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Smart cities as hubs: Connect, collect and control city flows

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ABSTRACT

Regardless the Smart City (SC) broad scope, which ranges from a service-oriented ecosystem with the use of almost all the emerging technologies to a resilient urban environment, practice shows that the SC is mostly capitalized for utility upgrades, urban renovation, and real-time city monitoring. Moreover, recent city implementations register attempts to utilize technology for controlling the entire city flows. The aim of this communication paper is to discuss the SC hubness and more specifically the fact that the SC can become a "hub" that collects, processes, and transmits data; brings together people to co-design and evolve; and controls service, material and people flows in all city types. As a result, this paper defines the role, the uses and the architecture of this "SC-as-a-Hub" operation labeled "SCHub", which can standardize and control all the city flows.

1. Introduction

The evolution of the *Smart city* (SC) has followed specific roadmaps during the last 30-years (Anthopoulos, 2017): it started with Internet connectivity requirements in the early 1990s; took advantage of the Information and Communications Technologies (ICT) for urban growth in the early 2000s; and turned to innovation for urban sustainability in the early 2010s. Today, it is more likely to consider the SC as an "advancement" that transforms cities to sustainable, friendly, and resilient.

Cities around the world followed this SC evolution, which can be classified in specific clusters: cities focusing on people and innovation to co-define their future; cities offering typical smart services to their communities (i.e., parking; lighting etc.); cities renovating or developing brand-new districts (i.e., Songdo, Sidewalk Toronto etc.) or even entire cities from-scratch that provide large-scale smart services (e.g., Masdar, Toyota Woven city etc.). Especially these last representatives introduce methods where smart technologies control all the city flows (e.g., consumable supplies) beyond the existing, typical ones (e.g., information, energy, water, waste etc.).

The SC evolution has recently been based on Internet of Things (IoT) for data collection and new value production in the city (Kitchin, 2014), and on platforms that enable data visualization and city management. The city goes beyond a "connected space", where information, services, materials, and people flow: the SC can monitor, manage, and enhance all these flows. Thus, the SC plays the role of a "hub" for cities, where anyone could connect and gain access to all or any of the above flows. This paper observed this phenomenon and aims to answer the following research questions (*RQs*):

RQ1: How the SC is being transformed to a hub?

RQ2: What is the role and the architecture of the SCHub?

Both these questions are important to be answered since the "ness" must be confirmed (RQ1), while its definition (RQ2) will help the cities and communities to host "an umbrella system" (the so-called "SCHub"), which will be scalable, open and cross-SC-platform. Additionally, when this hub will be clarified in technological terms, it can serve any city and standardize its flows.

The rest of this paper is structured as follows: Section 2 uses facts and theoretical evidence to prove the SC hubness. Section 3 defines the architecture of the SCHub and presents use-cases that it can serve. Finally, Section 4 contains some conclusions and future thoughts.

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Table 1
Results from scientific resources.

Source	"Smart city" AND "platform" AND "IoT"		*"Smart city platform"*	
	Jan. 2020	Jan. 2021	Jan. 2020	Jan. 2021
SCOPUS®	690	955	94	118
Google SCHOLAR®	26,400	37,600	1170	1540
Science Direct®	1736	2736	77	107

Table 2
Indicative SC platforms.

City platform product	Source
Cisco Kinetic (retired in Jan. 2021)	Cisco (2020)
Siemens Mindsphere	Siemens (2018)
Microsoft Citynext; Microsoft Azure Digital Twin	Microsoft (2020)
IBM Intelligent Operations Center	IBM (2020), Bhowmick et al. (2012)
Intel City Manager	Intel (2016)
SAP Future Cities Software	SAP (2020)
HUAWEI Intelligent Operation Center Solution	Huawei (2018)
Hitachi Visualization Suite	Hitachi (2020)
CA	CA Technologies (2019)
Invipo Smart City Platform	Invipo (2020)
other IoT platforms: KAA, Temboo, SeeControl IoT, SensorCloud, Etherios, Xively, Ayla's IoT cloud fabric, thethings.io, Exosite, Arrayent, OpenRemote, Arkessa, Axeda, Oracle IoT cloud, Nimbits, ThingWorx, InfoBright, Jasper Control Center, Echelon, AerCloud, Plotly, ThingWorx, GroveStreams, Zetta etc.	Nakhuva and Champaneria (2015); Mineraud, Mazhelis, Su, and Tarkoma (2016); Ray (2016)

2. Background

The SC has been defined as *a city model that uses state-of-the art ICT to a) improve living, efficiency and competitiveness with respect to future generations* (ITU, 2014, p.2) or *to b) facilitate the planning, construction, management and smart services* (ISO/IEC JTC1 Information Technology, 2015, p.2); while the "smartness" of a city describes *its ability to bring together all its resources, to effectively and seamlessly achieve the goals and fulfil the purposes it has set itself (*i.e.*, to function and make it a livable space for the residents and visitors)*.

Although the SC does not have a goal in itself but they are "instruments" for cities, according to these definitions the SC adopts cutting-edge ICT, interconnects the city resources, delivers effective and efficient services, while it enables city's digital transformation, and in this respect it connects (resources), collects (data), and controls (digital transformation), which could be labeled "city 3Cs". Thus, numerous cities have planned SC strategies (Anthopoulos, 2019) with *IoT* embeddedness for data collection, *city platforms* -also labeled *city dashboards* (Kitchin, 2014; Ray, 2016) or *IoT platforms* (Fahmideh & Zowghi, 2020)- that visualize them; and *applications* that transact with the dashboards. The *city platform* is defined as *a computer system […] that, under control of the city, uses information and ICT to access data sources and process them to offer urban operation and services to the city* (ITU, 2018, p.2). In these terms, the *SC platform* is a *city platform that offers direct integration of city platforms and systems, or through open interfaces between city platforms and third parties, to offer the urban operation and services supporting the functioning of city services, as well as efficiency, performance, security, and scalability* (ITU, 2018).

