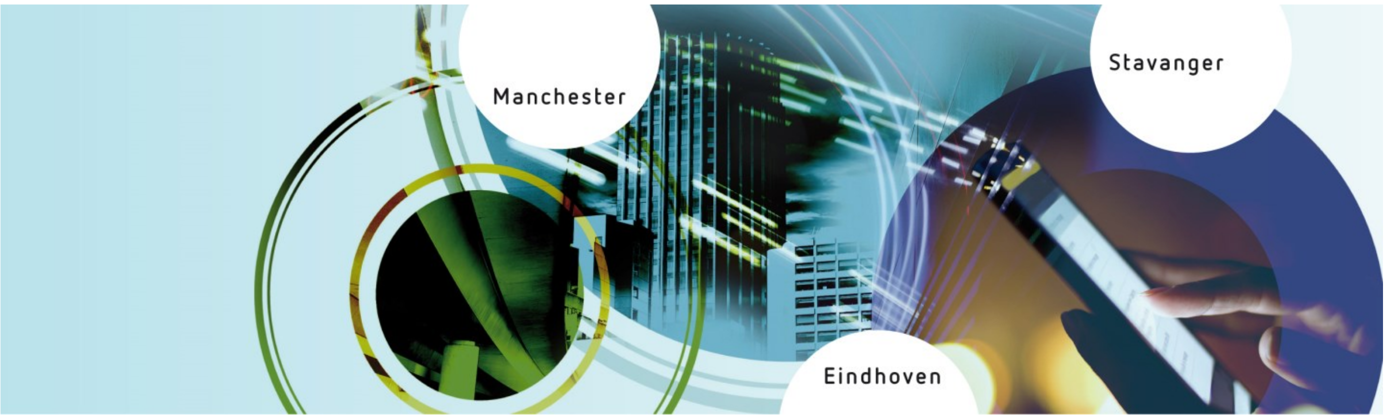

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DEMONSTRATE · DISSEMINATE · REPLICATE

D6.1 ICT Reference Architecture

WP 6, Task 6.2

July, 2015 (M06)

H2020-SCC-2014-2015/H2020-SCC-2014: "Smart Cities and Communities solutions integrating energy, transport, ICT sectors through lighthouse (large scale demonstration - first of the kind) projects"

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Executive Summary

The current deliverable is called "D6.1 ICT Reference Architecture" and is part of "WP 6 - Smart City Framework & Replication". Those two aspects already reveal to a large extend the purpose of the current document. Given that ICT is at the heart of today's Smart City approach, it is of paramount importance to investigate concepts, which would enable the unification, the common understanding and the replication of ICT architectures/solutions/models across multiple cities. This unified and replicable approach can be best achieved by a very abstract model, aiming to capture the taxonomy and high-level structure of complex integrative ICT solutions for Smart Cities.

Given the above considerations, it is useful to have a look at other (more specific) ICT domains and consider principles, which have already been established and have served the community for years. The concept of reference models/architectures has been widely adopted and used within the telecommunications and Internet domain. Typical examples of well-known such models are given by the ISO/OSI reference model that captures the different layers and structures within a telecommunication network, as well as the TCP/IP reference model that provides an easy to grasp overview of the complexity of Internet protocols. Hence, this deliverable aims at defining such an abstract ICT reference architecture, which should be able to explain and give an overview of the different aspects of complex and integrative Smart City solutions. Thereby, we provide different views on the emerging reference architecture – Informational, Organizational, and Technical. Especially, the Technical View is organized in layers and two verticals thereby spanning over various technologies, starting from sensor networks and reaching to data portals and mobile applications and services.

The presentation is based on a literature review, where similar ICT approaches for Smart Cities are reviewed, and some of the key concepts transferred to the currently proposed solution. Finally, a case study is presented, which shows how the architecture can be instantiated for a mobility solution.

The current deliverable lays the ground for further research on ICT Smart City architectures within Triangulum, and for the replication of the ICT solutions from the lighthouse cities to the follower cities. Thereby, the abstractness of the emerging ICT architecture would enable the accommodation of, and the mappings between different concepts and solutions (e.g. from legacy providers) across the cities. In that line of thoughts, the proposed ICT reference architecture will create a common understanding and common view on the employed technology.

1 Introduction

As Smart Cities emerge as a social, academic and industrial topic, it becomes increasingly clear that Information and Communication Technology (ICT) is at the heart of research and development efforts in that area. The topic of Smart Cities covers a large amount of aspects with the goal to improve the quality of life for citizens within an urban environment, especially given current predictions that in near future the larger number of humans will be living in cities. Some of the main topics for Smart Cities, which are considered by current R&D efforts, are constituted by Energy, Transportation/Mobility, eHealth, Water, Building Automation and further that emerge out of the specific needs of the city in question.

In all above-mentioned aspects, ICT plays a crucial role as being the vehicle to enable the exchange of information between the involved modules and components towards the realization of relevant scenarios within the domain in question (e.g. Energy or Transportation/Mobility). Thereby, ICT can be fairly seen as the glue, the key enabler, which offers a platform for meeting the requirements of the society.

Given the importance of ICT, it is paramount to approach the ICT aspects of Smart Cities in a structured way that is able to accommodate the diverse needs and possible/available solutions on the market. Hence, there is a need for a reference model, which would be able to capture in an abstract manner the general structure of ICT solutions for a Smart City - especially such consisting of multiple independent interoperating components, e.g. from different vendors. Thereby, the reference model could borrow some principles and ideas from other very successful reference models from the area of Internet and traditional telecommunications, such as the TCP/IP model or the ISO/OSI model.

What is typical for such reference architectures is that they do not try to explain in detail the functioning of a particular system, but instead aim for a very abstract description, which can be mapped to or can accommodate a large number of concepts, ideas, and solutions. In that sense a reference model, provides a general structure and taxonomy regarding the ICT eco-system within a city. Furthermore, a reference model serves as a theoretical platform, which can be instantiated for various use cases and solutions.

The goal of this deliverable is to specify such an abstract reference architecture for ICT in Smart Cities. This architecture will be used to structure the ICT aspects of the Smart City solutions, which will be developed and deployed within the project. Furthermore, the emerging ICT reference architecture will be used to enable the instantiation and replication of ICT based Smart City solutions, which will need to be transferred from the lighthouse cities to the follower cities.

The rest of this document is organized as follows: section 2 elaborates further on the purpose and target group of the concepts presented in this document. Section 3 deals with the main ICT asset for Smart Cities, which is given by the *Data* that is gathered processed and used in applications and services. The following section 4 summarizes the key challenges that should be addressed by the design of the proposed ICT reference architecture. Section 5 constitutes the main part of this document, presenting the structure of the ICT reference model and the different views on it, such as *Technical* or *Organizational* view. Section 6 presents an example instantiation of the ICT reference architecture for the scenario of electric mobility in urban environment. The following sections presents related work including standards for communication and data security. The final section 8 concludes this deliverable and drafts the path for further activities within Triangulum.

2 Purpose and target Group

The goal of the concepts in this deliverable is to provide an architecture for Smart Cities which would enable the implementation of Smat City solutions in accord with the interests of the involved players. This reference architecture will be applied to the three Lighthouse cities (Manchester, Stavanger Eindhoven) and subsequently transferred to the follower cities (Leipzig, Prague, Sabadel). The second process makes use of insights won during the first attempt and should be exemplary for further implementations. The purpose is thus to enable and ensure the interoperability and replicability of ICT solutions across the involved cities. For each city a bottom-up sub-plan for capturing the ICT needs and characteristics not to be developed, parts of which can be reused for other cities where appropriate. Interpolation from these sub modules to a more general architecture with optional modules is the natural prolongation of that process. On the contrary, the current document aims at a top-down approach by coming up with an abstract reference architecture, which will be later refined by the above-mentioned bottom-up discussions.

In general, the target group of this document and the here presented concepts is given by the stakeholders in a Smart City eco-system. These involve, but are not limited to, the following:

On the administrative side, there is the **city council**, which is mainly concerned with the general well-being of the city and citizens and the fulfillment of its delegated tasks and goals. This can be ensured, for instance, by optimizing energy consumption, thereby reducing budget expenses and environmental load, or by providing an adequate transport-system and adopting additional ICT-Solutions. These ideally make the city more attractive for its citizens, possible immigrants, new startups and outside companies, contributing substantially to the prosperity of the city.

The city council holds key information about localities and has the right of legislation. Their task would be to act as a kind of proxy by establishing the communication between local stakeholders and remote organizations, which are involved in envisioning, deploying, instantiating and using the ICT reference architecture proposed in this document. Furthermore, they can enable or facilitate the Smart City progress by passing/adopting necessary laws and setting the tracks for the general success of Smart City initiatives and projects, such as Triangulum.

Secondly, there is the group of **local and locally operating companies**, which mainly care about streamlining their businesses and the creation of entirely new business models. Additionally, they are interested in the long-term sustainability and future potential of their production and operating location. **Start-Ups** profit from the possibilities of entering yet unoccupied market niches and commit themselves by realizing parts of the Smart City infrastructure, including essential ICT aspects.

Local IT and infrastructure providers are part of the companies, which benefit from Smart City solutions in the ways indicated above. In addition to that, they are the core component of the architecture by providing the backbone of the framework in terms of solutions, management and operations.

Citizen are of equal importance, since they are not only one of the main beneficiaries, but also the biggest source of momentum within the city. Citizens' engagement, public opinion and media coverage are a strong factor in convincing the above-mentioned stakeholders regarding the quality and profitableness of ICT-Solutions.

3 Data Aspects

Looking at data and data communication as the cornerstone of a Smart City and in particular for an ICT reference architecture, the following subsections elaborate on the various important considerations to be done regarding data, the way data is stored and processed, as well as data formats.

3.1 Data Classification

Data builds the foundation of a Smart City, as all solutions rely heavily on the information extracted of it. For the purpose of the proposed ICT reference architecture, it is useful to classify the available data into different classes, in order to see what kind of solutions are feasible and which steps need to be taken in order to ensure the functioning of each of the constituent parts, e.g. the Communication, Data Processing and Data Analysis.

