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Software systems from smart city vendors

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ABSTRACT

The concept of a smart city has recently gained attention in academic, industry, and governments. Smart cities could be considered as urban areas that use data collection sensors and digital technologies which cooperate to create benefits for citizens in terms of well being, inclusion and participation, environmental quality, and intelligent development. Smart city vendors provide software systems to support application developers, city managers, urban planners, and policy-makers in designing, implementing, deploying, and managing smart city applications for an effective urban development and management. Although there exist a variety of smart city software systems, their benefits and limitations are still unknown. In this paper we review smart city vendors and we provide insight into their software systems for smart cities. Thus, we come up with a good entry point, and here survey a large amount of information to help developers, city managers, urban planners, and policy-makers to take better decisions when choosing smart city software systems.

1. Introduction

The urban population of the world has grown rapidly from 751 million in 1950 to 4.2 billion in 2018. For the past ten years, more than half of the world's population (55%) has lived in cities. In fact, the latest United Nations forecast predicts that 68% of the world's population will be living in cities by 2050.[1] At that point, the world's total urban population will be almost equal to the earth's entire population today. Thus, the number of people living in big cities will have grown from one billion to more than five billion. This trend will also lead to the rise of more megacities (cities that have over 10 million inhabitants). By 2030, the world is projected to have 43 megacities, most of them in developing regions. Therefore, demands on infrastructures will grow accordingly.

Smart cities have become a global phenomenon and municipal leaders around the world are interested in the potential opportunities of adapting their cities for the future. Although there is no consensus of what exactly a smart city is (Camero & Alba, 2019), a smart city can be defined as a geographical area in which high technologies such as information and communication technologies (ICT), logistic, energy production, and so on, cooperate to create benefits for citizens in terms of well being, inclusion and participation, environmental quality, and intelligent development (Dameri, 2013).

Research works propose different number of fields to frame the city. An influent one, adopted by the European Union (EU), allocates them within six axes: Smart Economy, Smart Environment, Smart Governance, Smart Living, Smart Mobility, and Smart People (Giffinger et al., 2007).

With every connected device in smart cities there is software to enable it to communicate with other devices and central databases gathering data to ease our lives. This defines a smart city software system as an environment that supports software developers in designing, implementing, deploying, and managing applications for smart cities (Santana, Chaves, Gerosa, Kon, & Milojicic, 2017). However, the software for smart cities is different from the software on desktops, tablets, or even smartphones. Thus, smart cities require the development and use of standards and communication protocols to allow heterogeneous devices to communicate and leverage common software applications. Many existing smart city deployments are based on closed systems. They usually are private software systems sold by a particular vendor, who does not provide many details about its software design and architecture. Contrarily, open systems encourage interoperability across platforms, portability, and open software standards while discouraging lock-in around specific products or companies.[2] Both closed and open software systems can provide public APIs. A public API, also known as an open API, is an application programming interface that allows the owner of a network-accessible service to give universal access to consumers of that service, such as developers. Thus, public APIs endow software developers with programmatic access, from different

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[1] https://esa.un.org/unpd/wup/Publications/Files/WUP2018-PressRelease.pdf

[2] Note that open systems could be open-source software or not.

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programming languages (i.e., Java, Python, C + +, Go, etc.), to a software application.

This paper provides insight into smart city vendors, their software systems for smart cities and its application in practice. Most companies try to follow existing standards to gain market for their software tools, so it is important that we first revise international organizations and how they contribute to smart city standardization. Then, we conduct a study about smart city vendors and their software systems to know i) which software systems they offer (closed or open), ii) which smart city axes these software systems are related to, iii) whether smart city software systems provide public APIs to developers, iv) which communication technologies smart city software systems are compatible with, and v) cities where these software solutions have been deployed. We thus make the following contributions in this paper: (i) we summarize existing smart city standardization, (ii) we review up to 48 smart city vendors and their software systems, and (iii) we give recommendations to make informed decisions when choosing smart city systems.

This study is amenable for city managers, urban planners, and policy-makers to make better decisions when choosing software systems to develop and manage smart cities. Let's take, as an example, a use case in which a city manager wants a software system for smart lighting and garbage collection management. The city manager could choose a software system which is exclusively allocated within the Smart Environmental axis. Let's now suppose that, one year later, the city manager wants to integrate Smart Mobility in the city. Nevertheless, (s) he realizes that the software system acquired one year ago is not suitable for Smart Mobility. Thus, the city manager must acquire a different software solution, probably investing again time and money. On the one hand, this use case reveals that wrong decisions made by managers in their policies could happen because of a poor understanding of the technical issues involved. On the other hand, this shows the need of the proposed study in order to help city managers to make informed decisions.

The rest of the paper is organized as follows. Section 2 summarizes related work. Section 3 introduces the concept of smart city and presents the six different axes within which it is usually allocated. Section 4 introduces international organizations and their contribution to smart city standardization. Section 5 presents our study about smart city vendors and provides insight into their software systems. Finally, Section 6 concludes the paper and outlines some future work.

2. Related work

There are scientific articles with technical details on how to build a smart city, the technologies used, and many other related to the smart city topic.

In the work of da Silva et al. (2013), authors discussed various smart city architectures and presented a set of requirements for the implementation of smart cities. Zanella, Bui, Castellani, Vangelista, and Zorzi (2014) provided a comprehensive survey of the enabling technologies, protocols, and architectures for an urban IoT. They also discussed the technical solutions and best-practice guidelines adopted in the Padova smart city project, in Italy. Yin et al. (2015) conducted an exhaustive literature survey of smart cities introducing the main issues facing the smart city concept. Then, authors presented the fundamentals of smart cities by analyzing its definition and application domains and provided a data-centric view of smart city architectures and key enabling technologies. Finally, authors conducted a survey of recent smart city research. These previous studies focused on smart city architectures instead of software systems. Smart city architectures provide guidelines on how to use the technologies to conceive and implement smart city projects (Harrison et al., 2010).