The above findings show that "IoT" and "platform" are major SC components, and their combination returned an emerging number of articles (Table 1), while "smart city platform" also emerges (Table 2).

A generic SC platform architecture (Fig. 1) shows that it is accompanied by Application Programming Interfaces (APIs) that enable connections with IoT and other software applications in the city. Additionally, the SC platform offers secure identities (IDs) for these connections and software utilities (SDKs) to the developers. Standardization of SC platforms is on the fly (i.e., ISO, 2020; ITU, 2018; ITU, 2021).

Fig. 1. A generic SC platform architecture.

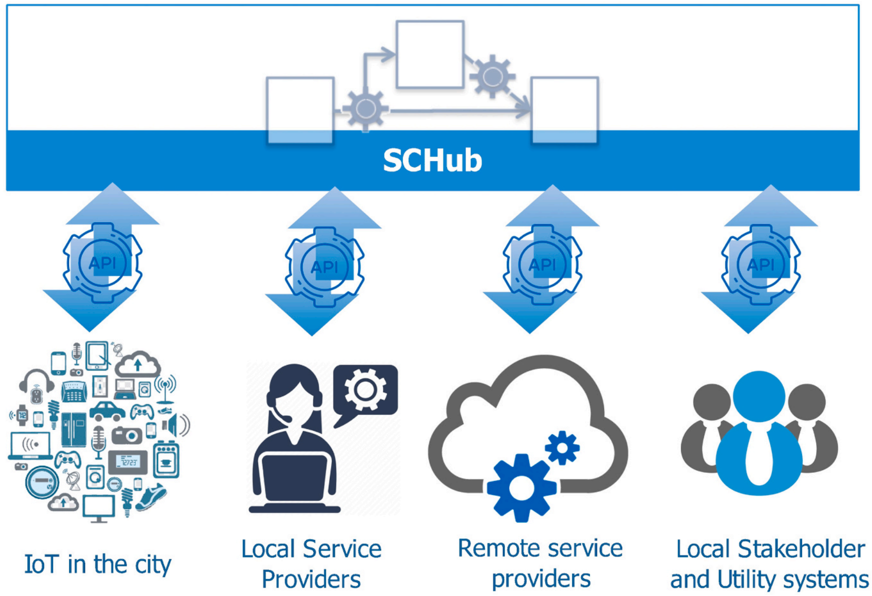

Fig. 2. The concept of the SC Hub.

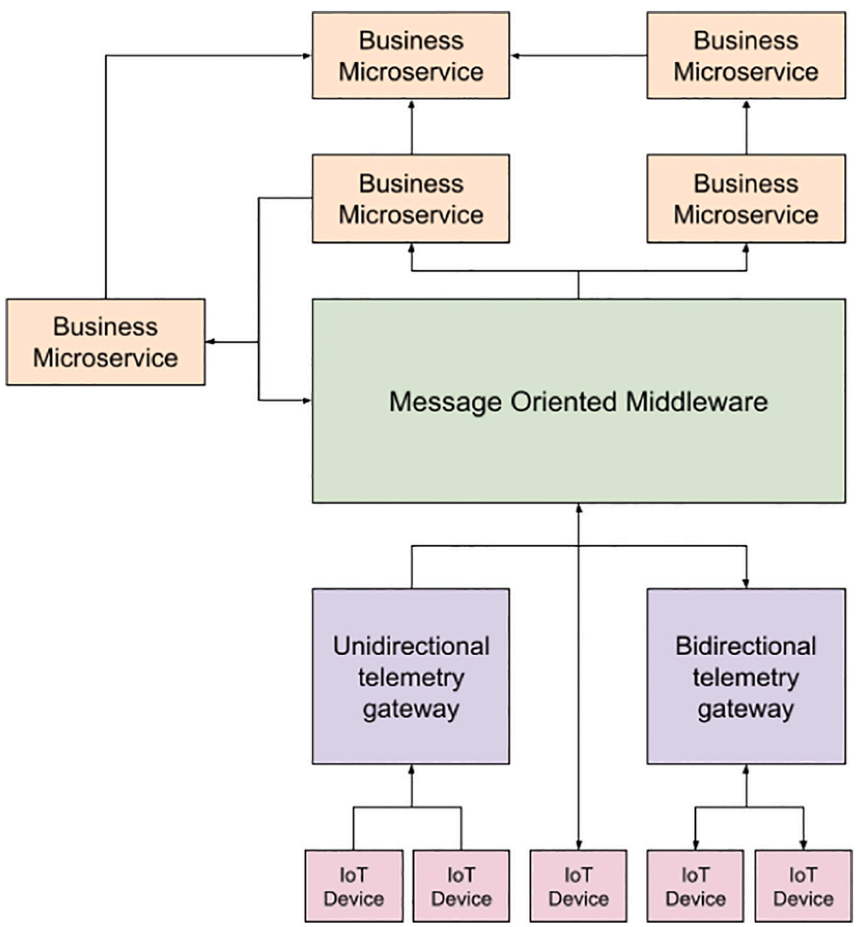

Fig. 3. SCHub reference architecture.