This classification can be done in three major ways: 1) According to the persistence of the data, 2) according to source and ownership, as well as 3) according to the format of the data. The following paragraphs will regard the first two ways in detail, followed by a section, which will present a more thorough discussion on data formats.

Persistence of Data

Real Time Data: **Real time data** is made available by the means of sensors nets, which are currently deployed for many different purposes and record diverse sets of properties and data. Examples of different sensor data, available in Smart City and environmental contexts, as well as existing instantiations and corresponding sensor networks are provided in Table 4 in Appendix A. The items therein provide an overview of key examples on how technology can facilitate the collection of real-time sensor and environmental data.

Another type of real-time data is extracted over the legacy Internet from news feed pages such as RSS-feeds, mailings lists, twitter and Social Network Timelines. As these documents are generally prepared by individuals and published manually with a corresponding delay, they could also be seen as only **quasi real time**. However, these two groups (sensor/environmental data and social network data) are treated as combined in the following sections, since they represent data, which is generally of streaming nature and the “measurements” are of high relevance for a single period of time.

Static Data: Real-time data is generally accessible via APIs, either relating to the sensor network infrastructure or to the news feed provider. Once this real-time data is processed and persistently stored, it becomes **static historical data**. In addition, static data includes all kind of files which are available over a long period of time and do not change in general. This includes, but is not limited to, public transport timetables, geographical and spatial data, laws, information about public entities, such as location, responsibility and opening times, census and election, general poll data as well as enriched data[1]. This data can be used and combined to create documents or can be itself contained in documents. A central data hub is envisioned within Triangulum, which will provide a first entry point for finding this kind of data and where anybody could offer own data on.

[1] Data which has been improved out of the raw data and/or the real time sensor data with e.g. semantic relations or quality information.

Both types of data - **real-time** and **static** - is accumulated and published by different entities. These entities have already been introduced in section 2 as the target group. They can voluntarily decide to make own use of their data and to partially or fully disclose that data.

In certain cases, it is mandatory and deliberate that this data is confidentially kept by its owner, in order to ensure the privacy (such as personalized data) or to prevent the security of the system from being compromised (e.g. crucial electric and water grid information).

In other cases, the owner might not want to release that data, since efforts were taken to accumulate or receive it and the disclosure of which might jeopardize a targeted market advantage. If it is still desired to have this data available to others, a solution has to be found. Single sensors can record a multitude of properties and big sensor networks, as required for many Smart City applications are a major cost factor and in addition require non-negligible legal efforts. Moreover, the administration and citizens do have an interest in keeping the amount of sensors low and easy to oversee, in order ensure an only minor environmental burden and the possibility of cost-effective removal[2]. A possible solution could be achieved by sharing sensor nets among different entities and collaborating during the creation of these, in order to avoid redundancy. Data could also be available on “paid-per-use” basis or under the requirement of a membership, in case of data, that requires billing and charging - e.g. membership fees for an industrial forum. Entities holding this kind of data should thus be approached and informed about the different possibilities and incentives.

3.2 Data Formats

The data format is a key prerequisite regarding the ways in which the data can be used. As in Smart Cities data is not just collected but also automatically processed by computers, machine readable formats are more desired. The major disadvantage of machine-readable format is their poor readability for humans. Also the closer we get to raw (sensor) data, the more steps it takes to extract the desired information. It is evident that there is no single best solution; very often various use cases create a demand for various data formats. Since storage is often not a major issue, certain data could be kept redundantly in different formats to serve the different needs. Figure 1 shows different currently available data formats and their corresponding machine-readability.

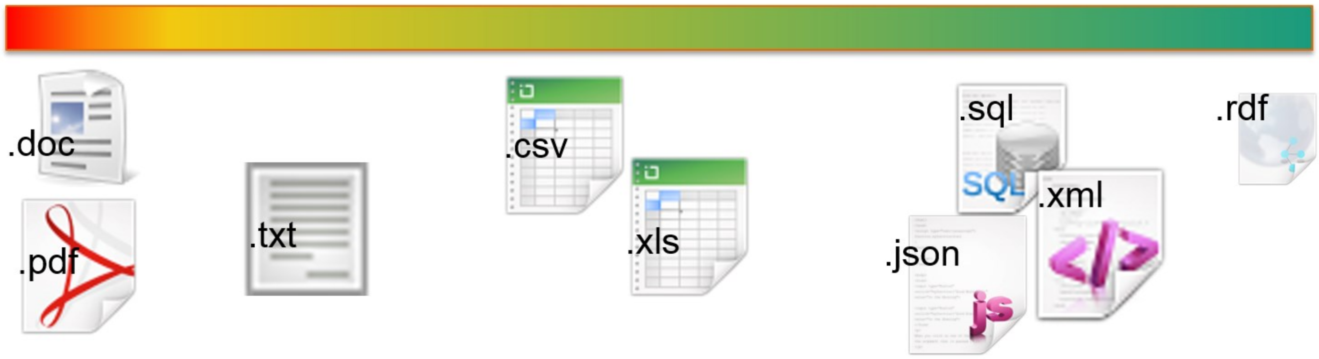

Figure 1: Different data formats according to their readability by machines. The leftmost entries require a lot of overhead conversion effort to be made available to machines, during which important information might be lost. Further right, more readily processed file formats are to be found, until we get to data files which were specifically made for this purpose.

[2] E.g. sensors in the size of millimeters, which are used in big batches. Once their battery is exhausted, they become inactive and are usually left behind.

Data coming from Sensors are by default machine readable, as the recording device is a machine itself. By transformation of the raw data into desired data formats, the owners can serve as an intermediate entity in the data processing chain.

Still there are ways in which machines might obtain information included inside files, which are not classified as machine-readable. By means of Natural language processing texts can be transformed and information extracted. Pictures and video material can be analyzed by appropriate methods, in order to get information about objects of interest.

Legacy data, which is the data that lies already at the disposal of administrations and companies, can be of very diverse format. For instance, the majority of printed documents are published as *pdf*-files, since their original intended usage was to be read by humans. As machine text and natural language processing advances, more usage could be drawn from that data, however conversion from *pdf* into more machine readable formats is inconvenient and brings the risk of information loss, such as the difference from heading to content or information encoded in tables[3]. This illustrates the point from above, showing the need for data storage in adequate file formats. The major task in the scope of the ICT considerations of a city is thus to identify the data formats which are needed in a particular Smart City context and to consider the transformation of "legacy" data by providing an assisting advice to the different stakeholders.

[3] A pdf-file consists of different object. These objects, such as text-blocks or headings receive a reference. These references are stored in a table according to their position on the pages, and by this way markup the layout of a document. Any other relationship among these references is not indicated. Thus programming efforts and previous knowledge of the specific layout of the document are required in order to extract this heading-text relationship. Similar problems occur with other structured data, such as tables. In a JSON file, a paragraph entity could be created, storing two objects with the corresponding identifiers "heading" and "text-content".

4 Key Challenges on ICT Reference Architecture

Diversity and Partiality of Existing Smart City Architectures: A reference architecture can be defined by extracting essentials of existing architectures (e.g., methods and services or usage of standards). Guidance in form of best practices and/or formalized engineering processes can be associated to reference architecture to instantiate domain-specific architectures from the reference architecture [6]. Examples of Smart City implementation projects have demonstrated a very broad diversity of ICT architectures. These individual and partial solutions do not yet constitute a normalized evidence base to be extracted for describing a generic ICT reference architecture. Nevertheless, they are starting points for the identification of several ICT architecture components. This deliverable and belonging concepts should aim at combining findings from existing Smart City architectures and existing architectural framework (e.g., TOGAF [75], GWAC [76]) with academic research results on the field, for defining a comprehensive ICT Reference Architecture.

Complexity of Smart City systems: As broadly discussed and agreed, Smart Cities architectures should follow a holistic view on Smart City systems. Such systems are related to different application domains, e.g., transportation, environment, energy, health care, safety, education, and demonstrate complex operation and maintenance processes, mainly related to their nature, and involvement of multiple stakeholders from different disciplines and domains. Besides the operational complexity, various Smart City systems have to fulfill strict quality requirements such as reliability, availability, maintainability, security and privacy [7]. Due to the complexity of Smart City systems, following a holistic view over different application domains is a challenging task to be addressed by the current research.

Identification of useful and missing standards: The list of useful Smart City standards might be long and overwhelming (see section 7.2). Therefore, for the identification of useful and missing standards, a well-defined method to support standard gap analysis and its presentation is required.

5 Design of ICT Reference Architecture for Smart Cities

The following sections present the design of the ICT Reference Architecture for Smart Cities, which will be instantiated by the participating cities (lighthouse and follower cities) in the scope of Triangulum. At first a general introduction is given, which includes the understanding of a reference architecture in the scope of Smart Cities. Then, the presentation proceeds by presenting the belonging abstract architectural design. The architectural design itself is composed of different views including a *Technical View*, an *Informational View* and an *Organisational View*, which includes aspects such as Billing, Charging and Business Procedures in general. In the course of the presentation, the technical interfaces among the different layers of the reference architecture are elucidated and example communication protocols are given, which constitutes standards for the exchange of information between the involved components.

5.1 Introduction

The proposed ICT reference architecture constitutes a key aspect that enables the implementation of Smart City concepts within the involved lighthouse and follower cities. The starting point regarding the definition of such an ICT reference architecture are given by the discussions, which were taking place among the consortium members during the project definition phase. This includes the experiences of partners such as *Fraunhofer FOKUS* and *Clicks and Links LTD*. Different illustrations of layered architectures were taken into account, which were proposed by the experts from various IT service and consulting providers from the involved cities. In the course of these discussions, the involved partners defined the core of the emerging ICT reference architecture as a **high-level blueprint of the common IT and communication technology artefacts (components and modules)** to be deployed within a Smart City. Thereby, the ICT reference architecture is meant to provide the basics and facilitate a **common understanding regarding the ICT related terminology in the city context** as well as to outline the **standard/common sources of data** and the belonging **data consumers**. Another, key aspect – it can be even claimed as the most important one – is given by the facilitation of **interoperability** among the identified components, modules, layers, and general artefacts within the emerging reference model. The interoperability aspect is supported by pointing out the **interfaces** among the above listed items. This theoretically enables the combination of and freedom to select different vendors providing solutions/implementations, which map to the parts of the emerging ICT reference architecture. Thereby, the interoperability features ease the replication of the ICT based solutions among the involved cities – especially with the focus of transferability of concepts and components from the lighthouse to the follower cities.