Santana et al. (2017) studied software systems for smart cities analyzing 23 projects concerning the most used enabling technologies, as well as functional and non-functional requirements. In addition, authors presented a reference architecture derived from the requirements pointed out by the surveyed studies. This is the closest related to work to ours. However, we did not focus on functional (such as external data access, data processing, etc.) and non-functional (such as security, privacy, etc.) requirements of smart city software systems but on platform type (closed–open), availability of public APIs, and supported communication protocols. In addition to the previous, while Santana et al. (2017) selected smart city software systems from the literature, we have found software systems from smart city vendors involved in smart city projects carried out around the world. Thus, to the best of our knowledge, this is the first technical survey of software systems from smart city vendors.

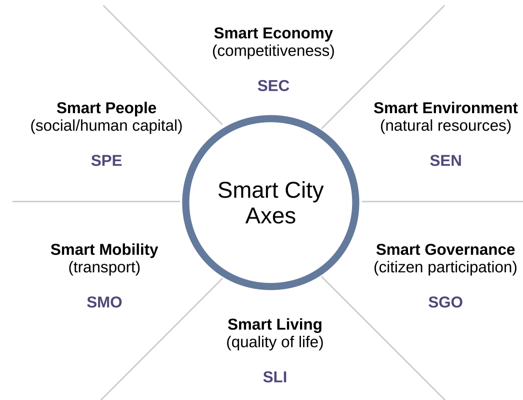

Fig. 1. Smart city axes according to Giffinger et al. (2007).

3. Smart city axes

Since we will give structure and classify the existing software in many ways, we do need a guide (a standard one, if possible) to later label the domains of work for vendor platforms. Smart cities are usually allocated withing six different axes, which are shown in Fig. 1. This figure also shows the short-name used from now on when referring smart city axes. We consider an axis as a set of functionalities related to a domain of work. Next, we identify and briefly describe each of them.

3.1. *Smart Economy (competitiveness)*

This axis includes factors related to economic competitiveness such us footfall and crows density analytics, outdoor digital marketing, or tourism management. Mobile users' information on mobility patterns and behaviors provide useful and relevant insights to enrich the city government's decision making regarding tourism services and urban planning.

3.2. *Smart Environment (natural resources)*

This axis is described by natural conditions (climate, green space, etc.), pollution, resource management, and also by efforts towards environmental protection such as energy efficiency for buildings, smart lighting, or smart garbage collection.

3.3. *Smart Governance (citizen participation)*

This axis comprises aspects of political participation, services for citizens, and the functioning of the administration.

3.4. *Smart Living (quality of life)*

This axis comprises various aspects of quality of life as culture (smart heritage), health (mobile tele-care, online citation), safety (flood detection), and housing (video security).

3.5. Smart Mobility (transport and communication tech)

This axis includes local and international accessibility as well as the availability of information and modern/sustainable transport systems.

3.6. Smart People (social and human capital)

This axis is described by the quality of social interactions regarding integration and public life. This includes technology solutions for the development and implementation of teaching methods, providing a platform that evaluates children performances in each skill, individually and in groups.

4. Smart city standardization

Two barriers exist to effective and powerful smart city solutions. First, many current smart city information and communications technology (ICT) deployments are based on custom systems that are not interoperable, portable across cities, extensible, or cost-effective. Second, a number of architectural design efforts are currently underway but have not yet converged, what creates uncertainty among stakeholders. In order to reduce these two barriers international standards organizations, professional organizations, and international communities are contributing to smart city standardization.

When it comes to smart cities, there are a number of key areas where the world's foremost international standards organizations work together. From the wake of the World Smart City Forum,[3] held on 2016 in Singapore, representative of different standard organizations meet yearly to accelerate smart city standardization. This forum is organized by the International Telecommunication Union (ITU), the United Nations specialized agency for information and communication technologies, in partnership with the International Electrotechnical Commission (IEC), and the International Organization for Standardization (ISO). These organizations collaborate at the global level with European standardization organizations, such as the European Telecommunication Standards Institute (ETSI). Professional organizations and international communities, such as the Institute of Electrical and Electronic Engineers (IEEE) and the World Wide Web Consortium (W3C), also work on the standardization of smart cities. Fig. 2 shows international standards organizations working on the smart city. Next, we introduce these organizations and their contribution to smart city standardization.

4.1. International Telecommunication Union (ITU)

ITU is the United Nations specialized agency for information and communication technologies.[4] ITU members have established a study group named "ITU-T Study Group 20: IoT and its applications, including smart cities and communities". The study group is addressing the standardization requirements of IoT technologies, with an initial focus on IoT applications in smart cities. ITU-T has also established a focus group on smart sustainable cities (FG-SSC). The focus group assesses the standardization requirements of cities aiming to boost their social, economic, and environmental sustainability through the integration of information and communication technologies in their infrastructures and operations. This focus group acts as an open platform for smart-city stakeholders to exchange knowledge in the interests of identifying the standardized frameworks needed to support the integration of services in smart cities.

[3] https://www.worldsmartcity.org/

[4] https://www.itu.int/

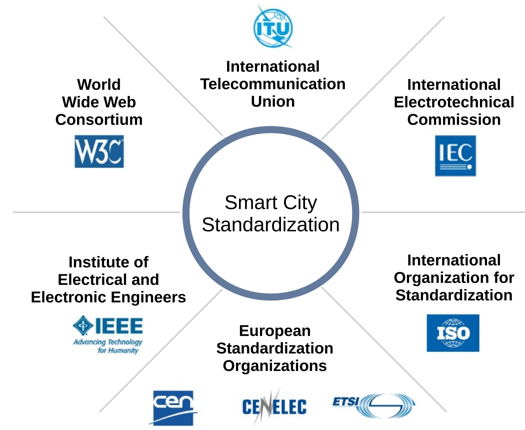

Fig. 2. International standard's organizations working on the smart city.

4.2. International Electrotechnical Commission (IEC)

The IEC is the world's leading organization for the preparation and publication of international standards for all electrical, electronic, and related technologies.[5] The IEC is actively involved in developing new international standards to support smart projects, including smart city development. Many standard organization initiatives have been launched. Among those is the IEC Systems Evaluation Group on smart cities (SEG1). The purpose of SEG1 is to summarize and evaluate the status of standardization in the field of smart cities and to work out plans for new standardization work to be taken in IEC. SEG1 is currently preparing a reference architecture and standardization roadmap in cooperation with different organizations, fora, and consortia.

