashboard, which enables individuals to visualize and better understand, monitor, and control the energy consumption of household appliances
[43]	Smart home	Using the Web's infrastructure, Web applications can be designed that benefit a large number of simultaneous users, who can fully automate their houses (i.e., the smart home)
[30]	Landsliding early warning	Sensor nodes that are implemented in a landsliding high-risk zone collect and display real-time telemetry observations of, e.g., soil movement and precipitation
[51]	Multimedia remote controller	A prototype based on a Web application that can exchange information with nearby electronic devices and on a mobile Bluetooth application
[44]	Smart farm	A prototype relying on Semantic Web standards that uses livestock monitoring technologies, environmental sensors, and an ontology-enabled architecture for personal real-time alerts for on-farm situation awareness

Currently, it is difficult to find WoT applications in actual use in cities. Several of the applications mentioned in Table 2 are envisaged use cases and have not yet been applied in real-world scenarios. There are various areas in which such WoT applications may be used, for example, in the measurement and visualization of traffic flows (cf. [42, 45]) or energy consumption (cf. [39]). WoT applications could also be helpful in the development and functioning of smart homes (cf. [43]), smart farms (cf. [44]), or natural disaster warning systems (cf. [30]). More generally, a Web application framework aimed at improving the interaction among things and between things and humans [7] as well as a system that facilitates the sharing and control of the access to resources in the WoT [46] are presented in the table.

As in the case of the IoT (because the WoT is specialization of the IoT [10]), one can conclude that the WoT has the potential to improve city development through a closer interaction and integration of residents and machines.

5 The Internet of Things Compared with the Web of Things

First, a general comparison of the IoT and the WoT is made, followed by a comparison of the main aspects of both approaches in the context of smart and cognitive cities.

5.1 General Comparison

The IoT only involves the interconnection of (smart) things with the Internet, without considering any technology or network structures [8]. Therefore, while the Internet is the correct option to connect physical things, the option for a universal platform on which to construct applications using things is the Web [9]. To illustrate this point, Table 3 shows a literature-based comparison of both approaches, in which ‘+’ indicates positive (incl. potential) impacts and ‘−’ indicates negative impacts (incl. threats). In this comparison, only decisive criteria are included (i.e., those that are mentioned most frequently in the consulted literature). Additional criteria (e.g., automation, quality of life, sustainability) were considered. However, because the IoT and the WoT have similar advantages in these fields, they have been omitted. Therefore, Table 3 only includes criteria with respect to which major differences appear between the IoT and the WoT and therefore is incomplete.

As Table 3 shows, the WoT has several advantages over the IoT. For example, the WoT is much easier to maintain and program. It is also substantially more secure than the IoT, and its standards are more universally applicable than the fragmented IoT standards. Only in the aspect of privacy do both systems display problems. However, even in this respect, the WoT is one step ahead of the IoT.

Table 3 Comparison of the IoT and the WoT

	IoT	WoT
Maintainability	• Significant effort required to write custom convertors for each new device [10] • Long-term maintainability vulnerabilities (because of competitive cost and technical constraints) [47] • Improved maintainability of the systems through integrators [50]	• Existing widespread (Web) technologies enable substantial ease of development [8] • Maintaining Web applications is more cost-efficient [51] • No risk that the Web will suddenly cease to function and require an upgrade [10]
Privacy	• Potential harm is amplified in the IoT by the scale and greater intimacy of personal data collection [47] • Privacy breach (i.e., when a thing is put online, it remains online) [53] • Privacy requirement in the IoT is currently only partially covered [52]	• Potential privacy violations (i.e., Web services having drawbacks) [46] • Public sharing might result in serious privacy implications [39] • Standard protocols for securely encrypting data between clients and servers on the Web [10]
Programmability	• Complex ease of design and development [48] • Much computing power for identification/addressing schemes [49] • High barrier for adoption (i.e., complex IoT protocols) [10]	• Easier; surrounding devices are accessed through Web applications [8] • Open ecosystem (i.e., creating applications using standard Web services) [46] • Same programming model for interaction with Web API [10]
Security	• Vulnerable to attack (e.g., unattended components, wireless communications, low capabilities of energy and computing resources) [5] • Possibility of personal data being stolen [53] • Security problems [27]	• Secure interactions with HTTPS [8] • Less risky (i.e., constantly tested, updated, and fixed systems) [10] • Authenticated and secure communication between clients and gateways with HTTPS and OAuth [40]
Standards	• Complex standards landscape [29] • Standards funded and governed by corporations are not neutral [10] • Risk of fragmentation and lack of adoption of adequate standards [4]	• Adoption of IP (i.e., open standards for thing communications) [7] • Promising results when using Web standards (i.e., easily accessible) [39] • Open and free standards [10]

