A minimum set of common principles for enabling Smart City Interoperability

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Abstract. The current investments for smart infrastructure development in cities result in the proliferation of self-consistent and closed applications (often called "silos"), which provide services with strong vertical integration but without ease of mutual horizontal integration. This paper investigates the state of several initiatives addressing this problem. It arrives at a proposal for diminishing and, ideally, breaking down these silos. This vision can be achieved by introducing the idea of building Smart Cities on a common set of architectural principles, Pivotal Points of Interoperability (PPI), and by applying these principles to the definition of a set of open Smart City Platform Specifications.

Keywords: Smart City, Interoperability, Standard

Introduction

Recent reviews describe many investments for smart infrastructures in cities (NIST, 2018) (Catriona MANVILLE, 2014), such as smart metering or sensors for intelligent mobility/lightning. Cities are going beyond the experimentation phase of innovative applications demonstrating benefits and feasibility of the smart city concepts (European Commission, 2017).
The result is a proliferation of services for citizens and public administrations with many new data sources, applications and data managers. Unfortunately, they are designed as single applications with their own specific objectives and functions.
Such silos hamper the diffusion of open data, raise the amount of investments for any new service, prevent citizens and public administrations from obtaining full advantage from the existing infrastructures and services, and hinder the composability of solutions and services and their replicability within different cities and contexts - thus favouring vendor lock-in. All these criticalities raise the challenge for interoperability between services and across the domains of the smart city.
This paper investigates the state of prominent initiatives and approaches dealing with this challenge and presents a proposal for diminishing and, ideally, breaking down interoperability barriers among silos.
The concepts of Interoperability and related standards are outlined in the next section.
The following sections are dedicated to the landscape of the current initiatives, including standardization and novel approaches like Pivotal Points of Interoperability (PPI) introduced in the Internet of things - enabled Smart City Framework, also known as the IES-City Framework (IES-City).
The last two sections present a proposal for Smart City Platform Specifications (SCPS) as a mean to tackle the interoperability issues in the smart cities domain and summarize conclusions of this paper.

Definition of interoperability and standards

Interoperability is a key enabler for new information flows among smart city or Internet of Things (IoT) applications. However, turning this enabler into cogent technical specifications is not yet clear. Interoperable systems share a common meaning of the exchanged information, and this information must elicit agreed-upon types of response.
A reasonable definition of Interoperability for smart cities might be found in (Gary Locke, 2010): «the capability of two or more networks, systems, devices, applications, or components to exchange and readily use information, securely, effectively, and with little or no inconvenience to the user».
An important concept implied by the previous definition is that interoperability is a complex property resulting from a broad set of aspects: functional, business, human, trustworthiness, timing, data, boundaries, composition and lifecycle (CPS Public WG, 2016).
Standardization has achieved different maturity levels on these aspects: substantive progresses has been made at the technical level with faster and more secure protocols for data transmission (GSM for example); progress has been smaller on the facilitation of application integration.
Smart Cities are growing thanks to both digital migration of existing services and the composition of new services upon existing ones. The number of potential new applications and services (and data flows to deploy) is rapidly increasing (Hollands, 2008; Vatsal Bhatt, 2017). Factors hampering interoperability include the number of already existing solutions with different institutions and organisations in charge, along with the lack of convergence in the field of the standardization initiatives.

State of Art about present Smart City initiatives

The proliferation of architectural design efforts for smart cities has resulted in divergent and, sometimes, non-aligned standards.
Looking at the many Smart City initiatives trying to address this problem, it is evident how strong a motivation this subject has within the smart city community. These initiatives try to act on the following issues:
- Lack of coherence in existing Smart City standards.
- Lack of mechanisms for comparing and harmonizing standardization initiatives.
- Lack of harmonization and coherence among the existing architectural efforts.