3. The concept of "smart city as a hub"

Due to the SC definition that introduces the 3Cs and the increasing role of IoT and platforms that enable SC data flows between different systems and of various formats (Bischof et al., 2014; Pourzolfaghar & Helfert, 2017) (Fig. 1), introduce the idea of the "SC-as-a-hub" (or *SCHub*), which is inspired from the typical network hub. A typical network hub enables alternative ICT devices to connect and exchange data (IEEE, 2019), regardless their purpose. In similar terms, the SCHub will enable alternative systems to connect to the SC and offer or gain

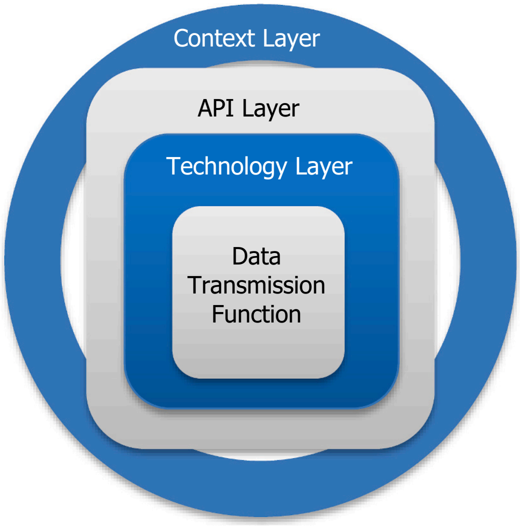

Fig. 4. SCHub Architecture.

access to information and services (Fig. 2). In contrast to the SC platform, the SCHub does not oblige data to be stored in a common repository or cloud, while the developers will follow specific but open SDKs (e.g., the CitySDK (2012)) to develop compatible information and service flows. More specifically, the SCHub will offer APIs (like network slots) for partners' connectivity (i.e., IoT owners, service providers, utilities etc.). As such, all partners should comply with the SCHub specifications and exchange data under predefined formats.

3.1. Connecting data sources: the SCHub reference and conceptual architectures

The SCHub architecture is inspired by an IoT architecture, whose main components have been extensively discussed in (Fahmideh & Zowghi, 2020; Fremantle, Kopecký, & Aziz, 2015; Ray, 2016), Their application in the SCHub concept however needs special attention to address the specific needs of the SC deployment environment and scale. More specifically, the SCHub reference architecture must tackle the following parameters:

Generality: the SC reference architecture must be general enough to be able to accommodate both current and future needs for integration of devices and services.

Applicability: the SC reference architecture must be applicable at city scale. This allows to optimize the reference architecture by not including components and services that are needed in different deployment levels and at the same time makes it easier to make the design decision necessary to optimize this type of deployment.

Privacy: the SC reference architecture must keep a balance between the privacy of the collected data, which may include personal identifiable information while at the same time allow the use of data by services and integrators that will create additional value and insights which will be for the benefit of the SC.

On the other hand, the key design principles of a SC reference architecture concern the following:

API-first design: The design of all components at all levels of the architecture must be focused on providing a standardized way for machine-to-machine communication. This can be achieved by making sure that each component provides clear and standardized APIs that will allow the integration among them.

Baked-in security: Each component of the architecture is designed with security baked-in as opposed to bolt-on. The scale and complexity

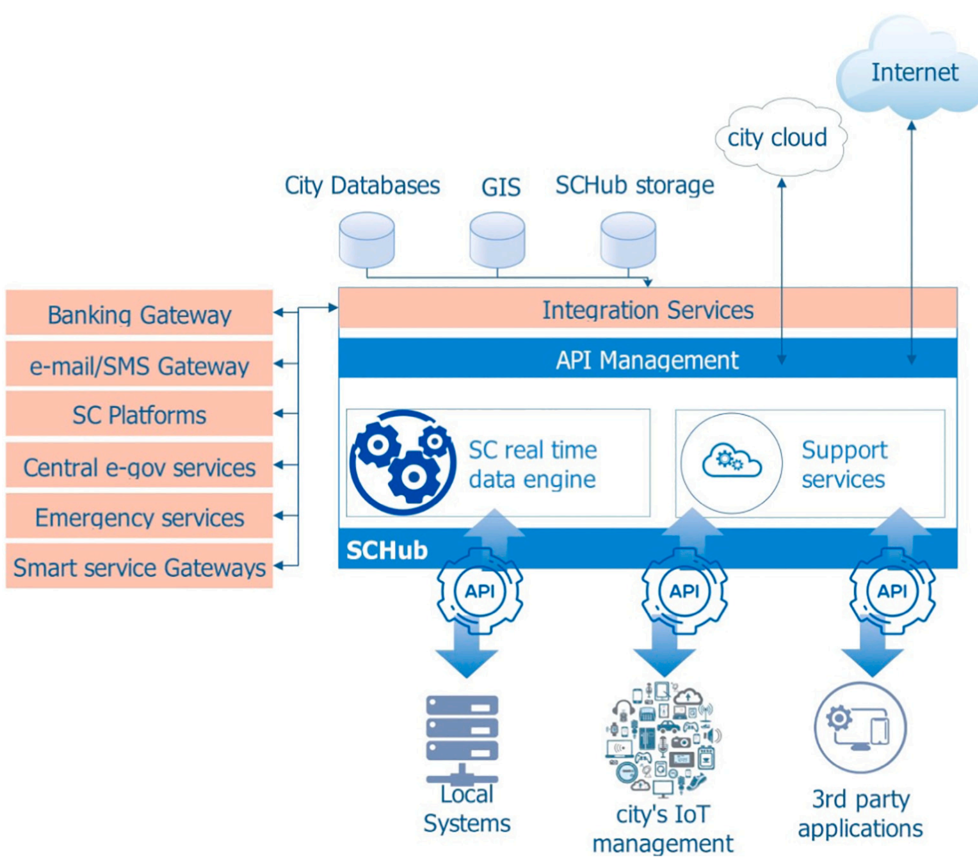

Fig. 5. The technology layer of the SCHub.