4.3. International Organization for Standardization (ISO)

ISO standards provide cities with an overall framework for defining what "being smart" means for them and how they can get there. For example, ISO 37101 sets out the basic requirements for sustainable development in communities, helps cities determine their sustainable development objectives, and put in place a strategy to achieve them. This management system standard covers everything a city must address to become smarter, such as responsible resource use, environmental management, citizens' health and well-being, governance, mobility, and more. ISO also has standards directly related to energy efficiency and renewables, road traffic safety management system, or security and privacy management systems.

4.4. European Standardization Organizations

In Europe, standards are developed and agreed by the three officially recognized European Standardization Organizations: the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC), and the European Telecommunications Standards Institute (ETSI). The CEN-CENELEC-ETSI Sector Forum on Smart and Sustainable Cities and Communities (SF-SSCC), created in January 2017, is a long-term joint group of the standardization organizations that acts as an advisory and coordinating body for European standardization activities related to smart cities.[6]

4.5. Institute of Electrical and Electronic Engineers (IEEE)

The Institute of Electrical and Electronic Engineers (IEEE) is the world's largest technical professional organization for the advancement

[5] http://www.iec.ch/index.htm

[6] https://www.cencenelec.eu/standards/sectorsold/smartliving/smartcities/.

of technology.[7] This organization is working on the standard 2413 for a reference architecture for smart city, which is intended to be used by architects, designers, operators, and citizens. The architecture defined in this standard will promote cross-domain interaction, aid system interoperability, and functional compatibility.

4.6. Web of Things at W3C

The World Wide Web Consortium (W3C) is an international community where member organizations and full-time staff work together to develop Web standards.[8] W3C seeks to extend the Web from a Web of pages to a Web of things. The starting point is the idea of things that stand for physical or virtual entities, whether connected or not. These are exposed to applications as software objects with APIs corresponding to the thing's properties, actions, and events. The Web of Things proposes to counter the existing fragmentation through metadata that enables easy integration across IoT platforms, and which simplifies application development through a common interaction model that is independent of the underlying protocols.

In addition to the introduced communites and organizations, there are also programs and collaborative platforms for smart cities such as the European Innovation Partnership on Smart Cities (EIP-SCC) and the Global City Teams Challenge (GCTC). On the one hand, the EIP-SCC is a major market-changing undertaking supported by the European Commission bringing together cities, industries, small and medium-sized enterprises, investors, researchers, and other smart city actors. The on-line platform encourages the exchange of ideas and initiatives to develop concrete solutions models for joint challenges related to smart cities.[9] On the other hand, the GCTC program is a collaborative platform for the development of smart cities and communities.[10] It is led by National Institute of Standards and Technology (NIST), which is a bureau of the U.S. Department of Commerce, in partnership with other U.S. federal agencies, including the U.S. Department of Homeland Security Science and Technology Directorate (DHS S&T), National Science Foundation, International Trade Administration, and National Telecommunications and Information Administration. The GCTC enables local governments, nonprofit organizations, academic institutions, technologists, and corporations from all over the world to form project teams, or action clusters, to work on applications within the city and community environment.

5. Smart city software systems

Technology vendors have seen in smart cities an interesting business during the last years. In order to obtain an extensive list of smart city vendors we use the existing collaborative platforms EIP-SCC (Europe) and GCTC (U.S.), both introduced in Section 4. The EIP-SCC on-line platform allows us find completed or ongoing smart city projects around the world and know more about their needs, the barriers they have overcome, and the partners involved on that projects. The GCTC program is a collaborative platform for the development of smart cities and communities. There are more than 300 organizations participating in GCTC smart city technology projects, called *action clusters*. These participants include representatives from U.S. cities and states, major cities in other countries, government agencies, private companies, non-profits, universities, hospitals, and a variety of municipal-focused organizations. We use both platforms extracting smart city vendors. Once this information had been extracted, we will investigate these vendors individually to provide insights into their software systems for smart cities.

5.1. Methodology

The platform EIP-SCC contains a list of smart city projects.[11] Each project has its own website, where a list of partners is available. Partners usually are cities, universities, and private companies. We manually processed this list of partners to select private companies. For each company, we visited its website and checked which solutions, products, and–or services they offer. The platform GCTC contains information about previous and current action clusters of smart cities.[12] Action clusters are assemblies of partners committing to work on specific issues related to smart cities, by sharing the knowledge and expertise with their peers. Each action cluster has a descriptive name, a year of creation, a team lead, a list of municipal governments, and a list of members. These members usually are universities, city management organizations, and private companies. We manually processed the list of members of each action cluster to select private companies. For each company, we visited its website and searched for solutions related to smart cities. For both platforms, we considered a private company as a smart city vendor when it provided a software system for smart city solutions. These companies compose the sample of our study and, from now on, we refer them as *smart city software vendors*.

For the selected smart city software vendors we investigate the smart city axes their solutions are related to, and whether provided solutions are based on closed or open software systems. Then, we look for case studies of these solutions. This allows us to collect names of cities where these software solutions have been deployed. We have also searched on the Internet for resources used by vendors to promote their software solutions (i.e., conferences, courses, tutorials, whitepapers, workshops, and webinars). These resources provided us with the technical aspects needed to dive deep into the fundamentals of their software systems. Thus, we have identified which software solutions provide public APIs. Then, we studied the communication protocols these software systems are compatible with.

Communication protocols usually differ in their interaction models, i.e., publish-subscribe and request-reply. The publish-subscribe model provides a distributed, asynchronous, loosely coupled communication between data generators and destinations. The request-reply communication model allows a client to request information from a server that receives the request message, processes it, and returns a response. Despite the fact that there are different communication protocols used in the Internet of Things (IoT), such as AMQP, CoAP, DDS, MQTT, REST HTTP, XMPP, etc., the two most mature choices, which are also favored by developers, are MQTT and REST HTTP (Dizdarevic, Carpio, Jukan, & Masip-Bruin, 2019). MQTT is an IoT connectivity protocol designed as an extremely lightweight publish/subscribe messaging transport.[13] REST HTTP is based on the request-reply model and emphasizes scalability of component interactions, generality of interfaces, independent deployment of components, and intermediary components to reduce interaction latency, enforce security, and encapsulate legacy systems (Fielding, 2000).