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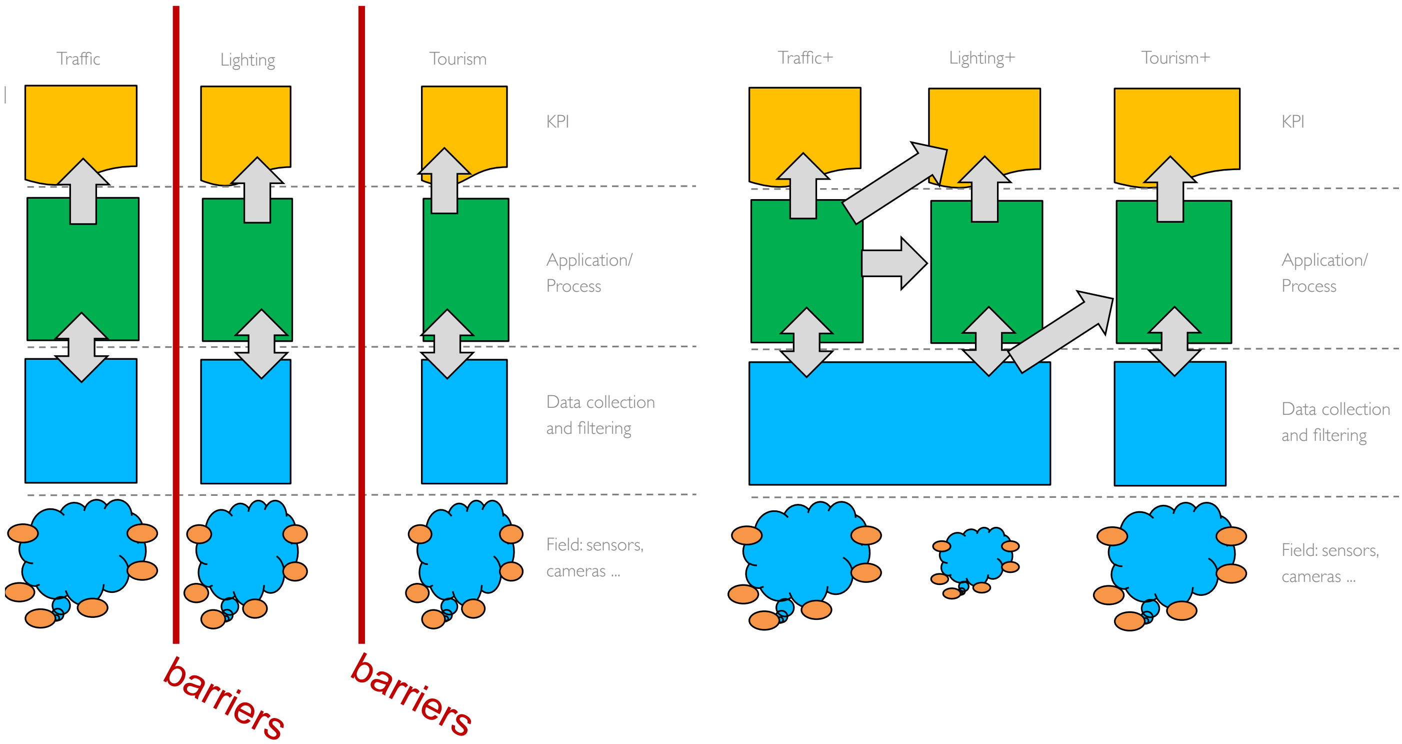
They address interoperability issues from varied perspectives as illustrated in Figure 3:

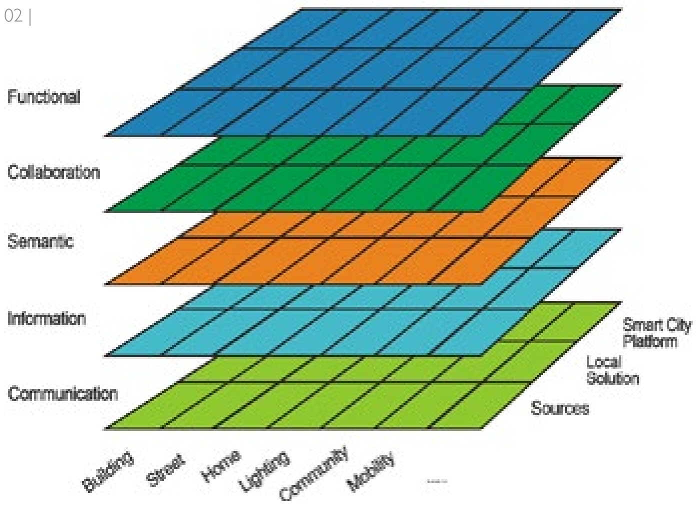
- the starting point for working on the coherence of existing standards is to understand their landscape: The British Standards Institution (BSI) analyzed existing Smart City-oriented standards. The result was a report called "Mapping Smart City Standards" (BSI, 2016), which organizes the standards into three levels (technical, process and strategic standards).
- In order to compare Smart City projects from an interoperability perspective, it is desirable to establish a reference analysis framework: In the Smart Grid context a very powerful model exists: the Smart Grid Architecture Model (SGAM) (SGCG, 2012), built by the Smart Grid Coordination Group (which joins CEN, CENELEC and ETSI). It enables identification of data exchange interfaces, standard classification and mapping of different architectures on the same reference model. Its success inspired different efforts to imitate it in the Smart City context. Some examples are the Smart City Infrastructure Model (SCIAM) (Marion Gottschalk, 2017) and the Generic Smart City Architecture Model (GSCAM) (Christian Neureiter, 2014).
- An important dimension for achieving harmonization among different standardization initiatives is the identification of an optimal implementation policy: an effort in this sense is carried out by the European project ESPRESSO, which is making recommendations in favor of the adoption of a global Smart City Strategy (ESPRESSO, 2016). These recommendations comprise the use of standards, specification of data formats and avoidance of supplier lock-in. Another European initiative is the Sector Forum on Smart and Sustainable Cities and Communities (SF-SSCC), involving the main European Standardization Development Organization (CEN, CENELEC and ETSI) (CEN-CENELEC, 2017).
- Other initiatives are working on putting many cities around one common architecture: The City Protocol Society (Aloisi, 2016) is developing a network of cities including Amsterdam, Dubai, Barcelona and Montevideo based on its Functional Platform; similarly, the Open & Agile Smart Cities (OASC) initiative comprises more than 50 cities using FIWARE based architectures (FIWARE, 2015). Another approach, driven by the Global City Team Challenge, convenes sets of cities and providers as "super clusters" to produce open "blueprints" for sets of Smart City applications (NIST, 2018).

01 |



01 | Smart City silos

02 |



02 | Reference model for the Smart City Interoperability

Based on the SGAM and related works, we are proposing our analysis grid (Fig. 2), with a third axis: Information and Communications Technology (ICT) (z-axis), along with application domains (x-axis) and, critical to our paper aims, the interoperability layers (y-axis). And these latter are: Functional (key concepts, component, functionalities), Collaboration (configuration of interoperable communications), Semantic (semantic of the common language), Information (syntax of the common language) and Communication (data exchange interfaces).
A principle gap observed in the collection of approaches reviewed above is the lack of consensus on both a common language/taxonomy and a set of Smart City architectural principles (the definition of "Smart City" itself is not singular (Hollands, 2008).
Finding this consensus would allow the distance between different sets of standards and architectures to be dramatically reduced and this in turn would allow the previous approaches to be more effective. Starting from this idea, the IES-City project was initiated.