The following constitutes a tangible list of main goals for the emerging ICT reference model, which specify and elaborate further the above considerations:

1. Provide a **unified view and understanding on the ICT strategies and deployments** of the involved cities
2. **Identify interfaces** between standard ICT components in a city, which implies the specifications/selection of suitable **data formats** (e.g. XML/JSON scheme, RDF and Ontology vocabularies) **and protocols (**HTTP, REST, 6LowPan, ZigBee, COAP, Real-Time-Publish-Subscribe Protocol)
3. **Accommodation of legacy systems** within the concepts and artefacts of the ICT Reference Architecture
4. Enable the **exchange and interoperability** of components and solutions thereby employing the **identified interfaces** to combine and let them operate together in Smart City scenarios
5. Strengthen the use of **Open Source components**, in order to **enable cities and communities to become vendor independent**

6. Strengthen the usage, publication and dissemination of **Open Data as a key enabler of a Smart City**
7. Enable the **replication of Smart City concepts** between lighthouse and follower cities (and in general to other cities)

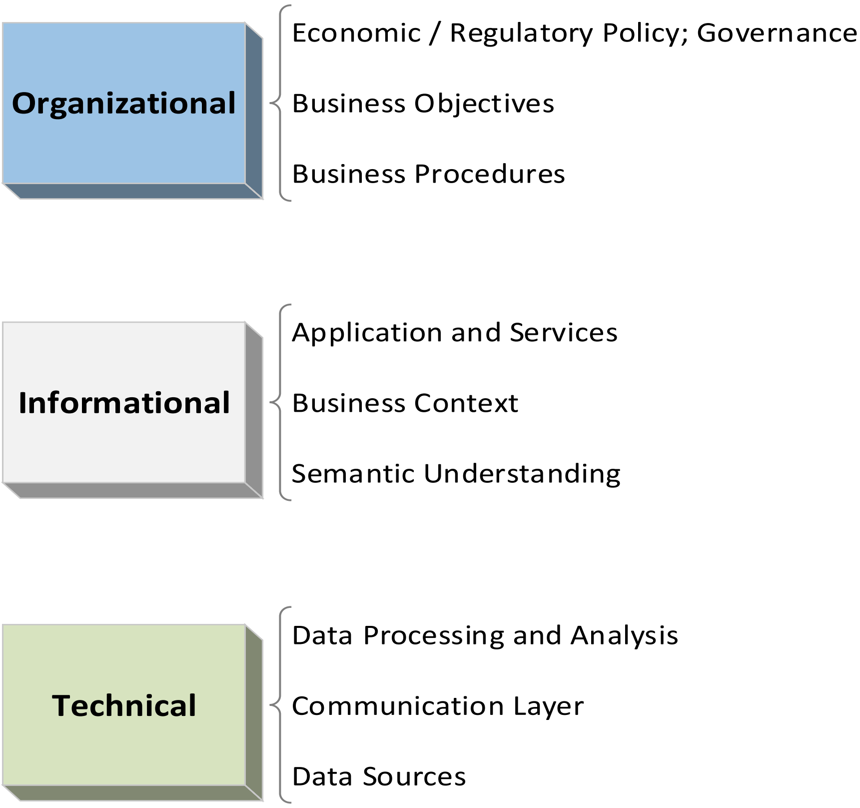

Figure 2: The different Views on an ICT Reference Model for Smart Cities based on [30].

In accordance with the above considerations, different views on the emerging ICT reference model are taken into account. These views also drive and structure the current line of thoughts and presentation and are illustrated in Figure 2. The structure is dominated by the *Organizational*, *Informational* and *Technical* views on the left hand side. The Technical view is focused on the raw data sources and the communication means to fuse data together and make it available for further processing and analysis. The data processing and analysis interconnects and correlates different aspects of the raw data enriching and enhancing it to become *Information* thereby moving into the Informational view. With the Informational view, the information is refined, structured and enriched as to support semantic relations and a Semantic Understanding of the raw data and resulting information items. That means that different data/information pieces can be put in relation to each other leading to an enriched and deep understanding of the possible influences and implications in complex situations. Furthermore, the semantically enriched data/information is put into a Business Context that drives the development of advanced Applications and Services for Smart Cities, e.g. mobility or energy. Finally, the above technical and informational aspects should be properly organized according to Business Models (including Business Procedures and Objectives) as well as various governance and regulations aspects. For example, it is possible to implement various billing and charging models for data, in case of commercial (non-open) data providers.

The above explanations refer to a broader interpretation of the model presented in [30]. For the current ICT reference architecture, we adopt the *Views* bur lay down a slightly different structure of layers within the views. Theses layers for each view are correspondingly listed and explained in the belonging sections.

The above discussions give an overview into the general needs and approach towards the definition of the required reference model. The following section proceeds with the high level definition of the Technical View thereby structuring it in appropriate layers.

5.2 ICT Reference Architecture: Technical View

The technical view on the proposed ICT Reference Architecture is shown in Figure 4. It includes various layers, such as *Data Sources* layer, *Communication Layer* and further, which are described in the following paragraphs. These areas reflect the data and information which is gathered and the way it is further processed, prepared and utilized in order to provide services and applications for the citizens, guests and business entities (SMEs and industry) in a city. In parallel, two key aspects are depicted as columns on both sides of the architecture thereby crosscutting the different layers and providing some overall functions, which are of key importance for all the technical layers. These are related to the Management and Security of the technology, which instantiates (i.e. implements) the proposed abstract reference model.

Next, each of the layers within the technical view in Figure 4 is presented and elucidated on in turn.

5.2.1 Data Sources Layer

The *Data Sources Layer* encompasses the various sources of any data of relevance within a city. Typical sources of relevant data are given by Sensor Networks, Social Media, Smart Metering data relating to energetic consumption, as well as Governmental Data, which is currently the main source of Open Data across Europe. Furthermore, different commercial providers can act as sources of information, which may be localized or mapped to this layer. This may also include crowdsourcing data, which is gathered through the usage of certain mobile applications and intended for commercial purpose (for example charging for data etc.). Furthermore, data from sensor networks as well as smart metering data is also likely to be a subject for charging and billing.

The above considerations reflect on possible sources within the Data Sources Layer. These are elaborated separately in the following thereby touching on key characteristics. However, various other data sources are possible and could also be considered as having the characteristics of this layer. These sources depend strongly on the particular use case, for which the emerging reference architecture is instantiated.

<u>Sensor Networks:</u> Sensor Networks are increasingly being deployed throughout cities in Europe. Examples of some existing deployments are given in Appendix A within Table 4. Sensor networks typically consist of two parts:

1) The sensors' segment in which data is routed among the sensors until it reaches

2) a gateway (sink node) that takes the data and forwards it to another network segment - e.g. using a fixed line or any sort of wireless mobile communication network (GSM, UMTS, LTE, GPRS, WLAN). This network segment is in turn connected to the Internet, such that the data can flow into any sort of a backend database and be further used for services and (mobile) applications.

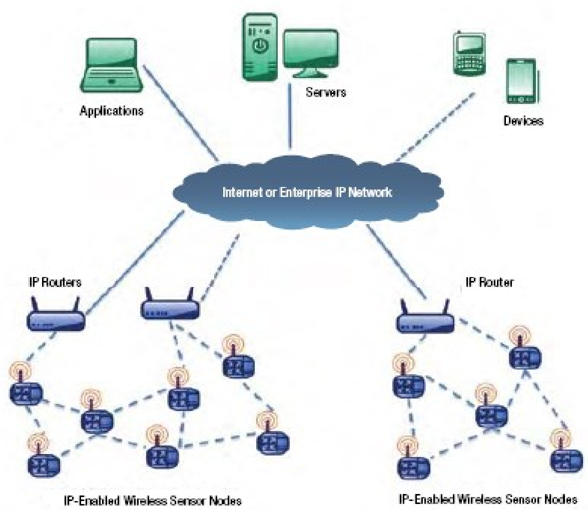

FIGURE 2

A network of end-to-end IP-enabled, small footprint wireless network nodes, IP routers and Internet applications. Not all wireless sensor networks support IP throughout. There is a variety of other mesh network protocols by which the sensors communicate. Illustration courtesy Arch Rock.

Figure 3: Example of an IP-based Sensor Network [31]

Figure 3 gives an example of a sensor network as described above. Thereby, Figure 3 illustrates and discusses (refer to the explanatory text) the IP technology as the converging platform for all type of sensors, no matter whether the sensor nodes support IP or not.

Actually, a variety of protocols can be applied within the sensor segment itself, including standards such as ZigBee [32], 6LowPan [33], CoAP [34], IEEE 802.15.4 [35], and Bluetooth [36]. Furthermore, different routing protocols for setting the forwarding paths for data from a sensor node to the sink node/gateway are in place, e.g. RPL (Routing Protocol for Low power and Lossy Networks) [37] or OLSR (Optimized Link State Routing) [38], which is a typical protocol for mesh networks networks. Communication protocols for sensor networks should consider various constraints which emerge by the fact that sensor devices have limited computing power and limited energy resources[4]. That is, it is expected that communication in the sensor segment is conducted with less overhead (e.g. in terms of packet headers that need to be processed) and in a way as to reduce the energy consumption in the involved nodes.

Typically, sensor nodes measure environmental aspects such as (temperature, humidity, pressure …). Different sensor node platforms can be found on the market, which normally make use of operating systems for embedded devices. Typical platforms are given by Thinkerforge [39] or Arduino [40] to mention some of the known names. Some typical operating systems, which are used for sensors are TinyOS [41], Contiki [42], FreeRTOS [43], and Embedded Linux [44].