5.2. Results

We found 48 smart city vendors providing software systems for smart city solutions after our search in EIP-SCC and GCTC. Table 1 shows the distribution of smart city software vendors by country. For each country, the second and third columns show the number and percentage of vendors providing software systems for smart city solutions, respectively. Most smart city software vendors are located in the U.S. (28, 58.3%), Spain (6, 12.5%), and Germany (3, 6.2%). The actual number of vendors could be different from our findings, but the rest of

[7] https://www.ieee.org/
[8] https://www.w3.org/WoT/
[9] https://eu-smartcities.eu/
[10] https://pages.nist.gov/GCTC/
[11] https://eu-smartcities.eu/projects/
[12] https://pages.nist.gov/GCTC/action-clusters-2018-2019/
[13] https://mqtt.org/

Table 1
Smart city software vendors by country.

Country	# of vendors	Percentage
U.S.	28	57.1
Spain	6	12.2
Germany	3	6.1
Australia	1	2.0
Belgium	1	2.0
Finland	1	2.0
France	1	2.0
Italy	1	2.0
Japan	1	2.0
Netherlands	1	2.0
South Korea	1	2.0
Sweden	1	2.0
Switzerland	1	2.0
Turkey	1	2.0

countries like South Korea or Turkey seem not to have many platforms to promote smart cities in the market.

Table 2 summarizes the smart city software vendors of our study. First column contains the name of the company. Second column, the country where the company is located. Third column specifies whether the company was found in the EIP-SCC and–or GCTC platforms. Fourth column shows the smart city axes software systems are related to. Finally, fifth column contains the name of the software system provided by companies for smart city solutions. As it is shown, 10 (20.8%) smart city software vendors were found in both EIP-SCC and GCTC platforms. From here we highlight the importance given for these companies (such as Bosch, CISCO, Hitachi, IBM, Microsoft, Siemens, and Telefonica) to develop concrete solutions for challenges related to smart cities and promote these solutions in collaborative platforms as EIP-SCC and GCTC. We also found that 28 (58.3%) companies provide software system solutions for all the smart city axes: SEC, SEN, SGO, SLI, SMO, and SPE. This is remarkable, because so many present efforts dismiss a wide impact in all needed axes. However, there are also companies focused on a particular subset of the smart city axes. For example, eight (16.7%) companies provide software systems exclusively related to the SEN (Smart Environment) axis. Concerning the last column (Software system), we found that two companies (AT&T and Intel) provide the same software (CityIQ IoT Platform) for smart cities. CityIQ IoT Platform[14] is powered by Predix,[15] an industrial IoT platform developed by General Electric (GE). Therefore, although we found 48 smart city software vendors we analyze 47 different smart city software systems.

Next we will focus on the smart city software systems provided by the vendors under study. Table 3 shows more details about these 47 software systems. First column contains the name of the software system. Second column specifies whether software systems are open or not. Third column shows whether software systems provide public APIs. Fourth column specifies communication protocols compatible with software systems. Finally, fifth column shows the existing resources on the Internet for training and promotion porpoises. As it is shown, 31 (66%) smart city software systems are open and 16 (34%) are not. We found 14 (29.8%) software systems providing public APIs and all of them are open software systems. We also found 17 (36.2%) software systems defined as open that do not provide public APIs. Interestingly, we did not find any closed smart city software system providing public APIs. Concerning communication protocols, we found that MQTT and REST HTTP are the most popular protocols, being REST HTTP even more popular than MQTT. The latter is supported by 23 (47.9%) software systems while the former is supported by 36 (75%) software systems. All software systems supporting MQTT (23, 47.92%) also support REST HTTP. Despite the popularity of these protocols, for 11 (23.4%) software systems we did not find any reference to communication protocols: much is still to be done in the transparency of information on software platforms for smart cities.

Table 4 shows a great number of cities around the world where software solutions of the smart city vendors under study have been deployed. First columns contains the name of the company. Second column, the country where the company is located. Finally, third column contains a list of cities where the company has deployed its software system. We found that 44 (91.7%) of the smart city vendors have deployed their software solutions in one or more cities. For the four (8.3%) remaining smart city vendors (LinkLab, PTC, Scada, and Sensewere) we found no deployment of their software solutions in cities. This does not mean that these four smart city vendors have not deployed their software solutions in cities, but only that they do not provide city case studies on their websites.

5.3. Discussion

Most smart city vendors usually provide software system solutions for the six smart city axes. Although we found some solutions developed by companies located in Australia, China, Japan, and South Korea, companies providing smart city software systems are mostly located in the U.S. and Europe.

Concerning smart city software systems, we found that most of them are open. However, open systems do not mean open-source software. Open-source software is software with source code that anyone can inspect, modify, and enhance. Although most smart city vendors define their software systems as open, they are not open source. For instance, the CivicConnect Platform is built on top of industry standard open source components that reduce the costs of licensing and maintenance. This also enables rapid application development, flexible data integration, and technology adaptation.[16] Nevertheless, the software system itself is not open source, that is, it is usually sold to a price defined by the company. Another example is Living PlanIT, which defines its software system PlanIT UOS as enabled entirely by open cross-platform standards. However, the company mentions in the frequently asked questions of its whitepaper that there is no intention to make the UOS open source. Living PlanIT discusses that making the software open source would mean that no entity would be in control of the strategic goals of their product evolution.

All smart city software systems providing public APIs are open, although no all open software systems provide public APIs. This is expected because the main priority of any public API architecture is to ease access and consumption of the provided APIs by as many different clients as possible. Thus, using open source technology and community-driven standards make the most sense.[17] Public APIs preserve everyone's ability to build on each other's work, improving software iteratively and collaboratively. One could think that if a user builds her/his own business on top of an API, (s)he needs to ensure the service does not go away. However, in the context of our study users are smart city managers, urban planners, policy-makers and developers who are not interested in building a software system for smart cities but using an existing one. Thus, we see the usage of public APIs as a way to extend a software system and not as a strong dependency on the company which provides it. We consider this as an added value of a software system because it allows to extend its functionality without requiring its source code.