International initiative on interoperability: the IES City Framework

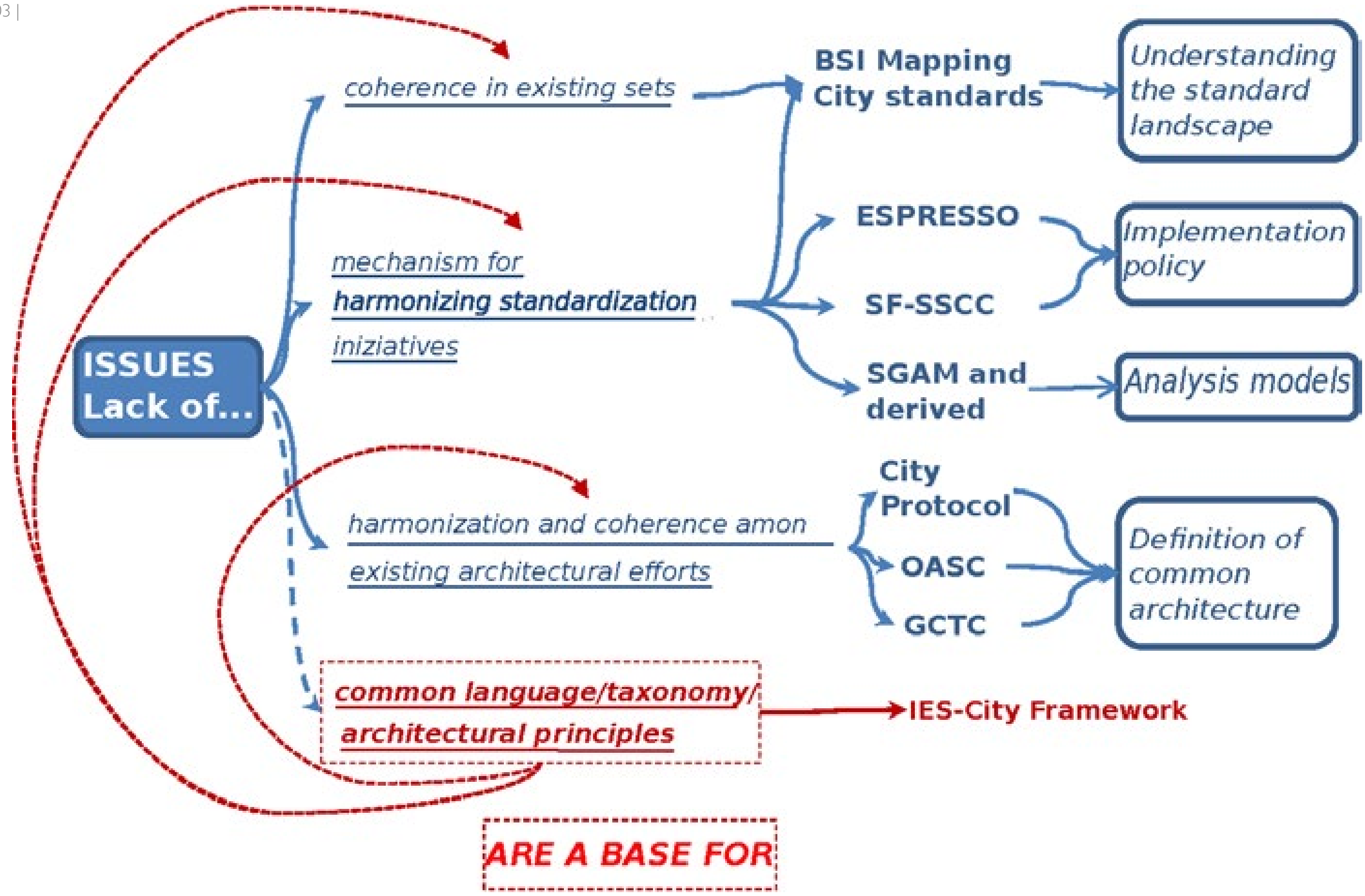
IES-City puts forward an analytical means and set of concepts to assist in the compositional convergence (aka horizontal interoperability) of smart city applications. A key concept is that, although smart city applications are developed by siloed teams, there are common choices that they have made that simplify integration: PPI (IES-City Framework, 2018). Additionally, these common choices are actuated at a small number of key integration points termed Zones of Concern (ZofC).

The analytical means are the application framework and the pivotal points of interoperability analysis.