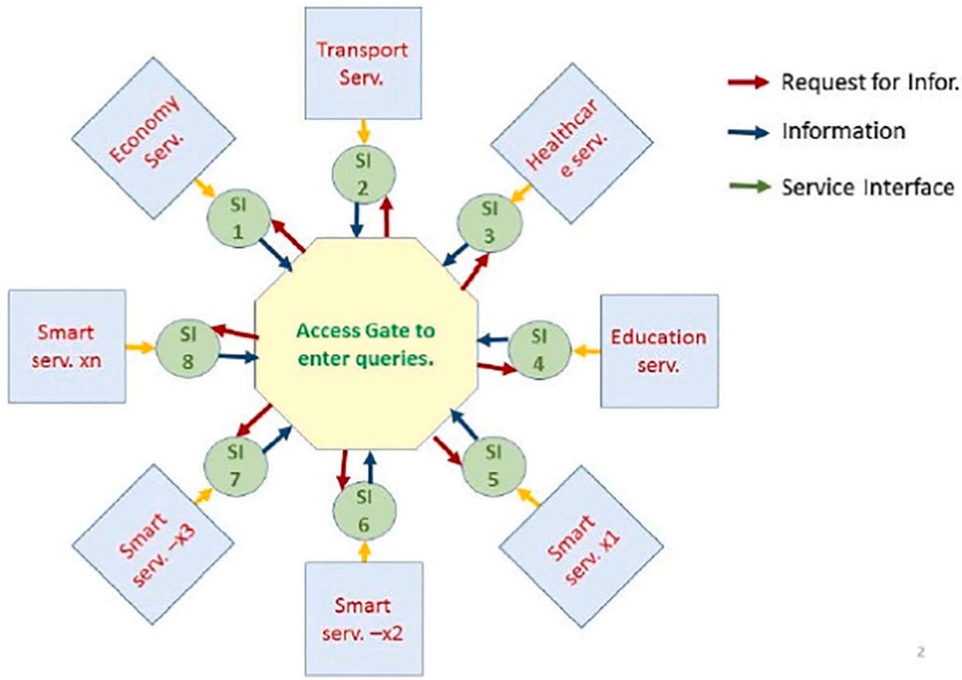

Fig. 6. The role of the data transmission function (Pourzolfaghar et al. (2017)).

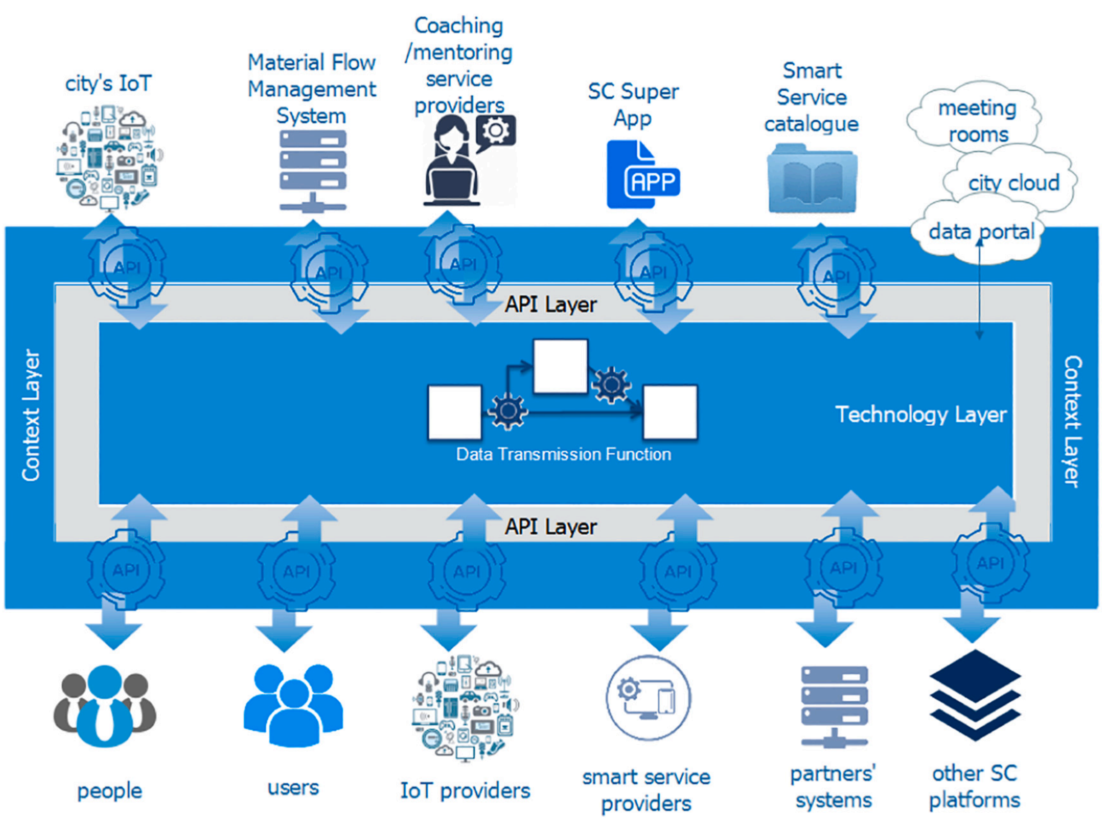

Fig. 7. SCHub multi-partner connections enabling several use cases.