Naturally, sensor networks deliver real-time data that is meant to stream over the Internet to the Backend Servers and be used as a data stream by the above layers towards the goal of providing corresponding services and applications within a city. The above descriptions give a high level idea of the role of sensor networks within the Data Sources Layers. Next, some properties of Social Media as a source of data within a Smart City are presented.

[4] Typically, sensors are powered by a battery.

Social Media: Social Media such as Twitter [45], Facebook [46], Instagram [47] as well as different Internet fora have increasingly reserved a place in the lives of citizens across the world. The sharing of (short) posts and messages, as well as photos or geo-positions, allows for acquiring a large amount of interesting raw data and information which can be used in various services and applications for a Smart City. Modern social networks offer APIs over which data can be obtained, processed and further stored in data platforms. Such APIs are mostly based on REST [48] and belonging protocols like HTTP [49], as well as additional data representation and data query APIs and formats – XML, JSON, SPARQL, RDF, OWL etc. Furthermore, social networks like Twitter and Facebook offer APIs and services for authorization and authentication, e.g. based on standards like OAuth2.0 [9], over which it is possible to regulate the access to resources and data and implement access policies to increase the security, confidentiality and integrity with respect to the data usage.

Smart Meter: Smart Meter data is another relevant data source within a city, especially when it comes to energy optimization and energetic improvements in buildings, as planned within the house cities. In that case the metering devices are installed within the buildings and measure periodically the consumption of resources of interest (e.g. energy, gas or water). This enables the real-time monitoring of energy consumption and the implementation of various scenarios to energetically optimize buildings, including an extension of the use cases to the Smart Grid. For example, it is possible to optimize the energy load balancing of a building with respect to usage patterns, thereby involving technology such as Micro Grid.

Different communication technology can be used for the network segment between the meters and the Internet (from where the data can be further processed/stored). Different types of fixed or wireless communication is imaginable and used including WiFi [50], GSM [51], SMS [51], 3G UMTS [52] and 4G LTE [52].

Governmental Data: Governmental Data is another important source within the Data Sources Layer. Typically, governmental data relates to statistics or artefacts, which are required in order to run the belonging entities/institutions from the public domain. This data might include maps, geospatial data, statistics, construction plans, road infrastructure information, transportation data (such as bus/train schedules), as well as laws and press releases. In general, this data is obtained/generated using tax payers money and should be correspondingly released under the terms of Open Data [55] licenses, such as CC-BY [56]. This implies that the data is provided without any charging for it and can be further used for Smart City applications and services, as well as a basis for articles, books and documents.

During the past years there was a strong push across the world with respect to Open Data platforms, including the platforms of the USA [57], Great Britain [58], Germany [59] as well as on city and district level with Berlin [60], Paris [61] and further cities across Europe. Correspondingly, some solid research and development has been performed in that area, which provides the base for the implementation of city data platforms/clouds in general. Some of these technologies might be considered for the Data Hub, which is one of the targeted outcomes of Triangulum Work Package 2. To mention some the available technology: CKAN (Comprehensive Knowledge Archive Network) [62] has established itself as a de-facto standard for capturing meta-data. Furthermore, platforms such as the Fraunhofer FOKUS Open Data Platform [63] and Socrata [64] are used for the implementation of several of the above-mentioned Open Data portals/platforms. The DCAT [65] meta-data format, Dublin Core [66] as well as INSPIRE ISO 19115 [67] are standards which allow the capturing, description, search ability and indexing of data in that context.

Having elucidated on the key aspects of the *Data Sources Layer*, and included some important examples of types of data, the next section continues with the description of the *Communications Layer* which enables the communication between the Data Sources layer and the above residing data platforms in the *Data Processing and Analysis Layer* on Figure 4.

5.2.2 Communication Layer

The *Communication Layer* resides above the *Data Sources Layer* in Figure 4 and includes all the facilities and infrastructure which are required to obtain/gather the data from the data sources (in the layer underneath), convey this to repositories and make them available for further processing. This means that all the communication technology which connects the sources to the data storage facilities, including the data storage itself, belongs to this layer.

In general, we would like to consider data sources with their intrinsically belonging communication infrastructure as part of the Data Sources layer. In order to establish a clear separation, the latter can be interpreted as all the networks that belong to the Internet, plus storage servers, must be counted as *Communication Layer*, whilst the specific "access networks" - e.g. the links amongst the sensors in a Sensor Network connecting towards the gateway/sink node or the wireless technology connecting a smart meter to a service provider network – are considered as belonging to the *Data Sources Layer*.

The Internet and the belonging networks communicate over the Network Layer technology of the TCP/IP stack, which is the IP (Internet Protocol) in its two available versions – IPv4 and IPv6. The networks that build-up the Internet encompass different management aspects and have different service provides that operate them. Correspondingly, they are referred to as Autonomous Systems (AS) that interconnect in order to build up the Internet. The inter-domain traffic between Autonomous Systems is realized by so-called Exterior Gateway Protocols (EGP) [53] which take care of advertising routes to reachable end systems and user networks and steering the exchange of traffic on inter-domain level. A widely used EGP protocol is given by BGP [54], which stands for Border Gateway Protocol. The exchange of traffic between Autonomous Systems can be either established directly between two Autonomous Systems, or can be organized using so-called IXPs (Internet Exchange Points), which constitute a sort of market place between AS providers where traffic is exchanged and billing is done on the fly. Within an AS, so-called intra-domain routing protocols take care of establishing the routes and enabling the traffic forwarding within the intra-domain network. Typical examples for such protocols are given by OSPF, IS-IS, and RIP(-ng).

As data is moving over the infrastructure briefly described above, it arrives at data centers, which host large amounts of servers and where data repositories store the data and make it further available. These, can be for instance traditional, legacy, physical data servers that run some large databases and are organized in Content Distribution Networks (CDNs). CDN are geo-graphically distributed data centers, which are designed as to quickly provide access to content thereby realizing aspects such as user load balancing between the servers and data centers. Given the modern trends in the domain of cloud computing, the data can also be hosted on virtual machines and correspondingly distributed over more complex structures on top of a virtualization layer, which is correspondingly represented by the virtual repositories in Figure 4.

5.2.3 Data Processing and Analysis Layer

Data collected in a central data hub or in any other entity of a Smart City has to be processed in order to extract the desired information. At these central locations, data from a variety of sources such as distributed public or proprietary sensor networks, governmental agencies, companies and even private citizens ideally converges to a single point of access and processing [18].

After the initial optional enrichment of the data with information about context, different analyses are to be performed on its basis. The results of which will not only offer critical insights into the progress of goal realization (Business Intelligence [19]) and influence the decisions taken by the individual stakeholders, but also offer the possibility for the creation of dynamic self-regulating systems such as smart grids.

As an example, cumulated data from past recoding periods can serve as basis for a prediction model of future energy needs. Integration within/as real time feedback loop would allow for anticipation and alleviation of unusual events such as consumption peaks [20]. Feedback of model predictions can then be also given on a per household basis to the inhabitants, in order to assist them with changing their behavior, in order to reduce their energy consumption,while keeping felt comfort constant or even raising it [21]. This can be referred to as Smart Energy management.

The stakeholders benefit by reducing budgetary efforts and environmental load, making the city thus more sustainable [22]. In addition, such an implementation would allow for performance monitoring of this particular Smart City solution and serve as justification or for identifying “contradiction” of taken measures, as savings can be analyzed reliably. This helps to build a pool of experience, which will be crucial for the replication step.

The realization of such a solution involves the integration of big amounts of data in near real-time and thus poses the need for scalable and fast stream processing engines. In addition, batch processing engines are required for the creation of appropriate models and information extraction for informed decision making.

The appropriate statistical analysis of (numeric) sensor data and video material collected throughout the city can be done by algorithms from fields such as machine learning [23] and computer vision [24] [25] respectively. Textual data collected from newsfeeds and social media platforms can be harvested by natural language [26] and semantic processing algorithms, also making use of ontologies.

Prior to release on publically accessible data portals, data which, if released, could violate individual rights to privacy but also critical information regarding security should be filtered out or processed in a way that the danger of right violation or security breach is not posed anymore (e.g. by smoothing sensor data over a set period of time). This is also to happen automatically. After that, third party stakeholders can take over processing of the collected data. The concept of having third parties take over data processing and create working business models out of it, is pivotal in a Smart City, as governmental funding is limited and does not always lead to the optimal outcome. Data disclosure and transparent analysis also helps to solidify citizen trust [27] and spark engagement [28]. To assist the external creation of services, appropriate interfaces alongside example applications should and can be offered and data lineage should be kept transparent.

As these processing needs are universal for all Smart Cities, the central data hub and data processing solutions can be part of the reference architecture. A good solution found during the lighthouse city implementation step could thus be replicated with minimal customization efforts over all the follower cities.

One such data hub is currently in preparation by the University of Stavanger in the course of Triangulum and a big data processing framework is to be envisioned and implemented by the project partners UiS and Lyse, with the future goal to collect and analyze data recorded by smart meters installed in Stavanger Lighthouse District households.