- Application Framework: provides concepts and tools helping to identify requirements for feasibility of Smart City applications and related achievable benefits, with case-studies. Through this tool, implemented as a spreadsheet, early investigations into the functional and technical requirements, readiness of city infrastructure, and benefits to city stakeholders may be readily performed. Analysis of over 100 smart city applications are included in this data set and tool.
- PPI Analysis: Whereas each existing technology is documented in significant detail, IES-City constructs a simple analytical technique based on a spreadsheet and the NIST CPS Framework to produce a distillation of the key technology choices made in composing an application. The CPS Framework identifies a dictionary of hierarchically arranged concerns about which requirements are developed and designs made to realize them. For example, if a smart city application has concerns about cybersecurity, it would identify these concerns according to the CPS Framework aspect of Trustworthiness which has sub-concerns of security, privacy, safety, resilience, and reliability. Security has sub-concerns of physical and cyber security. In IES-City, a set of technology under study is analyzed as to whether they address these common concerns, and if so, what technology solution they used. Knowledge of these choices reduces the complexity of integrating a new application with an existing one due to these pivotal points of interoperability because the developers understand these key interface choices.
- ZofC considers that groups of concerns can be realized in sets of services bundled and exposed as a known interface. To assemble an application out of an ocean of available technical choices, there are typically three roles of developers – the application developer, the device developer, and the infrastructure (often cloud) service provider. Since these roles are common, bundles of services implementing ZofC can be focused on a *Northbound Interface* where applications find services, and a *Southbound Interface* where devices find services.

The Italian consultation initiative about interoperability

The identification of a set of common principles is essential to break down interoperability barriers among silos and exploit the potential of city's infrastructures. It is not sufficient to identify only common technical principles. To make them effective, a common strategy, shared between all the involved stakeholders in a smart city, district or national level, should be defined in order to create the conditions to favor and improve their adoption. This conclusion derives from the consideration that the transfor-



03 | Collocation of the existing initiatives with respect of issues and leverages

mation process, to make the cities "smarter", requires addressing the needs of technological as well as of conceptual and methodological, and that this can be achieved only through creating synergies between all involved stakeholders.

An example of this kind of effort is currently in progress in Italy: an activity, named National Convergence Table (NCT). Involving research and industrial communities and cities, NCT has been launched by ENEA to identify a subset of common principles, identifying key PPI, fitting with national requirements defining a roadmap for their adoption, and thus creating a national ecosystem in which technologies can be integrated, replicated and customized.

Under the umbrella of the NTC, a round table on Interoperability, organized by ENEA, MIUR and MISE took place in November 2017, promoting a fruitful discussion on Interoperability among national key stakeholders. Findings have been collected and contributed to develop key point (such as: different building automation protocols, different energy management software, different proprietary devices and different semantic are used in national project; interface different standards; concern of data privacy and protection of personal data; sensitive data should be separated from operational data in smart meters to avoid vendor lock-in and the data access issues, …) within the SET-Plan Action 3.1 Temporary Working group on Energy Consumers. The initiative is continuing and other meetings are being scheduled.

One of the first outcomes of the NCT has been the recognition of the key role played by the public administrations in the efforts needed to activate the city's change. This resulted in the identification of public calls for tenders as powerful leveraging means for applying common interoperability principles. At the same time a lack of interoperability skills in the many public administrations has been observed.

Starting from this awareness, the NCT identified as its first objective, the definition of a set of open, scalable, modular, standards-based, and general specifications based on common principles enabling the interoperable data exchange between the vertical smart city's silos. The public administration will be able to use this set of specifications as the basis for technical annexes in public tenders, and so leading their service providers to adopt common and shared approaches and solutions.

The use of such a specification aims to defend city administrations from potential "vendor lock-in" by clearly stating data requirements. The specification also provides for the ability to preserve legacy solutions and technologies.

The Smart City Platform Specification (SCPS), is in progress. It is managed by ENEA with the support of Bologna University on the Semantic level but is open to everyone. Stakeholders are encouraged to contribute by providing use cases related to specific sub-domains.