As mentioned earlier in this section, we found two smart city software vendors providing the same platform: CityIQ IoT. This open software system is based on Predix Platform that is a distribution of Cloud Foundry. Cloud Foundry is an open-source cloud application platform, providing a choice of clouds, developer frameworks, and

[14] https://developer.currentbyge.com/cityiq
[15] https://www.predix.io/
[16] http://civicconnect.com/platform/
[17] https://searchmicroservices.techtarget.com/definition/open-API

Table 2
Vendors providing at least a software system for smart city solutions.

Company	Country	Platform		Axes						Name of the software system
		EIP-SCC	GCTC	SEC	SEN	SGO	SLI	SMO	SPE	
Amazon	U.S.	–	✓	✓	✓	✓	✓	✓	✓	AWS
AT&T	U.S.	–	✓	✓	✓	✓	✓	✓	✓	CityIQ IoT Platform
Ayyeka	U.S.	–	✓	–	✓	–	–	–	–	WAVELET
Bigbelly	U.S.	–	✓	–	✓	✓	–	–	–	Bigbelly Smart Waste Platform
Bosch	Germany	✓	✓	✓	✓	✓	✓	✓	✓	Bosch IoT Suite
CISCO	U.S.	✓	✓	✓	✓	✓	✓	✓	✓	Cisco Kinetic
Civic Connect	U.S.	✓	✓	✓	–	–	✓	✓	✓	CivicConnect Platform
CIVIQ	U.S.	–	✓	✓	–	✓	✓	–	–	CIVIQ
Cleverciti	Germany	✓	–	–	–	–	–	✓	–	Cleverciti
Eastbanc Technologies	U.S.	–	✓	✓	✓	✓	✓	✓	✓	TERRAiQ and iSee
Ecube Labs	U.S.	–	✓	–	✓	–	–	–	–	CleanCityNetworks
Enevo	U.S.	✓	✓	–	✓	–	–	–	–	Enevo
Ericsson	Sweden	✓	–	✓	✓	✓	✓	✓	✓	Ericsson IoT Accelerator Platform
Etra	Spain	✓	–	✓	✓	✓	✓	✓	✓	CITRIC
Everimpact	France	–	✓	–	✓	–	–	–	–	Big Data Software Platform for Smart Cities
GE	U.S.	–	✓	–	✓	–	–	–	–	Predix Platform
Google	U.S.	–	✓	✓	✓	✓	✓	✓	✓	Google Cloud IoT Platform
Hitachi	U.S.	✓	✓	✓	✓	✓	✓	✓	✓	Lumada IoT Platform
IBM	U.S.	✓	✓	–	✓	–	–	✓	–	IBM Watson IoT Platform
Indra	Spain	✓		✓	✓	✓	✓	✓	✓	Minsait IoT Sofia2
Ingenu	U.S.	–	✓	–	✓	–	✓	✓	–	Intellect
Intel	U.S.	–	✓	✓	✓	✓	✓	✓	✓	CityIQ IoT Platform
Itron	U.S.	–	✓	✓	✓	✓	✓	✓	✓	SLV City Management Platform
Kiunsys	Italy	✓	–	–	–	–	–	✓	–	INES Cloud
Leverege	U.S.	–	✓	✓	✓	✓	✓	✓	✓	Leverege IoT Platform
Leycolan	Spain	✓	–	–	✓	–	–	–	–	Smartluix
LinkLab	U.S.	–	✓	–	–	–	✓	✓	–	Conductor IoT Platform
Living PlanIT	U.S.	–	✓	✓	✓	✓	✓	✓	✓	PlanIT UOS
Microsoft	U.S.	✓	✓	✓	✓	✓	✓	✓	✓	Azure IoT
NEC	Japan	✓	✓	✓	✓	✓	✓	✓	✓	Cloud City Operations Center
Nokia	Finland	–	✓	✓	✓	✓	✓	✓	✓	IMPACT IoT Platform
Ntels	South Korea	–	✓	–	✓	–	✓	✓	–	NTELS IoT Platform
ÖLÇSAN	Turkey	✓	–	–	✓	–	✓	✓	–	City on Cloud
Paradox Engineering	Switzerland	–	✓	✓	✓	✓	✓	✓	✓	PE Smart Urban
Philips	Netherlands	✓	–	–	✓	–	–	–	–	CityTouch
PTC	U.S.	–	✓	✓	✓	✓	✓	✓	✓	ThingWorx Platform
Rombit	Belgium	✓	–	✓	✓	✓	✓	✓	✓	Romcore
SAS	U.S.	–	✓	✓	✓	✓	✓	✓	✓	IoT Solutions for Smart Cities
Scada	U.S.	–	✓	✓	✓	✓	✓	✓	✓	CitiWorx Sensing Platform
Schneider Electric	U.S.	✓	–	✓	✓	✓	✓	✓	✓	EcoStruxure
Senseware	U.S.	–	✓	–	✓	–	✓	–	–	Senseware
Siemens	Germany	✓	✓	✓	✓	✓	✓	✓	✓	MindSphere
Telefonica	Spain	✓	✓	✓	✓	✓	✓	✓	✓	Telefonica IoT platform
Trimble Water	U.S.	–	✓	–	✓	–	–	–	–	Trimble Unity
UI!	Australia	✓		✓	✓	✓	✓	✓	✓	UrbanPulse
Urban Clouds	Spain	–	✓	–	✓	–	–	✓	–	SMAQ
Wellness Telecom	Spain	–	✓	✓	✓	✓	✓	✓	✓	Smart City Brain
Xaqt	U.S.	–	✓	✓	✓	✓	✓	✓	✓	Metrograph

application services to make it faster and easier to build, test, deploy, and scale applications.[18] Different IoT infrastructure providers such as Amazon, Google, IBM, or Microsoft are supported by Cloud Foundry. MindSphere, the software system provided by Siemens for smart cities, is also powered by Cloud Foundry for developing cross-platform applications and lowering development efforts.[19] We also found that software systems provided by Etra, Everimpact, NEC, Telefonica, and Urban Clouds are powered by FIWARE. The FIWARE platform provides a rather simple yet powerful set of APIs that ease the development of smart applications in multiple vertical sectors. The specifications of these APIs are public and royalty-free. Besides, an open-source reference implementation of each of the FIWARE components is publicly available.[20] Despite the fact that some smart city software systems provided by vendors are based on open-source platforms, such as Cloud Foundry or FIWARE, developed solutions are not offered as free software and their source code is neither available.