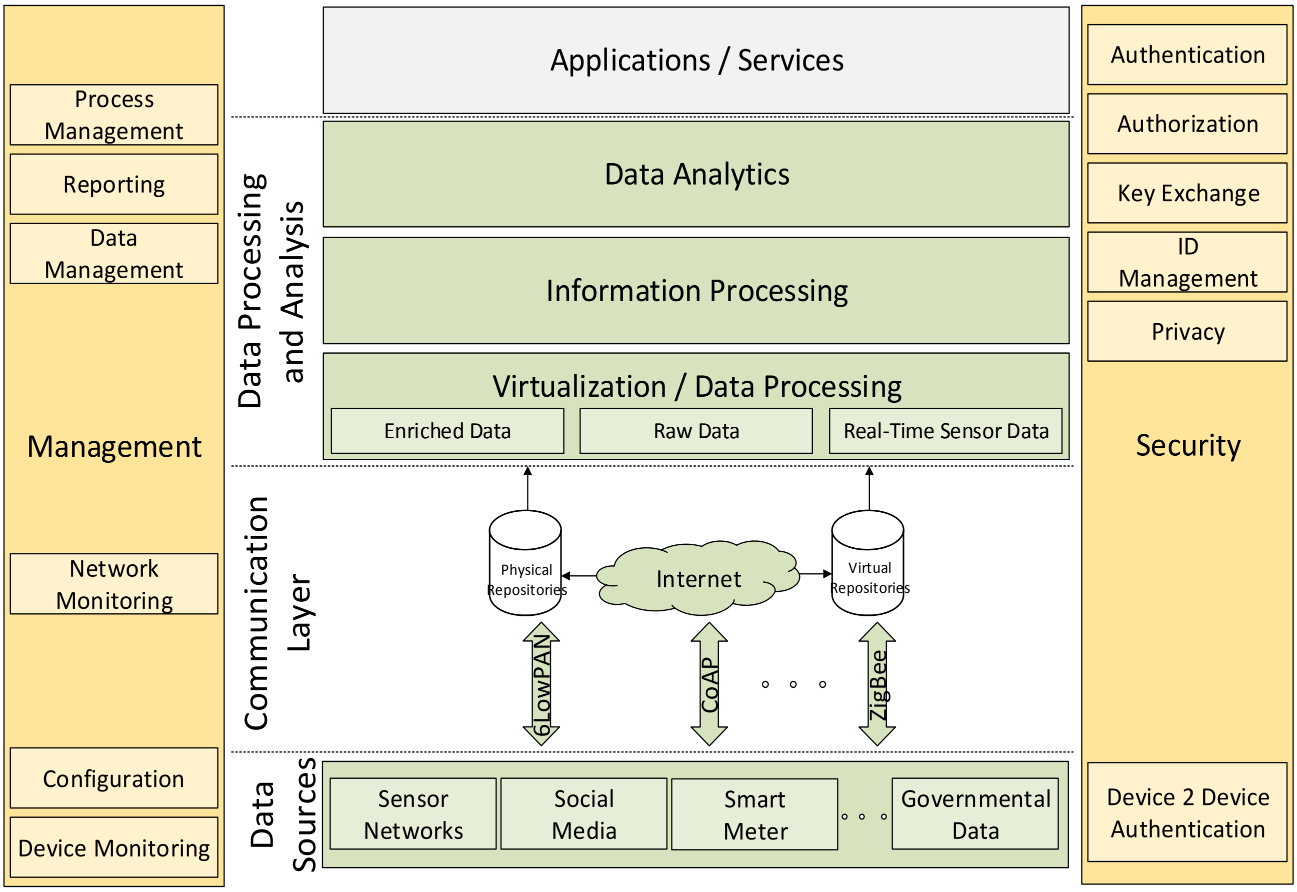

Figure 4: The Technical View on the Emerging ICT Reference Architecture

The two columns left and right, relating to Management and Security, are on one hand self-explanatory, whilst on the other hand, we provide a dive in related technology in section 5.5 – on the level of the Views provided the importance of these two aspects for the ICT reference architecture.

5.3 ICT Reference Architecture: Informational View

The current section presents the Informational View on the ICT Reference Architecture, which consists of the *Application and Services Layer*, the *Market Layer* and finally the *User Layer*. Thereby, the Application and Services Layer coincides with the top layer on Figure 4.

5.3.1 Application and Services Layer

On this layer, the information extracted and gained within the previous layer is incorporated into different Smart City applications and services. These applications can either work autonomously on the basis of predictions drawn from models as for the regulation of traffic and public lightening, give valuable feedback to decision makers as to the success of their policies or provide incentives for citizen to change their behavior in a manner which both benefits them and society.

They can range from very complex and critical systems involved in traffic light regulation and energy distribution and retention, over business oriented services as E-Vehicle rental, to simple information applications about the current state of the city, providing information about traffic peak hours, own energy consumption in comparison with other households and suggestions for optimizing the own behavior.
As this layer is often closely interrelated with the previous one (*Data Processing and Analysis Layer* from the Technical View), it is not always possible to make a clear cut separation. Services require data analysis and processing in order to work, and data analysis is performed with the aim of future use in such applications and services. Services and applications can thus also trigger data processing and then use the results further for simple display or to achieve state changes. Figure 5 shows part of this complexity.

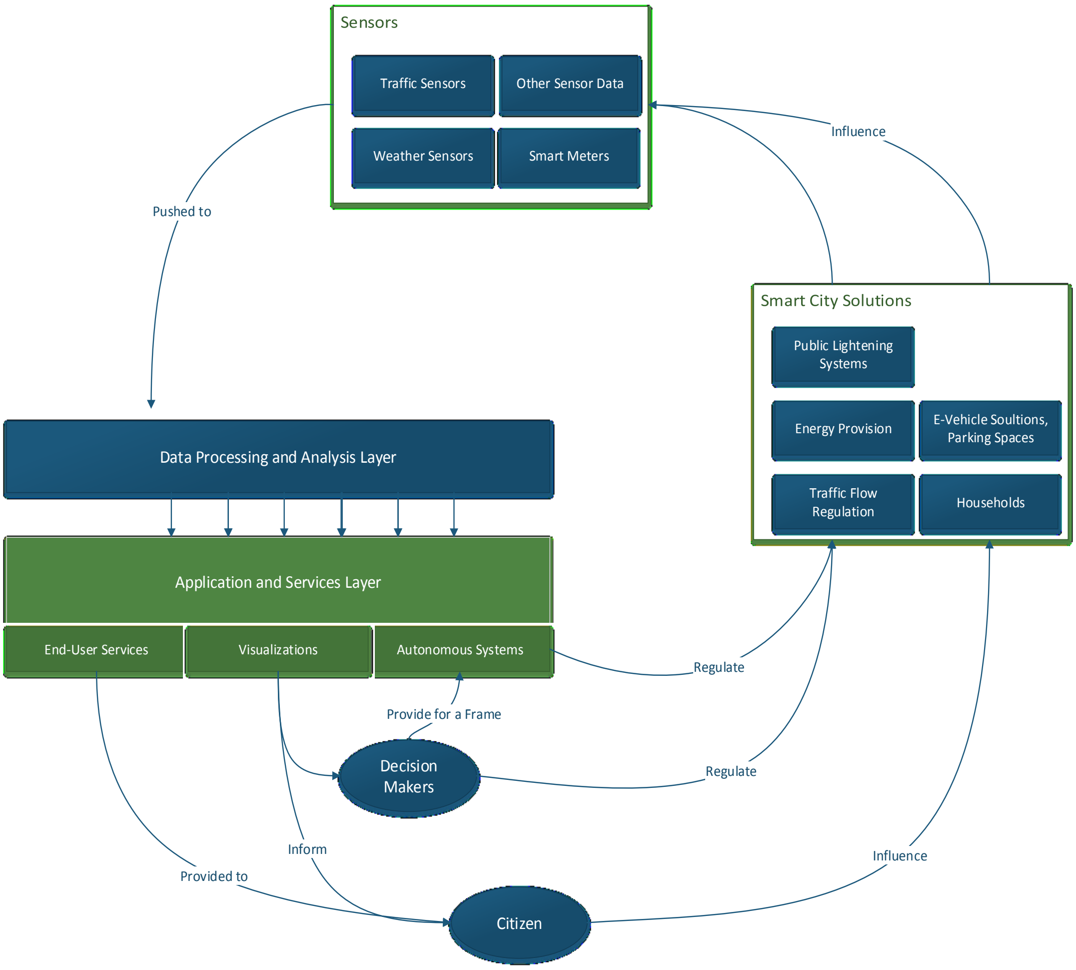

Figure 5: Integration of the Applications and Services Layer within a Smart City. Counter-clockwise from the top: Different sets of sensors collect information about the current state of entities within a smart city. This data is then processed and integrated with other data (not shown) within the Data Processing and Analysis Layer. The results are forwarded to the Application and Services Layer. There they are used for different end-user services, visualizations and as input for autonomous systems. As a result the state of entities within the Smart City is influenced, leading to renewed registration by sensors.

Within the lighthouse cities, the following applications have been envisioned and/or are currently realized:

Manchester will establish an open data platform, which also includes the possibility of doing 3d-Visualizations. These can then be used to predict view corridors for new buildings and offer exploration possibilities within an application. Smart City grid control will be based on insights gained through data analysis and visualization tools. Another useful application for direct use by citizens could show the nearest (e-)bike rentral points and bike availability. The development of such applications and services is encouraged by the planned incubation structures.

Stavanger will implement smart generic gateways in 100 homes in order to collect data and improve energy usage awareness. These give information of current energy consumption to inhabitants, give suggestions and incentives for personal behavioral change and report back to a central hub. These reports could be pooled together, peak energy consumption times and causes for these identified and acted upon. Prediction models resulting out of this data pooling could be used again to drive other applications.

Eindhoven will also build a data platform, which ought to be a basis for the future development of new services. Those services will for instance include a mapping of the electric vehicle (EV) and fuel cell charging points and efficient route planning services.

5.3.2 Market Layer

The market layer is concerned with applications and services marketplaces, which are online stores designed to help people and organizations to discover, purchase, and deploy integrated applications and services in different city domains. By taking an interoperable approach in Smart City solutions, applications and services can be developed independently by companies, specifically SMEs, but also by individuals or researchers.

Critical to the concept is the (open) data marketplace from which tools, services, and applications can push and/or pull urban data and access other services provided by the open service engine (e.g. for simulating and predicting load and usage profiles). They can then design new and develop innovative end-customer and business applications around it. In a Smart City environment, everyone can be viewed as a consumer, and almost everyone can be considered a producer providing services (in many cases information and knowledge for others to consume).

Smart Cities require a service marketplace in which decisions can be constructed as “votes” for that service or application. City consumers will play key contributing roles in determining what applications and services are successful. In-store mechanisms like user ratings and recommendations, number of downloads and popularity indexes can help on shaping applications and services quality. In addition, security and trust concerns e.g., awareness of the potential for fraudulent and deceptive practices, protection techniques, and problems resolution can be addressed through city-defined controlling rules and policies. Thus, the marketplace envisioned is mixed in that both policy-driven and open with government ruling some aspects of services and offers, and users deciding what to be offered and used [8].