The next section treats most of these aspects in more detail. However, it should be kept in mind that this comparison is only a literature-based one and thus does not represent an exhaustive list.

5.2 Benefits for Smart and Cognitive Cities

In 2011, the number of interconnected devices exceeded the world's human population. Currently, there are approximately 9 billion interconnected devices. The number predicted for 2020 is approximately 24 billion devices [23]. More than ever, the IoT and the WoT concepts are becoming interesting for cities.

The aim of a smart city is to more efficiently use resources to improve the quality of services and thus to increase the city's attractiveness [2]. Embedding devices into everyday physical objects and making them smart enable the integration of such objects into the global cyberphysical infrastructure [4, 6]. Thus, the interconnection of the physical and virtual realms can improve the management of cities and urban processes in various fields (e.g., education, health, logistics) [2]. Using IoT, a smart city confronts certain obstacles (e.g., long-term maintainability vulnerabilities [47], complexity in programming [48]). More precisely, the city must invest a significant effort to program and maintain custom convertors, identification, and addressing schemes for each device [10, 49, 50].

Such programming is coupled with standards. Because there is a large, complex standards landscape that is to a certain extent funded and governed by corporations, IoT development is complicated [29]. Therefore, the use of Web standards in the context of cognitive cities is particularly interesting. These open, free standards make it substantially easier for cities to share data with their residents [2, 10]. The possibility of accessing surrounding devices through Web applications and the use of open standards make these devices easily accessible in a universal way [7, 8, 39].

This open ecosystem of digitally augmented smart things makes it easier for developers to process real-time data from various fields (e.g., traffic pollution, public transportation) [46]. Because there is no risk that the Web will suddenly cease to function, the maintenance of such Web applications is cost-efficient, which enables substantial ease of development [8, 10, 51]. The sharing of real-time information between smart things and city residents results in a learning cycle and pattern recognition. Through this mutual learning process (i.e., connectivism [14]), collective intelligence [17] (i.e., urban intelligence [18]) can be achieved.

Regarding the maintainability, programming, and standardization of applications, it seems that the Web offers more potential for urban development than the Internet does. However, both approaches are confronted by issues of privacy and security. In the IoT, privacy requirements are generally only partially addressed [52], which makes the connected devices highly vulnerable to attack. In the worst case, personal data might be stolen [5, 53]. In the WoT, the Web continues to display several drawbacks that could have serious privacy implications [39, 46]. However, by applying the HTTP programming model, particularly HTTPS, it is possible to offer authenticated, secure communication between mobile clients and gateways [8, 40]. In addition, there is less risk of attack because Web services are constantly used, tested, updated, and fixed [10]. Even if the issues of security and privacy are difficult, the Web is better able to counter these challenges than the Internet.

6 Conclusions and Outlook

Because of the potential of connecting smart things with individuals and systems through the Internet, several studies (e.g., [54, 55]) suggest that the IoT will evolve into a future IoT (i.e., an advanced and extended version of the IoT). However, we believe that the next phase of the IoT will be the WoT (i.e., the IoT extended by the Web), particularly in the context of city development. Regarding the advantages of the WoT over the IoT maintainability, programming, and standardization, the authors recommend considering the WoT for the development of smart and cognitive cities. In particular, the following aspects make the WoT useful for cognitive cities: first, common standards and ease of programming, which enable more individuals to participate in the development of new applications; second, the higher security of communication; third, the reduced effort required to maintain the Web. It must be noted that the comparison of the two approaches is based on information sciences research and thus provides insight from only one perspective. To clearly state which approach is better (and to what extent) for city development, other perspectives (e.g., mathematical, engineering) should also be considered.