of a SCHub has by definition an extensive attack surface. In addition, the city itself can become a very attractive target for Cyberattacks as the attack surface grows and the integration of more devices and services increases with the adoption of an increasing number of smart services by the citizens. This evolution makes it imperative that each component operates in a secure way because the entire system is as secure as its weakest link. A zero-trust design approach to each device and service is mandatory in addition to the security measures that will be enforced on the entire system.

Privacy by default: The added value of SCHub will eventually come from the innovative and creative ways the generated data will be used to create new services for the citizen. As the size of the data increases their

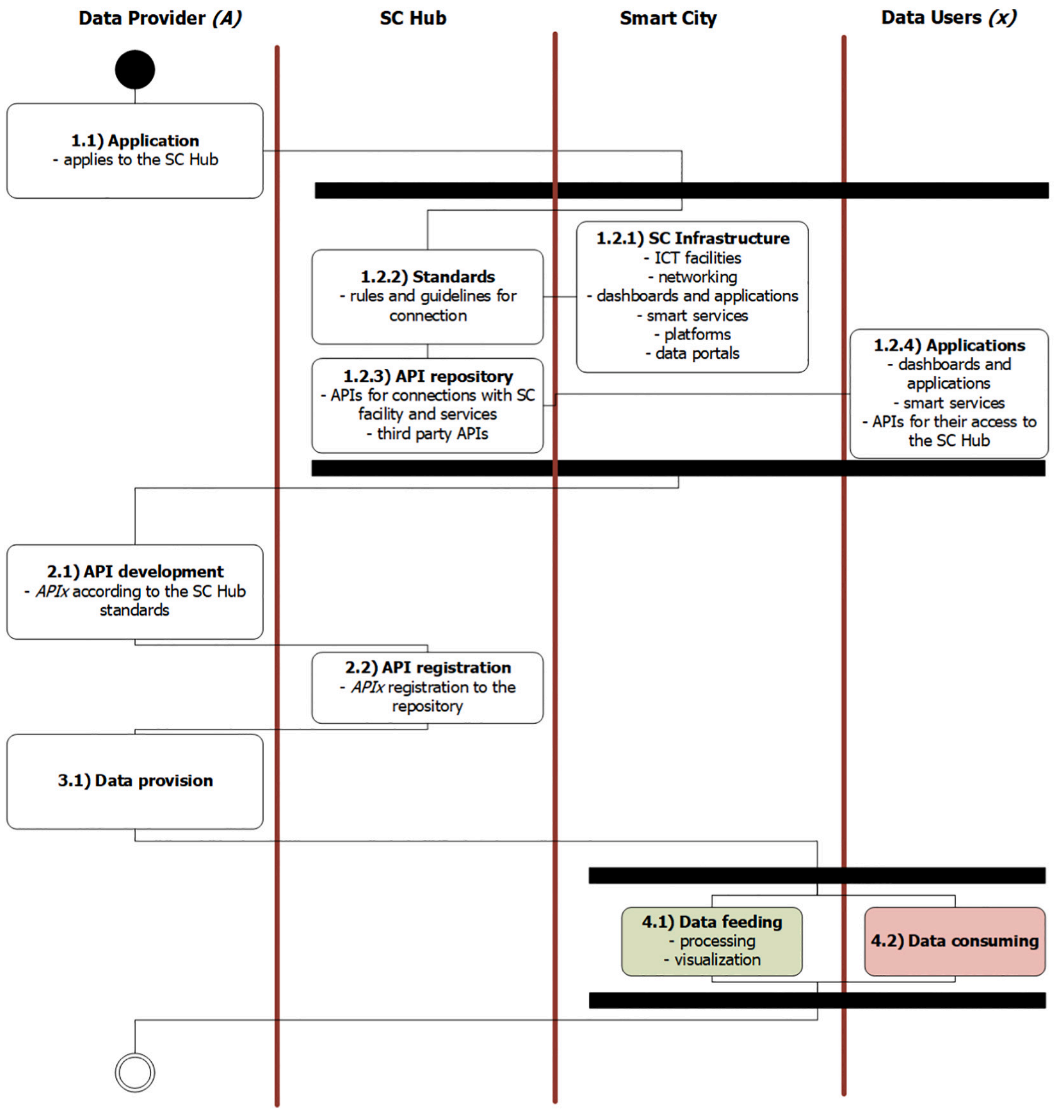

Fig. 8. UML use-case diagram for data provisioning via the SCHub.

use for malicious purposes will make it increasingly attractive to cyber-criminal groups. For this reason, all the data generated by the devices in the SCHub must be designed in such a way as to make sure any data sent to the SCHub are: tamper resistant; encrypted; and anonymized.

Any metadata that can be generated by correlation to provide value added services must not reveal the identity or other private information of individual citizens.