5.3.3 User Layer

The User Layer can be seen as the end users that download apps from the app stores and use them on their devices. Thereby, the devices might be given by smartphones, tablets, traditional PCs or notebooks. The users might be either using the apps on those devices or might be utilizing some services which can be found through the corresponding marketplaces. Thereby, the users might be either some citizens (e.g. using some mobility apps), companies utilizing the services created based on the Smart City data, or data journalists that make use of the technical features of an ICT Smart City architecture, in order to come up with better investigative articles. The User Layer complements the view on the ICT reference architecture with respect to how the data, turned into sensible information, is utilized within a Smart City.

5.4 ICT Reference Architecture: Organizational View

The Organizational View describes how Smart Cities need to operate to achieve stated objectives and goals of Smart Cities initiatives/programs and respond to the strategic drivers set out in their Smart City strategy and principles. The Organizational View of the ICT Reference Architecture embraces the idea that the smartest cities are looking to transform the way they have traditionally operated, that resulted on delivery silos, mainly built as function-oriented system, rather than on user's needs [5]. The layers of the Organizational View are:

- Smart City Governance Layer
- Business Procedures, Billing and Charging Layer

The subsections below describe in detail these layers and their components.

5.4.1 Smart City Governance

Johnston and Hansen [1] [2] defines ***governance*** as the interaction of processes, information, rules, structures, and norms that guide behavior toward stated objectives that impact collections of people, and ***governance infrastructure*** as the collection of technologies, people, policies, practices, resources, social norms, and information that interact to support governing activities. A Smart City needs a smart governance infrastructure, bringing together multiple stakeholders, worked-out processes (social and decision-making), rules and policies, and supporting tools in driving growth and adaptability of smart services within the city.

Derived from [3] [4] [5], Figure 6 below depicts the main elements of a Smart City governance model. These include:

1) **Objectives and Strategy:** Smart City Initiatives should have clear objectives that are to be realized through concrete and comprehensive strategies. Smart City strategies should be reviewed and revised regularly to be aligned with city's specific strategic initiatives. To be effective, Smart City strategies need to be principle-based [5].
2) **Smart City Principles**: As discussed in [5], Smart City principles or the so-called guiding principles are statements of values, which city leaders can use to steer business decision-making as they seek to implement a Smart City strategy. The statements below give an overview on Smart City guiding principles, as defined by British Standard Institute (BSI):

    - Establish a clear, compelling and inclusive vision for the city.
    - Take a citizen-centric approach to all aspects of service design and delivery.
    - Enable a ubiquitous, integrative and inclusive digitization of city spaces and systems.
    - Embed openness and sharing in the way the city works.

    Another interesting view on Smart City principles comes from the Urban Technologist Blog [29], where over twenty Smart City design principles for digital urbanism are identified. The author argued that an overarching set of five to ten principles would be much more useful in defining an approach to smarter cities that could be broadly adopted.

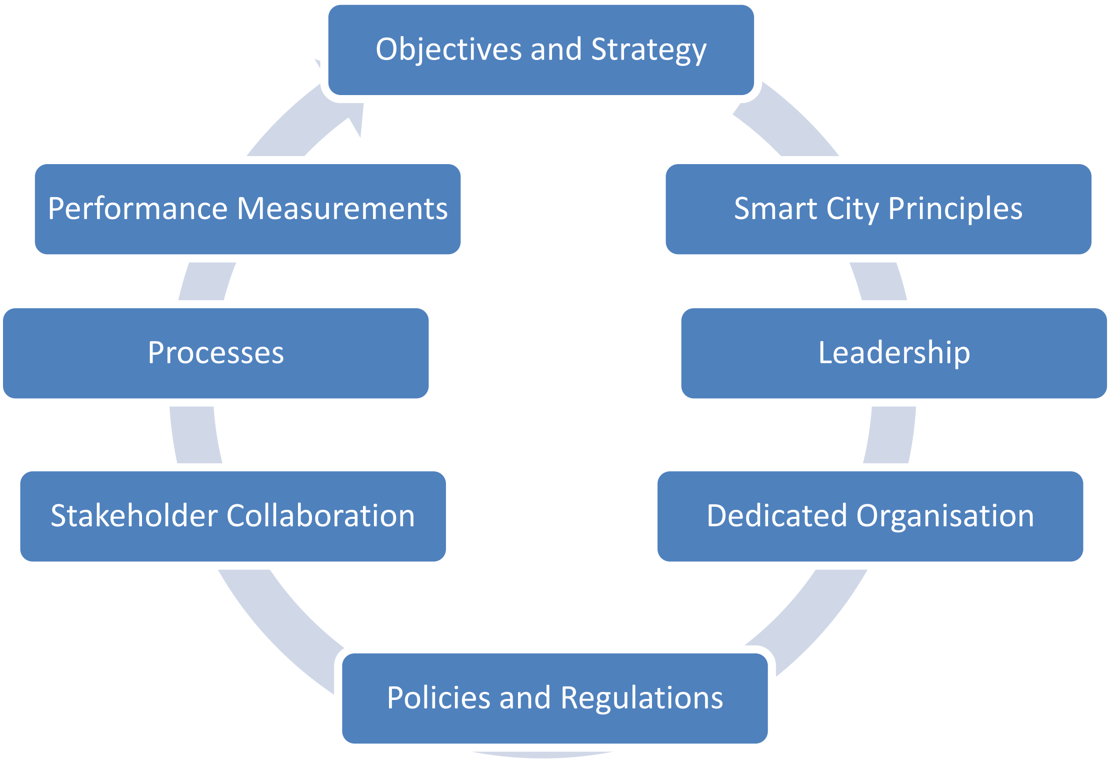

Figure 6: Smart City Governance Model

3) **Leadership**: The leadership engagement is important for Smart City initiatives/programs. Such engagement might include leadership by city mayor and/or by different city department's director, as a broad-based, cross-sectoral leadership team. Smart City leadership needs to identify specific governance and institutional mechanisms to address the challenges and critical success factors of Smart City initiatives/programs. Furthermore, the leadership should ensure an open and transparent governance process through public participation.

4) **Dedicated Organization / Dedicated Research and Think-tank Institution:** Creation of a dedicated Smart City team formed with diverse roles and skills is essential to promote Smart City development, ensure long-term implementation of city plans and to oversee the coordination of management processes and performance management of Smart City initiatives/programs. Such a team can be part of a dedicated organization or research and think-tank institution, and be recognized by city's agencies [2] [4].

5) **Policies and Regulations:** Policy and regulation actions include master-planning, providing certification for different types of practices or activities, institutional development, license regulations, promotional activities and development of framework acts.

6) **Stakeholder Collaboration**: Stakeholder involvement is a critical success factor for Smart City initiatives/programs. This can be managed through the establishment of a stakeholder engagement program, covering stakeholder participation, cross-sectoral partnership and engagement with other cities to learn lessons and exchange experience.

7) **Smart City Development/ Management Processes**: These include standard planning, development and post-implementation processes defined with clear role and responsibility with stakeholder involvement.

8) **Performance Measurement:** This includes Smart City performance criteria defined and used by the city agencies and the Smart City dedicated team.

As discussed in [3], the above-mentioned elements can further serve as criteria for analyzing the maturity level of a Smart City governance model.

5.4.2 Business Procedures, Billing and Charging

The aspects of Billing and Charging are of extreme importance for business models within a Smart Cities eco-system. In that line of thoughts, various business procedures stemming from the belonging business models need to be established on top of the ICT reference architecture.

In general, it is possible to monetize the use of (mobile) apps, services, and data. The apps is paid for when accessing the app stores. The service can be paid for based on different models, which are established in the SaaS (Software as a Service) domain, like pay per service call/invocation. For the data, billing and charging models from the traditional telecommunications domain can employed. This includes flat rate type of payment models, pay per volume, pre-paid etc.

To summarize: the usage of approaches for billing and charging as well as the presence of business activities and processes around the ICT reference architecture, will support the implementation of business models that will create the possibility for generating revenue for companies.

5.5 ICT Reference Architecture: Management and Security part of the Technical View

This section provides an overview about security and management aspects w.r.t the ICT Reference Architecture.

Security has to be considered across multiple domains and includes aspects such as authentication, authorization, identity management and privacy. Therefore, security is correspondingly represented across all layers in Figure 4. For a better understanding and for clarifying the differences, authentication and authorization shall be defined. Authentication describes the process of determining if an entity is what it is declared to be, whereas authorization tries to determine if an entity has the access rights for a specific resource. A few authentication and authorization systems shall be described, w.r.t its complexity and the technologies used.

Kerberos, which is currently available in version 5, is a ticket-based-system that allows secure authentication over a non-secure network [16] [17]. Kerberos is based on three entities: the client, the server and a dedicated Kerberos server [17]. The client wants to access resources/services on a server, which is secured by Kerberos. The dedicated Kerberos server provides an authentication service and a Ticket Granting Service (TGS). It authenticates both client and server and vice versa, whereas the TGS creates and verifies tickets in the authentication process.

OpenID is a decentralized authentication system for web-based services [14]. It is based on three entities: the principal (the user), the relying party and the OpenID provider [14]. As a first step, the principal registers with an OpenID Provider and receives his OpenID, which typically is an URL. With the help of this OpenID the principal can authenticate itsself against a relying party. During the login approach, the relying party redirects the principal to the OpenID provider that authenticates the user. After a successful authentication, the principal is redirected to the relying party, which can be used by the principal. It is important to stress that the relying party does not have any knowledge about the username and password of the principal.

The Security Assertion Markup Language (SAML) is an XML-based framework for authentication and authorization that has been developed by the Security Services Committee from the Organization for the Advancement of Structured Information Standards (OASIS) [11] [12]. Its functionality is similar to the previously described protocols. SAML is widely used in the context of Web Single-Sign-On [11].