An important issue in the context of the WoT that has not been mentioned is the search process, which enables connected objects to be discovered and filtered for a given use and to be combined or associated within Web applications. Objects can only be found if they are described with identifiable and traceable information. To use these connected objects in Web applications, dedicated description languages (e.g., WSDL, WADL) are required. With the emergence of Web-enabled objects, efficient techniques that facilitate the search for connected objects will be crucial for the WoT's success [56].

In addition, the privacy and security issues should be elaborated in more detail. Even if the HTTP programming model facilitates secure communication, the Web possesses other drawbacks that cannot be ignored.

Moreover, research on how the WoT can benefit smart and cognitive cities in specific real-life cases should be expanded. Only a small number of applications of and use cases for the WoT in cities have been developed, which indicates a substantial opportunity for future research in this area (e.g., the creation of a *Google* for cities).

Acknowledgements The authors would like to thank the Institute of Information Systems at the University of Bern, particularly Anne Gerster and Michelle Ballmer, for the helpful input. We are also grateful to Joël Vogt from the WoT company EVRYTHNG,[5] who provided constant support, help, and advice regarding the IoT.

---

[5] cf. https://evrythng.com.

References

1. Y. Chen, E. Argentinis, G. Weber, IBM Watson: how cognitive computing can be applied to big data challenges in life sciences research. Clin. Ther. **38**(4), 688–701 (2016)
2. S. D'Onofrio, E. Portmann, Cognitive computing in smart cities. Inf. Spektrum, 1–12 (2016)
3. E. Portmann, M. Finger, Smart Cities! Ein Überblick. HMD Praxis der Wirtschaftsinformatik **52**(4), 470–481 (2015)
4. D. Miorandi, S. Sicari, F. De Pellegrini, I. Chlamtac, Internet of things: vision, applications and research challenges. Ad Hoc Netw. **10**(7), 1497–1516 (2012)
5. L. Atzori, A. Iera, G. Morabito, The internet of things: a survey. Comput. Netw. **54**(15), 2787–2805 (2010)
6. G. Misra, V. Kumar, A. Agarwal, K. Agarwal, Internet of Things (IoT)—A Technological Analysis and Survey on Vision, Concepts, Challenges, Innovation, Directions, Technologies, and Applications (An Upcoming or Future Generation Computer Communication System Technology). Am. J. Electric. Electron. Eng. **4**(1), 23–32 (2016)
7. A.P. Castellani, M. Dissegna, N. Bui, M. Zorzi, WebIoT: a web application framework for the internet of things, in *Workshop on Wireless Communications and Networking Conference Workshops (WCNCW)*, (IEEE, 2012), pp. 202–207
8. S. Duquennoy, G. Grimaud, J.J. Vandewalle, The web of things: interconnecting devices with high usability and performance, in *International Conference on Embedded Software and Systems*, (2009), pp. 323–330
9. S.S. Mathew, Y. Atif, Q.Z. Sheng, Z. Maamar, Web of things: description, discovery and integration, in *IEEE International Conferences on Internet of Things, and Cyber, Physical and Social Computing*, vol. 9, no. 15. (2011), pp. 19–22
10. D. Guinard, V. Trifa, *Building the Web of Things* (Manning, Shelter Island, 2016)
11. E. Portmann, The FORA framework—a fuzzy grassroots ontology for online reputation management. Dissertation 2012
12. D. Pfisterer, K. Römer, D. Bimschas, H. Hasemann, M. Hauswirth, M. Karnstedt, O. Kleine, A. Kröller, M. Leggieri, R. Mietz, M. Pagel, A. Passant, R. Richardson, C. Truong, SPITFIRE: Towards a Semantic Web of Things. IEEE Commun. Mag. **49**(11), 40–48 (2011)
13. E. Portmann, M. Finger, *Towards Cognitive Cities—Advances in Cognitive Computing and its Application to the Governance of Large Urban Systems*, vol. 63. (Springer International Publishing 2016)
14. G. Siemens, Connectivism: a learning theory for the digital age. Int. J. Instr. Technol. Distance Learn. **2**(1), 3–10 (2005)
15. P. Kaltenrieder, E. Portmann, S. D'Onofrio, Enhancing multidirectional communication for cognitive cities, in *2nd International Conference on eDemocracy & eGovernment*, Quito, Ecuador, (2015)
16. J.S. Hurwitz, M. Kaufman, A. Bowles, *Cognitive Computing and Big Data Analytics* (John Wiley and Sons Inc, Hoboken, New Jersey, 2015)
17. T.W. Malone, M.S. Bernstein, *Handbook of collective intelligence* (The MIT Press, Cambridge, 2015)
18. R. Moyser, S. Uffer, From smart to cognitive: a roadmap for the adoption of technology in cities, in *Towards Cognitive Cities: Advances in Cognitive Computing and Its Applications to The Governance of Large Urban Systems*, ed. by E. Portmann, M. Finger (Springer International Publishing, Heidelberg, 2016), pp. 13–35
19. A.R. Hevner, S.T. March, J. Park, S. Ram, Design science in information systems research. MIS Q. **28**(1), 75–105 (2004)
20. G. Papakostas, E. Papageorgiou, V. Kaburlasos, Linguistic fuzzy cognitive maps (LFCM) for pattern recognition, in *IEEE International Conference on Fuzzy Systems (FUZZIEEE 2015)*, Istanbul, Turkey, (2015), pp. 1–7
21. T. Berners-Lee, J. Hendler, O. Lassila, The semantic web. Sci. Am. **284**(5), 28–37 (2001)