The core components of the SCHub reference architecture are the following (Fig. 3):

IoT Devices: The IoT devices collect information from the city. They act as the sensing part of the SCHub that generates the data which will be used by the higher layers of the architecture. The IoT devices can be simple sensors that measure some physical property of intelligent edge devices that can make calculations based on the data they collect at the IoT device level before sending them to the SCHub.

Telemetry gateway: The telemetry gateways are software of hardware endpoints where the IoT devices connect to transmit their information in a secure way. The telemetry gateway can be either one-directional to service IoT devices that support only sending of information or bi-directional to service IoT devices that support remote management and over-the-air firmware upgrade.

Message Oriented Middleware: The Message Oriented Middleware (MoM) connects the telemetry gateways and the Business Microservices. The MoM allows the scaling of the architecture to accommodate a few IoT devices and gateways for a small pilot project to a full-blown deployment with multiple gateways and hundreds of thousands of IoT devices and business services that consume that data. Depending on the scale of the SCHub this component will be sized accordingly to provide the required throughput at the proper cost for the SC.

Business microservices: The Business microservices consume the data produced either directly from the sensors or from other business microservices to add value to the SCHub. The key design principle is that these services must be designed in an API-first way both for the consumption as well as the production of their data.

The above reference architecture leads to the SCHub conceptual architecture, which -like a typical network hub (ISO, 1994)- consists of layers that enable data flows (Fig. 4): the *Context* layer, the *API* layer, the *Technology* layer and the *Data Transmission Function*.

The *context layer* includes the SC standards for transactions and security (Wenge, Zhang, Dave, Chao, & Hao, 2014):

1) *Basic standards*: for data acquisition, transmission, storage, vitalization, and processing.
2) *Application standards*: for software development, middleware and platforms.

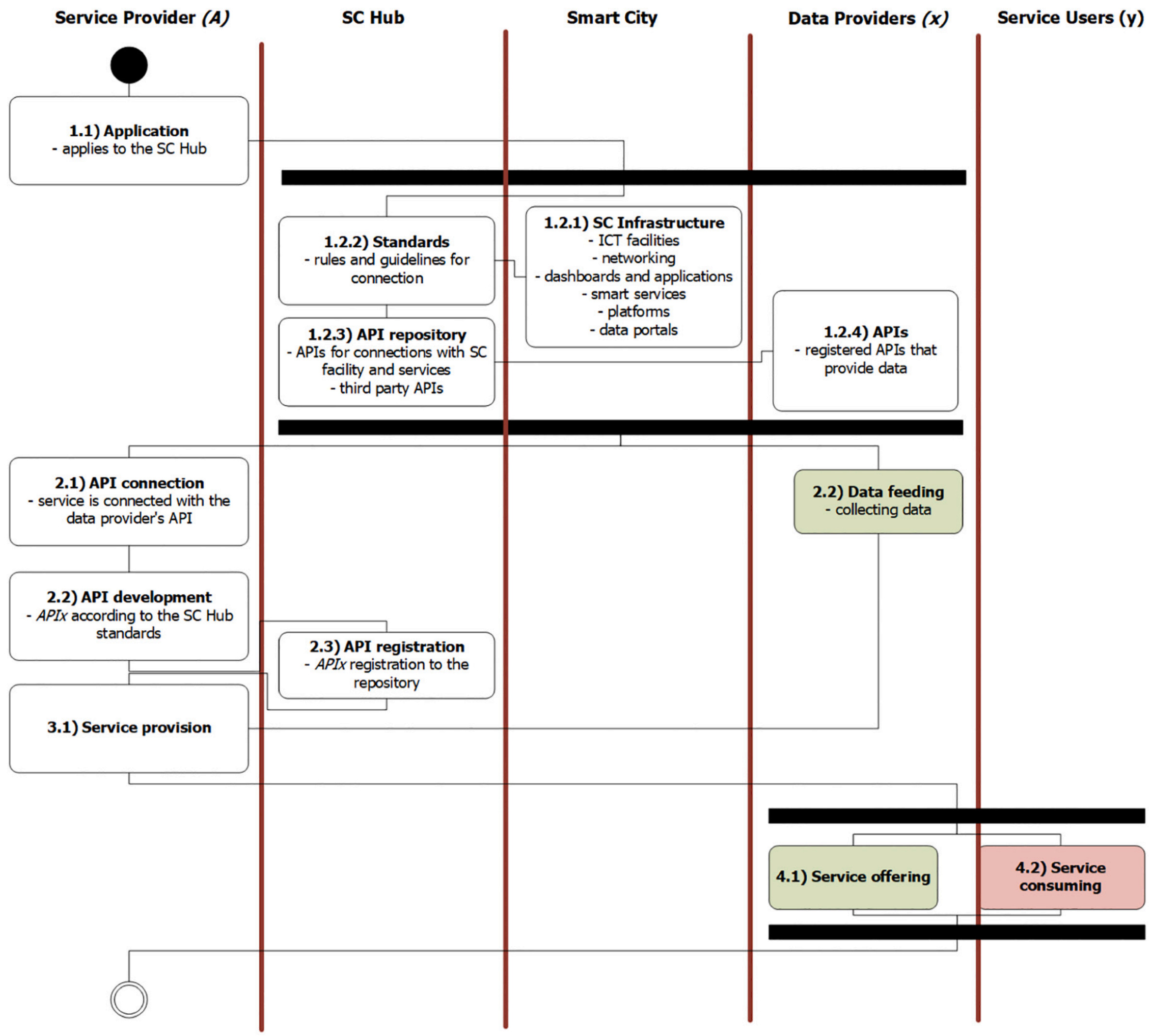

Fig. 9. UML use-case diagram for service provisioning via the SCHub.