OAuth is an open standard for authorization that is currently available in version 2.0 [9]. It is widely spread and major organizations like Google, Twitter and Facebook provide APIs based on OAuth. The whole communication in the protocol is based on HTTP requests and thus, the complexity of OAuth is low. Furthermore, OAuth is quite light weighted, because all security aspects are delegated to the transport layer (e.g. SSL/TLS). As a result, the usage of TLS is mandatory to avoid man-in-the-middle attacks.

The combination of OpenID and OAuth provides a sophisticated solution for authentication, authorization and identity management. With OpenID Connect the OpenID Foundation built an identity layer on top of OAuth [15]. On the other hand, devices that generate and collect data should authenticate against each other too. Both devices should negotiate a common protocol, which can be used later on.

Privacy is another key aspect of security, because many valuable data will be transferred within a Smart City. Aspects like data anonymization and adding noise to the data should be addressed.

Similar to security, management has to be considered across multiple domains and thus, is correspondingly depicted across all layers in Figure 4. Management consists of many different aspects such as monitoring of devices and networks, configuration, data management and reporting.

On the lower layers (e.g. data sources layer and communication layer in Figure 4), we need to have the possibility to configure various, heterogeneous devices and networks. This includes characteristics such as hostnames, routing, quality of service et cetera. Furthermore, it should be possible to track changes in the configuration settings. In case of a faulty configuration it is possible to revert to a functioning configuration. Therefore, one can increase the availability of services and the overall stability. Fault detection and the analysis of faults are other important aspects and should be included in the management suite. It should be possible to react to different faults in an appropriate way, including changing the configuration of devices and/or networks.

There are many different entities in a Smart City, including sensors, smart meters, applications, users et cetera. It should be possible to access information about these entities with some kind of data management. Typically, information about these entities would be stored in some kind of database, including current state, relations between devices, authorization and access rights. It should be feasible to retrieve or update information about any entity at any given time.

As a last consideration, it should be possible to generate reports about the current state of the devices, the network, currently active users or the whole system, since reports about non-functional aspects like security, stability and availability are important for all stakeholders. Additionally, a history of reports should be available too. Thus, it will be possible to highlight changes in the whole system, for example throughput variation between devices.

6 Instantiation of ICT Reference Architecture

This section describes a possible instantiation of ICT Reference Architecture concerning electric charging and electric mobility. General architectural aspects, including dynamic aspects, and a user perspective scenario are be described.

As described in the previous sections, different data sources can be integrated in the ICT Reference architecture. In this particular scenario, this data may include Map Resources, Governmental Road Data, Vehicle Provider Data, et cetera. These various types of data are integrated and offered over servers in the *Virtualization/Data Processing* sub-layer of the Reference Architecture, such that applications/services can be eventually developed on top of it (see Applications/Services in Figure 4, which resides on top of the Data Processing and Analysis layer).

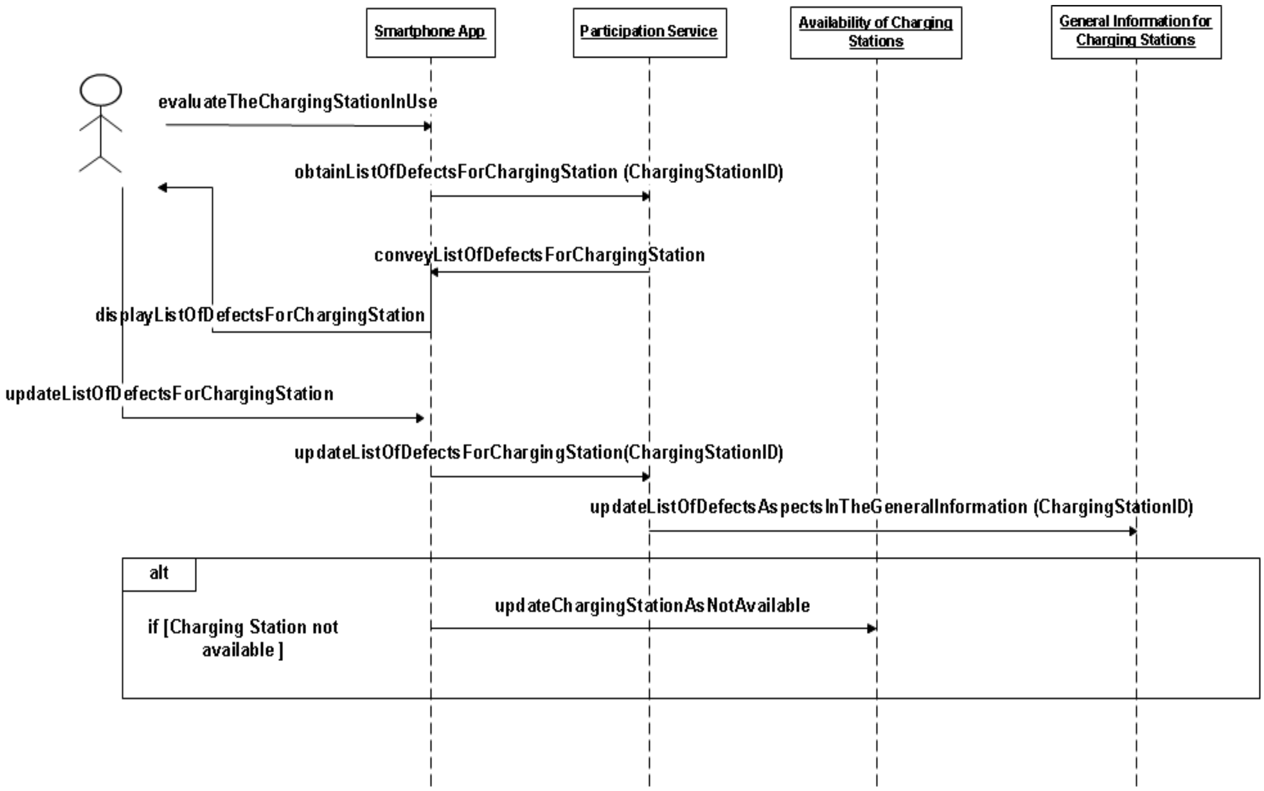

Figure 7: Interaction Flow for realizing participation for electric mobility [68]

Figure 7 illustrates an example of an interaction flow that utilizes the *Applications/Service* layer of ICT reference architecture for the purpose of end user participation for the evaluation of a charging station in the scope of electric mobility. The prerequisite that a customer has just charged the battery of an electric vehicle at a charging station is not illustrated.

Figure 7 captures the flow required for the customer in order to evaluate the charging station and/or submit a complaint. The interaction flow is based on three fictitious services: *Participation* service *Availability of Charging Stations* service and *General Information for Charging* service. These services would reside in the

Applications/Service Layer of the reference architecture (see Figure 4 on page 21). Thereby, the customer uses a smartphone app that communicates (*obtainListOfDefectsForChargingStation*) over the mobile network (3G/4G) with the *Participation Service* [68]. It returns the list of defects for the charging station in question (*conveyListOfDefectsForChargingStation*). These defects would be normally stored on a server residing in the *Virtualization/Data Processing* layer of the ICT reference architecture. This list of defects is presented to the user, such that she/he can check it and update it if needed. The possibly renewed list of defects is communicated by the smartphone app back to the Participation Service (*updateListOfDefectsForChargingStation*). Thereupon, the Participation Service updates the general information for the charging station in question by linking the updated list to the general charging station data over the *General Information Charging Stations* service (*updateListOfDefectsAspects-InTheGeneralInformation*) [68]. Lastly, in case the charging station was marked as damaged and unusable by the customer, its availability is updated (*updateChargingStation-AsNotAvailable*) over the *Availability of Charging Stations Service*.

The above-described sequence demonstrates only a minor part of the dynamic aspects of the reference architecture utilization for electric mobility in a lighthouse city, such as Eindhoven. The following paragraph elaborates the user perspective of a complete electric mobility scenario, which would benefit from an ICT reference architecture.

The subsequent figures describe the user perspective of the reference architecture utilization for the purpose of electric mobility in Smart Cities.

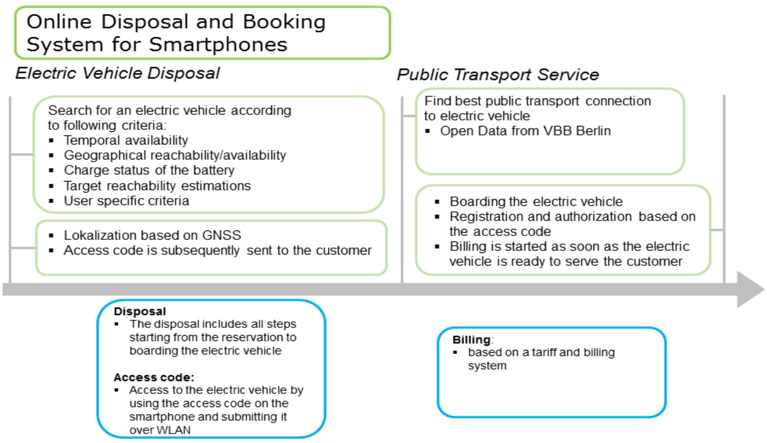

Figure 8: Accessing and Electric Vehicle over the ICT Reference Architecture [68]

Figure 8 describes the required steps in the scope of the disposal and reservation of an electric vehicle over a smartphone. The descriptions above the arrow elaborate the process itself, whilst the explanations underneath the arrow clarify on aspects of this process [68]. The user experience starts with the search for an electric vehicle according to a number of criteria, such as geographical reachability, temporal availability, target reachability estimations and other user specific criteria. Thereby, the user (belonging to the *User Layer*) must have obtained a corresponding app (*Market Layer*). The app and the services (*Application/Services* layer from the architecture) behind consume data which has been processed and prepared within the *Data Processing and Analysis* layer underneath and was obtained and centrally pooled over the *Data Sources* and the *Communication Layer* of the ICT reference architecture.