22. S. D'Onofrio, E. Portmann, Von fuzzy-sets zu computing-with-words. Inf. Spektrum **38**(6), 543–549 (2015)
23. J. Gubbi, R. Buyya, S. Marusic, M. Palaniswami, Internet of things (IoT): a vision, architectural elements, and future directions. Future Gener. Comput. Syst. **29**, 1645–1660 (2013)
24. International Telecommunication Union, *Overview of the internet of things* (ITU, Geneva, 2012)
25. E. Portmann, P. Kaltenrieder, W. Pedrycz, Knowledge representation through graphs, in *International Conference on Soft Computing and Software Engineering*, Berkeley, California (2015)
26. M. Yun, B. Yuxin, Research on the architecture and key technology of internet of things (IoT) applied on smart grid, in *Proceedings of the International Conference on Advances in Energy Engineering*, (2010), pp. 69–72
27. H. Zhang, L. Zhu, Internet of things: key technology, architecture and challenging problems, in *IEEE International Conference on Computer Science and Automation Engineering (CSAE)*, vol. 4, (2011), pp. 507–512
28. Eclipse IoT White Paper, *The Three Software Stacks Required for IoT Architectures*, (2016), pp. 1–16
29. P.F. Drucker, Internet of things—position paper on standardization for IoT technologies, in *European Research Cluster on Internet of Things*, (2015), pp. 1–142
30. M.O. Kebaili, K. Foughali, K. FathAllah, A. Frihida, T. Ezzeddine, C. Claramunt, Landsliding early warning prototype using MongoDB and web of things technologies. Proc. Comput. Sci. **98**, 578–583 (2016)
31. F. Gao, M.I. Ali, A. Mileo, RDF stream processing for smart city applications, in *RDF Stream Processing Workshop (ESWC2015)*, (Slovenia, 2015), pp. 1–3
32. A. Ghose, P. Biswas, C. Bhaumik, M. Sharma, A. Pal, A. Jha, Road condition monitoring and alert application, in *IEEE Pervasive Computing and Communication (PerCom 2012)*, (Lugano, Switzerland, 2012), pp. 489–491
33. D. Kyriazis, T. Varvarigou, A. Rossi, D. White, J. Cooper, Sustainable smart city IoT applications: heat and electricity management & Eco-conscious cruise control for public transportation, in *International Symposium and Workshops on a World of Wireless, Mobile and Multimedia Networks (WoWMom 2013)*, (2013), pp. 1–5
34. N. Zhang, H. Chen, X. Chen, J. Chen, Semantic framework of internet of things for smart cities: case studies. Sensors **16**(9), 1–13 (2016)
35. D. Carter, Urban regeneration, digital development strategies and the knowledge economy: manchester case study. J. Knowl. Econ. **4**(2), 69–189 (2013)
36. IoT Open Platforms, BUTLER Smart Parking Trial, http://open-platforms.eu/app_deployment/butler-smart-parking-trial/. Accessed 12 Jan 2017
37. S. Aghaei, M.A. Nematbakhsh, H.K. Farsani, Evolution of the world wide web: from web 1.0 to web 4.0. Int. J. Web Semant. Technol. (IJWest) **3**(1):1–10 (2012)
38. D. Guinard, V. Trifa, Towards the web of things: web mashups for embedded devices, in *International World Wide Web Conference, Workshop on Mashups, Enterprise Mashups and Lightweight Composition on the Web (MEM 2009)*, (2009), p. 15
39. D. Guinard, V. Trifa, F. Mattern, E. Wilde, From the internet of things to the web of things: resource-oriented architecture and best practices, chapter, in *Architecting the Internet of Things*, ed. by D. Uckelmann, M. Harrison, F. Michahelles (Springer, Berlin Heidelberg, 2011), pp. 97–129
40. V. Trifa, Building blocks for a participatory web of things: devices, infrastructures, and programming frameworks. Dissertation 2011
41. S. Tilkov, REST und HTTP Einsatz der Architektur des Web für Integrationsszenarien, dpunkt.verlag (2011)
42. A. Bröring, A. Remke, D. Lasnia, SenseBox—a generic sensor platform for the web of things, in 8th *Annual International Conference on Mobile and Ubiquitous Systems: Computing,*