3) *Security standards*: against threats, information leaking and improper use.

The *API layer* includes the APIs that enable data transmission, and their management functionalities (*design, publish, document, and monitor* (Fremantle et al., 2015)). The APIs serve both the receiver and sender roles for data transactions, and their design must ensure *openness* to applications and devices, *ease of use* to developers and citizens (Fremantle et al., 2015), as well as *completeness, consistency,* and *uniformity* (Caelli, Graham, & O'Connor, 1993). Completeness expresses how efficiently they serve the applications, while consistency and uniformity ensure data transparency.

The APIs are accompanied by documentation and follow common standards for data formatting, security, and privacy (Gupta, Tanwar, Tyagi, & Kumar, 2020), while an access gate is needed for interoperability (Fremantle et al., 2015; Heffner 2014).

The APIs must be *monitored* for low energy performance (Fremantle et al., 2015), while an API management strategy (Niehaves, Röding, & Oschinsky, 2019) is needed, to define:

1. The alignment to an existing SC strategy (Chen, Mocker, Preston, & Teubner, 2010; Niehaves et al., 2019).
2. The API co-design process with the SC stakeholders (Deloitte, 2018).
3. The API openness to technological changes, data strategies and security requirements (Gupta et al., 2020).

The *Technology layer* includes the SCHub infrastructure (Fig. 5), which contains the Microservices, the Gateways and the connections (APIs) of the reference architecture (Fig. 3) and they are determined as follows:

1. The *SC real time data engine*, which collects and processes data via the API layer.
2. The *support services* for configuration, user and ID management, and SC public portal operation.
3. The *API management* service.
4. *Integration services* that connect the SCHub with third-party gateways (e.g., banking, e-mail, SC platforms etc.).
5. *Storage* for its configuration and software for the support services, and potentially for data flows.
6. *Standards* with requirements to connect to the SCHub.

Finally, the *Data Transmission Function (DFS)* represents the message transmission Middleware of the reference architecture (Fig. 3), it receives requests, forwards them to the appropriate resources, and collects responses (Pourzolfaghar & Helfert, 2017)) with the use of an access gate for systems' interoperability (Pourzolfaghar et al., 2017) (Fig. 6).

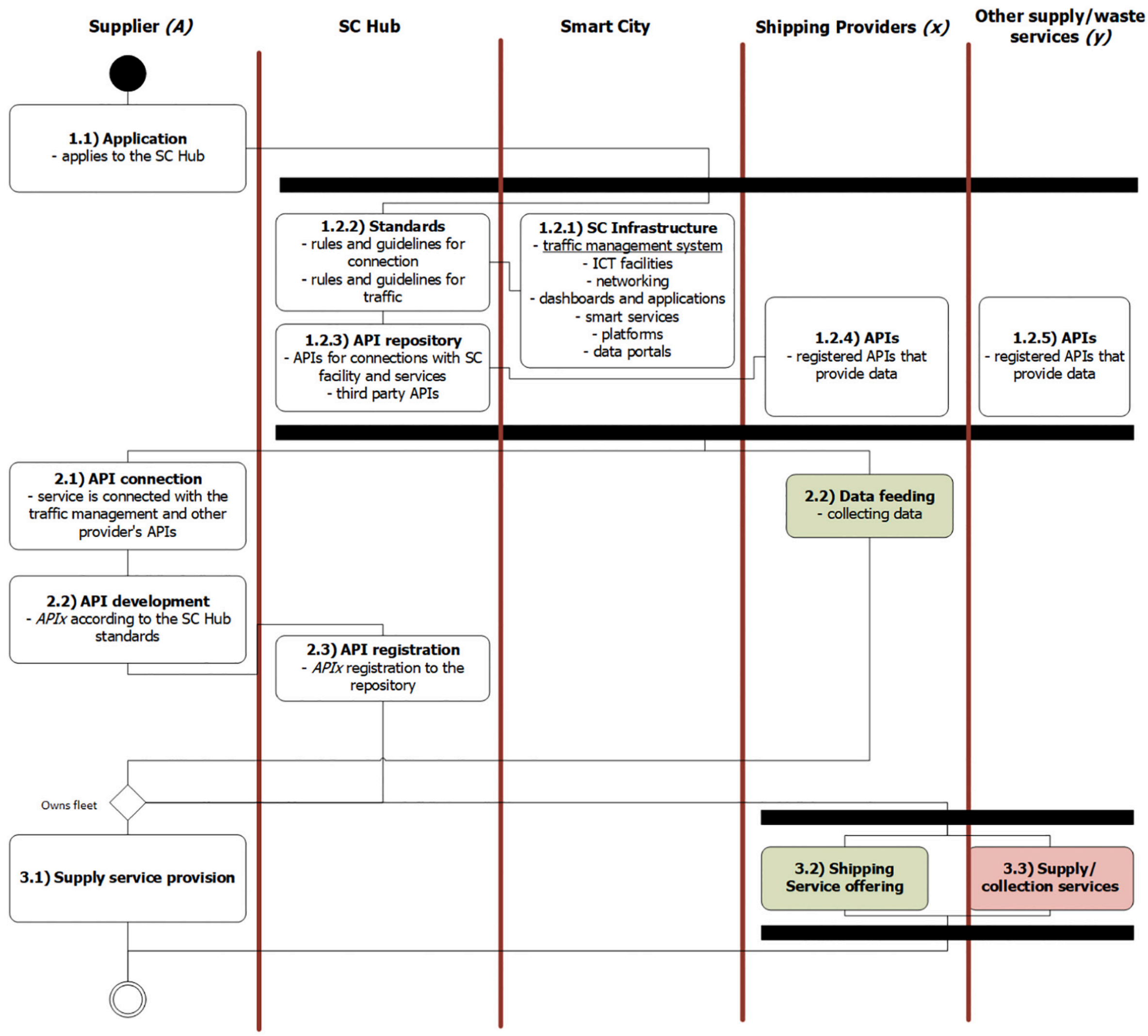

Fig. 10. UML use-case diagram for material flow control via the SCHub.