Concerning communication protocols, the combination of HTTP protocol with REST is the most popular one between smart city software systems. REST HTTP is probably so popular due to its simplicity and the fact that it builds upon existing systems and features of the Internet's HTTP (Hypertext Transfer Protocol) in order to achieve its objectives. With REST HTTP, Web services are resources users request access to. For instance, to create, read, update, and delete resources the HTTP POST, GET, PUT and DELETE methods are used, respectively. This mapping between operations with HTTP methods allows easily build REST models for smart cities.

Policy-makers, city managers, urban planners, and developers need guidelines to take informed decisions when choosing software systems for smart cities. Fig. 3 shows a decision tree which eases the task of choosing smart city software systems concerning different criterion.

[18] https://www.cloudfoundry.org
[19] https://siemens.mindsphere.io/how-it-works
[20] https://www.fiware.org

Table 3
Smart city software systems solutions provided by smart city software vendors.

Name of the software system	Open system	Public API	Communication protocols		Training and promotion resources
			MQTT	REST HTTP	
AWS	✓	✓	✓		✓ (tutorials, whitepapers)
Azure IoT	✓	✓	✓	✓	✓ (conferences, courses, tutorials)
Big Data Software Platform for Smart Cities	✓	✗	–	–	–
Bigbelly Smart Waste Platform	✗	✗	–	–	–
Bosch IoT Suite	✓	✓	✓	✓	✓ (tutorials, whitepapers)
Cisco Kinetic	✓	✓	✓	✓	✓ (webinars, workshops)
CitiWorx Sensing Platform	✗	✗	✓	✓	✓ (courses, tutorials)
CITRIC	✓	✗	–	–	–
City on Cloud	✓	✗	–	✓	–
CityIQ IoT Platform	✓	✓	✓	✓	–
CityTouch	✓	✗	–	✓	–
CivicConnect Platform	✓	✗	–	✓	✓ (webinars, whitepapers)
CIVIQ	✗	✗	–	–	✓ (whitepapers)
CleanCityNetworks	✗	✗	–	✓	–
Cleverciti	✗	✗	–	✓	–
Cloud City Operations Center	✓	✗	✓	✓	✓ (conferences)
Conductor IoT Platform	✓	✓	✓	✓	✓ (tutorials, whitepapers)
EcoStruxure	✓	✓	✓	✓	✓ (tutorials)
Enevo	✗	✗	–	–	–
Ericsson IoT Accelerator Platform	✓	✗	✓	✓	–
Google Cloud IoT Platform	✓	✓	✓	✓	✓ (conferences, tutorials)
IBM Watson IoT Platform	✓	✓	✓	✓	✓ (tutorials, workshops)
IMPACT IoT Platform	✓	✗	✓	✓	✓ (courses)
INES Cloud	✗	✗	–	✓	–
Intellect	✗	✗	–	✓	–
IoT Solutions for Smart Cities	✗	✗	✓	✓	✓ (courses, tutorials)
Leverege IoT Platform	✓	✗	✓	✓	✓ (whitepapers)
Lumada IoT Platform	✓	✓	✓	✓	–
Metrograph	✓	✗	–	–	–
MindSphere	✓	✓	✓	✓	✓ (tutorials)
Minsait IoT Sofia2	✓	✓	✓	✓	✓ (tutorials, workshops)
NTELS IoT Platform	✓	✗	✓	✓	–
PE Smart Urban	✗	✗	✓	✓	–
PlanIT UOS	✓	✗	–	✓	✓ (whitepapers)
Predix Platform	✓	✓	✓	✓	✓ (courses)
Romcore	✗	✗	–	–	–
Senseware	✗	✗	–	–	✓ (conferences)
SLV City Management Platform	✓	✗	–	✓	✓ (tutorials, whitepapers)
SMAQ	✓	✗	–	✓	–
Smart City Brain	✓	✗	–	✓	–
Smartluix	✗	✗	–	✓	–
Telefonica IoT Platform	✓	✓	✓	✓	–
TERRAiQ and iSee	✗	✗	–	–	✓ (conferences, workshops)
ThingWorx Platform	✓	✗	✓	✓	✓ (tutorials, webinars)
Trimble Unity	✗	✗	–	–	✓ (whitepapers)
UrbanPulse	✓	✗	–	–	–
WAVELET	✗	✗	–	✓	–

5.4. Threats to validity

Threats to validity concern factors that could have influenced our results and the generalization of our findings.

We selected smart city vendors from global platforms which encourage the development of concrete solutions models for joint challenges related to smart cities. Particularly, we extracted that information from the existing collaborative platforms EIP-SCC and GCTC. The former is supported by the European Commission while the latter is led by the National Institute of Standards and Technology. Although we found many smart city vendors from these platforms, we were limited to corporations that formed project teams or action clusters in the past to work on applications within the city and community environment. Therefore, our study was reduced to a subset of the existing smart city vendors in the world. However, this sample is representative enough because it involves companies from different countries and a mix of well-known vendors (such as Amazon, Google, IBM, or Microsoft) and less popular ones. An alternative is to search for smart city software systems done by any existing company in the world, a goal obviously unfeasible. It is clear that we need to restrict our study to most relevant companies and software systems, so our choice of these two initiatives in Europe and America is justified.

Concerning the information about software systems for smart cities, we extracted it from the official website of smart city vendors and from training and promotion resources provided by them. Thus, our results are as accurate as the information provided by smart city vendors.