Networking and Services (MobiQuitous 2011), vol. 104, no. 5 (Springer Berlin, 2012), pp. 186–196

43. A. Kamilaris, A. Pitsillides, The smart home meets the web of things. Int. J. Ad Hoc Ubiquitous Comput. **7**(3), 145–154 (2011)
44. K. Taylor, C. Griffith, L. Lefort, R. Gaire, M. Compton, T. Wark, D. Lamb, G. Falzon, M. Trotter, Farming the web of things. IEEE Intell. Syst. **28**(6), 12–19 (2013)
45. T.S. Dillon, H. Zhuge, C. Wu, J. Singh, E. Chang, Web-of-things framework for cyber-physical systems. Concurr. Comput. Pract. Exp. **23**(9), 905–923 (2011)
46. D. Guinard, V. Trifa, E. Wilde, A resource oriented architecture for the web of things, in *Internet of Things (IOT)*, (IEEE, 2010), pp. 1–8
47. Internet Society Whitepaper, The internet of things: an overview—understanding the issues and challenges of a more connected world, 1–75 (2015)
48. J. Chase, *The evolution of the internet of things* (Strategic marketing, Texas Instruments, Texas Instruments Incorporated, Dallas, 2013), pp. 1–6
49. E. Fleisch, What is the internet of things? An economic perspective, economics, management, and financial market **2**, 125–157 (2010)
50. F. Jammes, *Internet of Things in Energy Efficiency, Ubiquity Symposium*, (ACM, 2016), p. 2
51. J. Pascual-Espada, V.G. Diaz, R.G. Crespo, O.S. Martinez, B.C.P. G-Bustelo, J.M. Cueva Lovelle, Using extended web technologies to develop Bluetooth multi-platform mobile applications or interact with smart things. Inf. Fusion, **21**:30–41 (2015)
52. S. Sicari, A. Rizzardi, L.A. Grieco, A. Coen-Porisini, Security, privacy and trust in internet of things: the road ahead. Comput. Netw. **76**, 146–164 (2015)
53. Z. Jun, Internet of Things, Disruption or Destruction? Amsterdam Business School (2014)
54. R. Khan, S.U. Khan, R. Zaheer, S. Khan, Future internet: the internet of things architecture, possible applications and key challenges, in *IEEE 10th International Conference on Frontiers of Information Technology (FIT)*, (2012), pp. 257–260
55. J.A. Stankovic, Research directions for the internet of things. IEEE Internet Things J **1**(1), 3–9 (2014)
56. C. Benoit, V. Verdot, V. Toubiana, Searching the 'Web of Things', in *Fifth IEEE International Conference on Semantic Computing (ICSC)* (2011), pp. 308–315