The DFS connects data producers with consumers, registers new services, while it will be calibrated by the context layer and triggered by the API layer.

The above technologies require an operating system, while the SCHub could become a physical facility. The SCHub will enable the following indicative use cases (Fig. 7):

1. Data consuming: a registered user/application can gain access to SC data.
2. Data provisioning: a registered user/application can transmit data to the SC.
3. Service provisioning: a service provider can connect its web service or App to the SCHub. A service catalogue will contain the available services, together with their SDKs and guides.
4. IoT access to registered users for data collection.
5. IoT provisioning with the hardware-as-a-service model.
6. People connection via third party virtual meeting places or innovation hub simulators.
7. Material flows via third-party applications that oblige rules (e.g., traffic management).

3.2. Connecting people and materials: An innovation and supply chain hub

The SCHub can bring together people and stakeholders to co-design new services, obliging specific *design thinking* or *participatory design* frameworks (Mainka et al., 2016). Moreover, the SCHub can simulate a typical innovation hub via offering access to third-party virtual spaces (for mentoring and coaching) and services (e.g., e-mail, portal etc.).

Furthermore, the SCHub can control the entire urban supply chain system and optimize material flows, reduce waste and emissions, and enhance recycling (e.g., authorize a food delivery service only when traffic congestion is less than a threshold).

3.3. Applying the SCHub: comparative use-cases

A data provider (*A*) (i.e., IoT owner, social media, service provider, user etc.) wants to broadcast data to consumers *(x)* (i.e., users, applications, analyzers etc.). The provider follows the SCHub standards, develops an API (*APIx*), and registers it to the API repository (Fig. 8). For instance, energy consumption data exchanges for KPI calculation coming from numerous sources in alternative formats can be enabled.

A service provider *(A)* (i.e., an IoT-based notification service, a SC dashboard, AI-based analytics service etc.) wants to connect with data providers *(x)* and/or with users *(y)* via the SCHub (Fig. 9). The provider connects his service with the corresponding API, or he can develop his own *APIx* -compliant to the SCHub rules- and register it to the API repository.

When a supplier *(A)* wants to offer his products within the urban space, he connects his supply management system (SCM) to the SCHub (Fig. 10). The supplier's SCM exchanges data with others (i.e., a traffic management system, supply/waste services *(y)*) and schedules his delivery accordingly (i.e., avoid times *i* and *j*), and submits information to the services *(y)*. Moreover, supplier *(A)* can connect with shipping providers *(x)* and schedule trips according to their availability and to the traffic restrictions.

4. Conclusions and future research

This paper observed the evolving role of platforms within the SC context, which expands the concept of *city as a platform*, and introduced the SCHub that transforms the city to a "highly connected space" and monitors, manages and enhances information, service, material, and people flows. In this regard, two research questions were grounded: *RQ1* clarifies with literature evidence how the SC is being transformed to a "hub" that enables various flows that can be controlled by the *SCHub*, which is different to the SC platform. *RQ2* returned both a reference and a conceptual architecture for the SCHub, while use-cases for service, material and people flows were simulated with the SCHub.

Several benefits appear to result from the SCHub: the existence of the SCHub could simplify the deployment of different ICT solutions in the city, since any vendor would know how it can connect its solution and gain access to city resources and services. Moreover, the city would not rely on specific platforms and technologies, while it will oblige its rules for connection, access, and flows. These pros have to be determined, together with the SCHub feasibility, and in this regard, future thoughts concern the real implementation, testing, and standardization of the SCHub. Implementation and testing have been scheduled under the research project "Smart Cities as hubs: defining a system for city flows' management" (projectID: 2652/2021), which has been granted in December 2021 by the Hellenic Foundation for Research and Innovation (H.F.R.I.). The project has been launched on Feb. 22, 2022, it will last 36 months, and it will result to the prototype, that will be tested with several use-cases like this article's, in real city conditions in Greece, Germany and Ireland. Parts of the foundation of this article have been incorporated by the Thematic Group "City Platforms", hosted by the United for Smart and Sustainable Cities (https://www.itu.int/en/ITU-T/ssc/united/Pages/thematic-groups.aspx) in the development of the report about "City Platforms".

CRediT authorship contribution statement

Leonidas Anthopoulos Supervision, Writing - Original Draft, Investigation, Conceptualization, Methodology.

Zohreh Pourzolfaghar Project administration, Funding acquisition, Writing - Original Draft, Conceptualization, Methodology.

Kristina Lemmer Project administration, Funding acquisition, Writing - Original Draft, Conceptualization, Methodology.

Tobias Siebenlist Writing - Original Draft.

Bjoern Niehaves Writing - Review & Editing.

Ioannis Nikolaou Writing – Defining the SCHub architecture framework.

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