6. Conclusion

There is broad agreement about the huge potential for services for smart cities, however, this potential is being held back by fragmentation with a lack of interoperability across platforms, a bewildering variety of standards, and a rapid evolution of the low-level IoT technologies themselves.[21] The lack of standards makes controlling different connected devices and smooth deployment of various systems for different applications across a region or city very difficult. Many existing smart city deployments are based on closed systems, that is

[21] https://www.w3.org/2016/08/wot-white-paper/

Table 4
Case studies of smart city software vendors.

Company	Country	City (country)
Amazon	U.S.	Chicago (U.S.), Newport (England), Peterborough (England)
AT&T	U.S.	Boston (U.S.), Honolulu (U.S.), San Diego (U.S.)
Ayyeka	U.S.	Cincinnati (U.S.), Rutland (U.S.)
Bigbelly	U.S.	Albany (U.S.), Newton (U.S.), Philadelphia (U.S.)
Bosch	Germany	Monaco (Monaco), San Francisco (U.S.), Stuttgart (Germany)
CISCO	U.S.	Copenhagen (Denmark), Jaipur (India), Kansas (U.S.)
Civic Connect	U.S.	Fort Lauderdale (U.S.), Palm Springs (U.S.), San Francisco (U.S.)
CIVIQ	U.S.	Boston (U.S.), Dallas (U.S.), Philadelphia (U.S.)
Cleverciti	Germany	Dubai (United Arab Emirates), Vancouver (Canada), Moscow (Russia)
Eastbanc Technologies	U.S.	Columbus (U.S.), Maryland (U.S.), Washington DC (U.S.)
Ecube Labs	U.S.	Baltimore (U.S.), Melbourne (Australia), Seoul (South Korea)
Enevo	U.S.	Amsterdam (Netherlands), Edinburgh (Scotland), Islington (England)
Ericsson	Sweden	Dallas (U.S.), Goiania (Brazil), Stockholm (Sweden)
etra	Spain	Barcelona (Spain), Gdańsk (Poland), Madrid (Spain)
Everimpact	France	London (England)
GE	U.S.	Boston (U.S.), Honolulu (U.S.), San Diego (U.S.)
Google	U.S.	Chattanooga (U.S.), Manchester (England), Memphis (U.S.)
Hitachi	U.S.	Andhra Pradesh (India), Austin (U.S.), Moreno Valley (U.S.)
IBM	U.S.	Greenwich (England), Lisbon (Portugal), Rotterdam (Netherlands)
Indra	Spain	A Coruña (Spain), Galicia (Spain), Zürich (Switzerland)
Ingenu	U.S.	Albuquerque (U.S.), Aruba (Netherlands), Atlanta (U.S.)
Intel	U.S.	Boston (U.S.), Honolulu (U.S.), San Diego (U.S.)
Itron	U.S.	Copenhagen (Denmark), Glasgow (Scotland), Miami (U.S.)
Kiunsys	Italy	Florence (Italy), Monza (Italy), Naples (Italy)
Leverege	U.S.	Baltimore (U.S.), Washington DC (U.S.)
Leycolan	Spain	Gipuzkoa (Spain), Logroño (Spain), Navarra (Spain)
LinkLab	U.S.	–
Living PlanIT	U.S.	Almere (Netherlands), Copenhagen (Denmark), London (England)
Microsoft	U.S.	Denver (U.S.), Houston (U.S.), Taipéi (Taiwan)
NEC	Japan	Greenwich (England), Lisbon (Portugal), Santander (Spain)
Nokia	Finland	Amsterdam (Netherlands), Bristol (England), Pisa (Italy)
Ntels	Korea	Busan (South Korea), Goyang (South Korea), Pangyo Alphadom (South Korea)
ÖLÇSAN	Turkey	Bosphorus (Turkey), Istanbul (Turkey), Konya (Turkey)
Paradox Engineering	Switzerland	Bellinzona (Switzerland), Gijón (Spain), Siracusa (Italy)
Philips	Netherlands	Buenos Aires (Argentina), Los Angeles (U.S.), Siegburg (Germany)
PTC	U.S.	–
Rombit	Belgium	Antwerp (Belgium)
SAS	U.S.	Boston (U.S.), Wiesbaden (Germany), Wuxi (China)
Scada	U.S.	–
Schneider Electric	U.S.	Bremen (Germany), Carson City (U.S.), Geneva (Switzerland)
Senseware	U.S.	–
Siemens	Germany	Freiburg (Germany), Nuremberg (Germany), Pittburgh (U.S.)
Telefonica	Spain	San Nicolás de los Arroyos (Argentina), Santander (Spain), Seville (Spain)
Trimble Water	U.S.	Fort Wayne (U.S.), Sacramento (U.S.), Sutton (England)
UI!	Australia	Bad Hersfeld (Germany), Darmstadt (Germany), Queensland (Australia)
Urban Clouds	Spain	Alcobendas (Spain), Birmingham (England), Malaga (Spain)
Wellness Telecom	Spain	Kalmar (Sweden), La Rinconada (Spain), Seville (Spain)
Xaqt	U.S.	Kansas (U.S.)

systems whose internal design and architecture are unknown. Contrarily, open systems are built on top of industry standard components and its design and architecture are better known.

Choosing a smart city software system is not trivial, and this decision could end in poorly portable, non-interoperable, and–or non-extensible solutions within projects in a city. Despite the fact that city managers, urban planners, and policy-makers are overwhelmed with different software systems for smart cities, they unknown their differences from a technological point of view. Therefore, they are not able to make informed decisions when choosing a software system for urban development and management.

In this paper we introduced existing international organizations and their contribution to smart city standardization. Then, we reviewed 48 smart city vendors and provided insight into their software systems and their applications. We found that most companies provide software system solutions for all the smart city axes: SEC, SEN, SGO, SLI, SMO, and SPE. We also observed that most smart city vendors define their software systems as open although they usually are not open source (they just use open standards inside). We also found that software systems rarely provide public APIs to ease access to software features. This is a noticeable factor in closed software systems because the lack of public APIs prevents programmatic access to developers. With regards to communication protocols, we found that MQTT and REST HTTP are very popular, although REST HTTP is still more popular than MQTT for the time being.