NOTHBOUND INTERFACE	CPS FRAMEWORK: ASPECTS AND CONCERNS
Aspect/Concern	**Description**
Data	Concerns about data interoperability including fusion, metadata, type, identity, etc.
data semantics	Concerns related to the agreed and shared meaning(s) of data held within, generated by, and transiting a system
data models	Structure of data/information
granularity	Granularity of data
meaning	Semantic meaning of data element

The principles at the base of the SCPS

The design and definition of the SCPS benefits from our study and practical experience on projects about Enterprise Interoperability and involvement in IES-City. Starting from these studies we identified some crucial and general principles:
- avoidance of semantic ambiguities in specification definition, to ensure the interoperability between the applications;
- clear definition of the specification life-cycle: every step related with the SCPS (for example, definition, implementation, adoption, configuration, etc.) is considered and described;
- use of a flexible data format that is enforced by semantic constraints;
- usability of the specification, which is written for different kinds of users, technical or domain expert, management personnel, and end users.

Since the objective of SCPS is strictly related to the cross-domain data exchange at the application level (the "Northbound" interface, as defined by the IES-City), we mainly considered the PPIs related to data models and data meaning concerns (Fig. 4), on which we derived the definition of two pillars for SCPS:
- Semantic modelling (*data semantic concern*): The aim is to reduce or eliminate terminological confusion with the definition of shared knowledge and terminology. Ontology definitions can help in this task, and can represent a common basis to address communication management and resolving semantic ambiguity. Modularity and reusability are two key features that make ontologies a proper tool to be used inside the platform. This, in turn, matches well to a general requirement of modularity and scalability. We used ontology to describe the semantic structure of the data model, fixing properties, characteristics and data context.
- Syntax adoption (*data model concern*): This breaks down interoperability barriers by defining formats and interfaces for data exchange. Considering the wide scope of scenarios related to Smart Cities, we adopted a horizontal approach for standardisation, defining a general data format able to represent a broad set of measured data, coming from different sources and managed by different applications. This data format is used to provide a first validation step, while a deeper validation is performed using semantic validation against the ontological definition of the data model. In this way we have a general approach for managing data exchange among different application in a Smart Cities, but we can also provide application-specific profiles for data exchange.

Short description of the SCPS

The Smart City Specification (SCPS) provides a common set of concepts and artifacts for implementing a horizontal platform enabling exchange of data among vertical smart city applications. On the basis of the reference model (Fig. 2), the SCPS was split into five levels, coherent with the interoperability layers. Moreover, according to the enunciated principles, it was considered to be modular, in the sense that ideally each level could be adopted independently from the others. This aims to favor, for example, a path of gradual adoption of the SCPS, on the basis of need.
The Communication (Web Service Interface definition), Collaboration (data exchange setup) and Functional (Smart City Platform Architecture description) levels are implemented according a traditional approach (e.g. WSDL for SOAP WS). The architectural principles, explored in the previous paragraphs, were used in the definition of Information and Communication levels:
- Information Level: defines a format to provide for the interoperable exchange of data between heterogeneous systems or applications. It is composed of an abstract model and two syntactic implementations (JSON and XML). This data is designed in a flexible way to support various kinds of data coming from any vertical system or application. The data model is made of three parts:
  - specifications: a list of properties that comprise the meta-definition (meaning, data type and unit of measure) of the data to be exchanged. For example, the exchange data about average electric consumption of public buildings would be defined as the "average electric consumption" property having data type "double" and measurement unit "kilowatt hour";
  - context: provides contextualization information (e.g. the time zone related to the time stamps);
  - values: contains the measured data on the declared properties, organized in key-value pairs, together with time-period/instant to which they refer (for example the average consumption, hour by hour, of the monitored building).
- This data model can be imagined as a table, which names of columns are defined case by case.
- Semantic Level: provides the ontology defining the concepts and the structures of specific application data model, which

usually are defined at the Information Level, for assuring not only the semantic interoperability due to shared meaning, but also as a part of the formal validation of the format.

Conclusions

Interoperability is fundamental for smart cities, but is hampered by the ad hoc way in which cities are becoming smarter. Many initiatives are trying to address this problem, but there is a lack of consensus on both common language/taxonomy and architectural principles.