Based on our findings, we encourage smart city managers, urban planners, and policy-makers to use software systems (open or not) which provide public APIs. Public APIs not only empower smart city vendors to use software features at will but also individual developers. Thus, software systems that do not provide public APIs are vendor-dependant solutions and lock customers around specific products and–or companies. In order to assist smart city managers, urban planners, and policy-makers when choosing smart city software systems, we ended up with a decision tree to ease the decision making.

As future work, we will do an exhaustive search to complement this study including more companies and taking into account low level details of their software systems for smart cities.

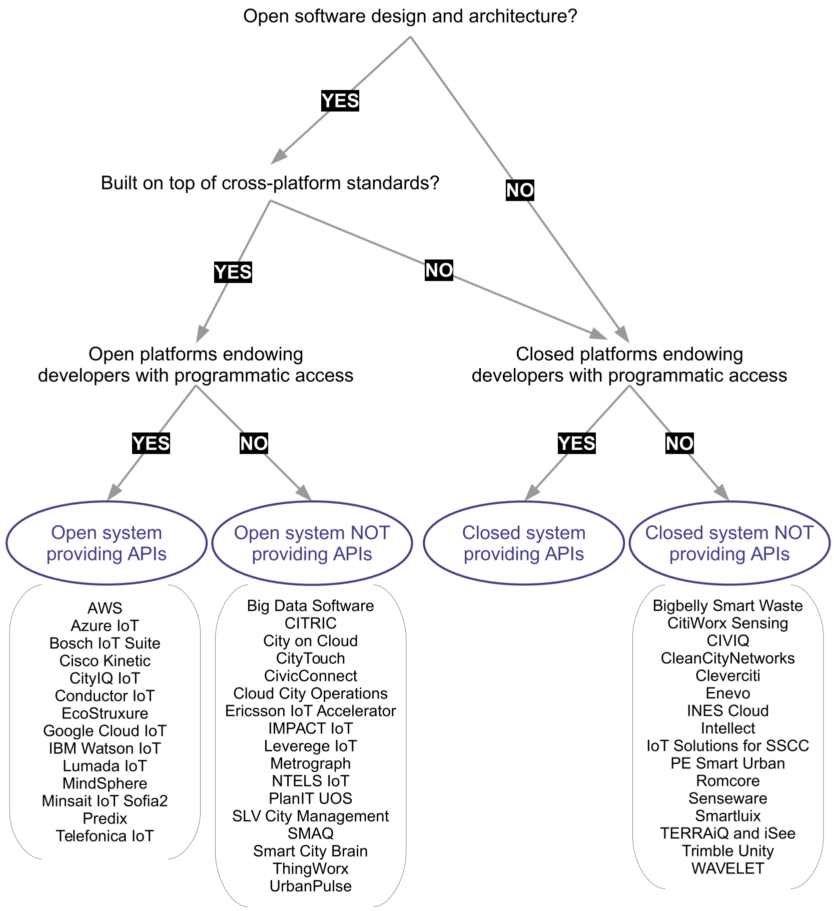

Fig. 3. Decision tree to choose smart city software systems.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Camero, A, & Alba, E. (2019). Smart City and information technology: A review. *Cities, 93*, 84–94. http://www.sciencedirect.com/science/article/pii/S0264275118304025. https://doi.org/10.1016/j.cities.2019.04.014.

Dameri, R. (2013). Searching for smart city definition: a comprehensive proposal. *International Journal of Computers & Technology, 11*, 2544–2551. https://cirworld.com/index.php/ijct/article/view/1142ijct. 10.24297/ijct.v11i5.1142.

Dizdarevic, J., Carpio, F., Jukan, A., & Masip-Bruin, X. (2019). A survey of communication protocols for internet of things and related challenges of fog and cloud computing integration. *ACM Comput. Surv. 51*, 116:1–116:29. http://doi.acm.org/10.1145/3292674. https://doi.org/10.1145/3292674.

Fielding, R. T. (2000). *REST: Architectural styles and the design of network-based software architectures.* Doctoral dissertation Irvine: University of California. URL http://www.ics.uci.edu/fielding/pubs/dissertation/top.htm.

Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler-Milanović, N., & Meijers, E. (2007). *Smart cities: Ranking of European medium-sized cities. Technical report.* Vienna, Austria: Centre of Regional Science (SRF), Vienna University of Technology. URL http://www.smart-cities.eu/download/smart_cities_final_report.pdf.

Harrison, C., Eckman, B., Hamilton, R., Hartswick, P., Kalagnanam, J., Paraszczak, J., & Williams, P. (2010). Foundations for smarter cities. *IBM Journal of Research and Development, 54*, 1–16. https://doi.org/10.1147/JRD.2010.2048257.

Santana, E. F. Z., Chaves, A. P., Gerosa, M. A., Kon, F., & Milojicic, D. S. (2017). Software Platforms for Smart Cities: Concepts, Requirements, Challenges, and a Unified Reference Architecture. *ACM Comput. Surv. 50*, 78:1–78:37. http://doi.acm.org/10.1145/3124391. https://doi.org/10.1145/3124391.

da Silva, W. M., Alvaro, A., Tomas, G. H. R. P., Afonso, R. A., Dias, K. L., & Garcia, V. C. (2013). Smart cities software architectures: A survey. *Proceedings of the 28th Annual ACM Symposium on Applied Computing* (pp. 1722–1727). New York, NY, USA: ACM. https://doi.org/10.1145/2480362.2480688.

Yin, C., Xiong, Z., Chen, H., Wang, J., Cooper, D., & David, B. (2015). A literature survey on smart cities. *SCIENCE CHINA Information Sciences, 58*, 1–18. https://doi.org/10.1007/s11432-015-5397-4.

Zanella, A., Bui, N., Castellani, A., Vangelista, L., & Zorzi, M. (2014). Internet of things for smart cities. *IEEE Internet of Things Journal, 1*, 22–32. https://doi.org/10.1109/JIOT.2014.2306328.