IES-City Framework, an international initiative launched by NIST, proposes to ameliorate this challenge by revealing a set of common Pivotal Points of Interoperability obtained through the comparison of existing smart city architectures. In Italy, the consideration of the IES-City approach to the national context through the Italian Convergence Table involving their principal smart city stakeholders, has indicated that a lever for applying common interoperability principles can be the creation of shared tender specifications. The goal of this effort is to write reusable technical annexes for acquisitions related to data exchange among vertical smart city applications. This involves the PPI discovered through the IES-City methodology and are related to data format and data meaning concerns.

The application of this approach has been carried out with the definition of a set of Smart City Platform Specifications, modular, replicable and potentially applicable both to new and to existing systems. Currently these specifications are being validated in a laboratory context. The next step will be the validation in a real district.

REFERENCES

Aloisi, J. (2016), *City Protocol. Empowering and Improving Cities*, NIST.

BSI (2016), *Mapping Smart City Standards*, BSI.

Manville, C., Cochrane, G., Cave, J., Millard, J., Pederson, J.K., Thaarup, R.K., Liebe, A., Wissner, M., Massink, R. and Kotterink, B. (2014), *Mapping Smart Cities in the EU*, European Commission, Directorate General for Internal Policies.

CEN-CENELEC (2017), *CEN-CENELEC-ETSI Sector Forum on Smart and Sustainable Cities and Communities*, available at: https://www.cencenelec.eu/standards/Sectors/SmartLiving/smartcities/Pages/SSCC-CG.aspx (accessed: 2018-2-20).

CEN-CENELEC-ETSI Smart Grid Coordination Group (2012), *Smart Grid Reference Architecture*, SGCG.

Neureiter, C., Rohjans, S., Engel, D., Danejas, C. and Uslar, M. (2014), *Intelligente Lösungen für das Leben in der Zukunft*, Frankfurt am Main, VDE VERLAG GMBH.

CPS Public WG (2016), *Framework for Cyber-Physical Systems*, Release 1.0, NIST.

Espresso (2016), *Smart City Strategic Growth Map*, available at: https://blogs.rhrk.uni-kl.de/espresso/wp-content/uploads/sites/26/2016/12/Espresso-brochure-full.pdf (accessed: 2018-2-20).

European Commission (2017), *EU Research & Innovation for and with Cities*, Yearly Mapping Report, Directorate-General for Research and Innovation.

FIWARE (2015), *More than 50 cities are now part of the Open & Agile Smart Cities (OASC) initiative*, available at: https://www.fiware.org/news/more-than-50-cities-are-now-part-of-the-open-agile-smart-cities-oasc-initiative/ (last accessed 2018-2-20).

Gary Locke, P.D.G. (2010), *NIST Framework and Roadmap for Smart Grid Interoperability Standards*, NIST Special Publication 1108, Release 1.0, NIST.

Hollands, R.G. (2008), "Will the real Smart City please stand up?", *City: analysis of urban trends, culture, theory, policy, action*, N. 12, Vol. 3, pp. 303-320.

IES-City Framework (2018), *A Consensus Framework for Smart City Architectures*, Draft Release v20180208, NIST.

Gottschalk, M., Uslar, M. and Delfs, C. (2017), "Smart City Infrastructure Architecture Model (SCIAM)", *The Use Case and Smart Grid Architecture Model Approach*, Springer Verlag, Berlin, DE.

NIST (2018), *Global City Teams Challenge*, available at: https://www.nist.gov/el/cyber-physica l-systems/smart-americaglobal-cities (accessed: 2018-2-20).

SGCG (2012), *Smart Grid Reference Architecture*, CEN-CENELEC-ETSI Smart Grid Coordination Group.

Bhatt, V., Brutti, A., Burns, M. and Frascella, A. (2017), *An Approach to Provide Shared Architectural Principles for Interoperable Smart Cities*, Springer Verlag, Berlin, DE.