Once an appropriate electric vehicle has been found and reserved by the customer, an access code is generated by the corresponding service and sent back to the customer's smartphone. This access code is later used during the WLAN communication between smartphone and the electric vehicle in order to unlock it. Having reserved an electric vehicle, the customer/user has to reach it. This can be done by creating and using a service for public transport information (once more, this would be a service in the *Applications/Service* layer in Figure 8). After reaching the electric vehicle, the customer boards it and can begin her/his journey.

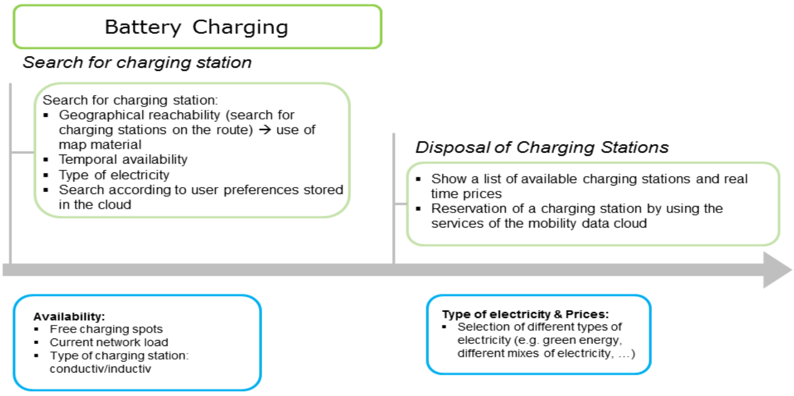

Figure 9: Support for Battery Charging over over the ICT Reference Architecture [68]

Depending on the battery charge condition, it may be required that the customer uses a charging station. In this case, the customer would need to go through the steps described in Figure 9. First, a charging station needs to be searched for over the app on the customer's smartphone. As in the case of the electric vehicle disposal, various constraints would need to be considered, such as geographical reachability, temporal availability, type of electricity (e.g. percentage of green energy). The search could be conducted over an *Availability of Charging Stations* service in the *Applications/Service* layer of the ICT Reference Architecture (as described previously), and a list of charging stations matching the customer's criteria is displayed on the customer's smartphone. The belonging data would have been again prepared, offered and gathered over the various layers under the *Applications/Service* layer of the ICT reference architecture, i.e. *Data Processing and Analysis* layer, *Communication* layer, and *Data Sources* layer.

Based on the list of charging stations, a suitable one is reserved over a *Charging Station Reservation Service*, and the charging of the vehicle's battery can be triggered as soon as the customer arrives at this station.

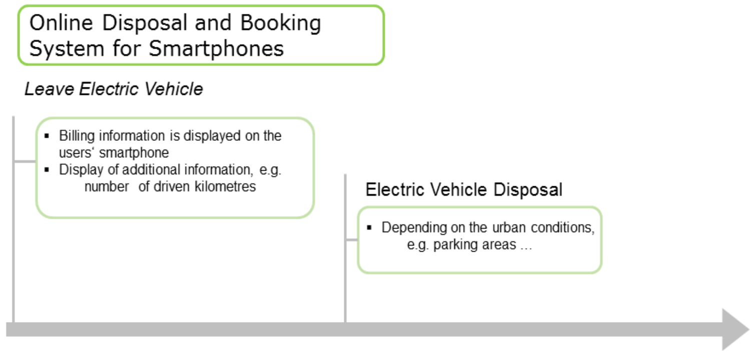

Figure 10: Electric Vehicle Disposal [68]

The last step in the presented utilization is constituted by the disposal of the electric vehicle. This is described in Figure 10, and consists of the customer leaving the electric vehicle and receiving the billing information for the time she/he has been using the vehicle. This information is displayed on the customer's smartphone and requires to be confirmed by the end user. Moreover, the disposal takes place in compliance to additional information/constraints, such as parking lots and various urban conditions (e.g. parking taxes etc.).

The scenario presented here, even though far from capturing all possible use cases and flows, exemplifies how a customer would use the reference architecture in the scope of collaborative electric mobility.

7 Related Work: Smart Cities Architectures & Standards

Next, the presentation focuses on key state-of-the-art research efforts and solutions, which are of interest for the proposed ICT Reference Architecture. Thereby, existing ICT architectures of relevance for the Smart Cities domain are presented, followed by elucidations on relevant standards.

7.1 Review of Existing ICT Architectures

The current section captures some of the more interesting works of the past years according to our perception. In general, a decent amount of research and development efforts was reviewed and key properties were captured in a corresponding structured manner (i.e. template). The belonging results are listed in detail in Appendix B. The rest of this sub-section gives an overview of some of these works.

In recent past, several attempts to implement a formal architecture to guide the design of Smart Cities have been made. Correspondingly, this section gives an overview of existing internet and communication technology architectures in context of Smart Cities. Relevant information like level of detail, technical aspects, interfaces, data sources or use cases are mentioned and shall help to classify each approach and depict it briefly.

In Informatics Economica Journal volume 16.4 [69], Liviu Gabriel Cretu proposes the Event-driven Smart Cities Architecture (EdSC) as a high-level approach towards a reference model for Smart Cities. The Smart Community Space serves as the core of EdSC. The key concepts of the EdSC are events, listeners and data. These concepts build a rule based system and allow the Internet of Things, the Internet of Services, the Internet of people and the Internet of data to connect and interoperate with one another. The data model uses RDF, OWL, RIF (Rule Interchange Format) and SPARQL for data representation and interchange. As mentioned beforehand, EdSC only serves as an initial reference model. Thus, aspects like applications, use cases or legacy system integration are not (yet) specified. Both interface- and API-description remain high level. Although not explicitly specified, suitable data sources for EdSC may be sensors, smart devices, people and services. The proposed architecture is highly entangled with technical aspects like Linked Open Data, Ontologies and Cloud Based Systems. No deployment based on EdSC has been carried out so far.

The Internet Connected Objects for Reconfigurable Ecosystem Architecture (iCORE) [70] is a 3-layer architecture designed to speed up the creation, deployment and execution of IoT services and applications. This 3-layer architecture uses abstractions and virtualization to control and use both platform functionalities and real world objects. The iCore Service Level's main purpose is the leveraging of so-called Real World Knowledge to enhance execution efficiency, the effectiveness and the situation awareness of services. It is the top-level layer in the iCore architecture. The iCore Composite Virtual Object Level executes the services provided by the service layer in respect to potential system resource concerns. The task of the iCore Virtual Object Level is to unify the heterogeneity of connected equipment, sensors and actuators by establishing so-called virtual objects as a virtual counterpart of the real object and interfaces towards upper iCore level. The iCore architecture makes use of semantic web technologies, sensor networks and open data. XML is suggested as the preferred data format. In line with the architecture, plenty of use cases like “smart home living assistant”, “smart urban security” or “Smart City transport” have been established. The iCORE architecture has been deployed as a testbed. The applied use cases and their execution can be considered as valuable lessons learned.

In *Smart Cities at the Forefront of the Future Internet* [71], a holistic approach for a unified urban ICT infrastructure is proposed. It shall be capable of sustainable economic growth and the management of complex interdependent urban systems. Further, on, three key functionalities of such infrastructure are identified. An Urban Communications Abstraction is intended to decrease inefficiency caused due the heterogeneity of existing or new communication infrastructures. As a consequence, the Unified Urban Information Model is needed to allow the interchange of data and information between different services and applications. Finally, the Open Urban Services Development shall provide open, flexible and easy-to-use interfaces, both on application and service level to attract public and private investments.

The ITU-T’s Ubiquitous Sensor Network (USN) addresses similar characteristics and serves as an example for a generic implementation. It uses Sensor Modeling language (SensorML) and Open Geospatial Consortium O&M language for data interchange. Potential data sources are sensors and governmental data. Even if there is no deployment scheduled for this architecture, use cases within the scope of the *SmartSantander Project* are available.

The Smart City Framework (SCF) [73] defines a high-level framework for Smart City projects. It forms the basis of the CityPulse project and shall serve as a reference model with defined interfaces. Technical aspects cover Open Data, Data Portals, Sensor Networks as well as Linked Data. XML or a comparable machine-readable format is suggested for data representation. The data is supplied by sensors, governmental data and social networks. SCF is neither deployed nor does it propose any applications, use cases or domains. Since SCF is mainly considered to be a framework instead of a concrete system architecture, the presented views are limited to functional view, interface and information view, as well as security and privacy view.

IBM’s Smart City Info Architecture and Functional Platform [74] describes an architecture based on the WebSphere Application Server. It considers both data portals and sensor networks as underlying technical aspects. A detailed description of the platform’s architecture, relevant aspect applications, use cases, interfaces, APIs and data models are not or not explicitly defined. However, in the Context of the EPIC Project, the architecture has been instantiated and deployed within a testbed.

In contrast to all other considered approaches, Nicos Komninos [75] does not focus on the architecture and the components of Smart Cities, but on the planning process itself. He introduces a holistic approach that allows a user-centric evolvement of Smart Cities. This approach consists of seven steps distributed in three stages and is designed to integrate the three major components of Smart Cities – urban space, innovation ecosystem and digital or smart environment. It is considered to be rather a strategic roadmap than an architecture addressing structural and technical aspects. The proposed roadmap has been utilized in a district in the city of Thermi (Greece) addressing use cases like smart market places, air pollution and available parking.

For further details, the reader is referred to Appendix B, where a list of structured reviews (using a particular template) is available.

7.2 Standards

The complexity of the different areas, domains, infrastructures, organizations and activities within a city or community has turned out to be a huge challenge for standardization work groups. The IEC SEG 1 Systems Evaluation Group – Task Group "Reference Architecture Model" had the task to develop a holistic reference architecture for a city. The objective of this model was to describe all key elements, actors and stakeholders relating the aspects of the Smart City in a precise and understandable way. Until today the group was only able to list necessary requirements for such a model.

Although standards could help cities to connect formerly independent solutions, there is no standardization activity for ICT reference architectures for Smart Cities so far. This chapter shall therefore give a broad overview on existing international and European standards and standards under development for relevant aspects of ICT reference architectures. The structure of this part corresponds to the different layers of the reference architecture.

7.2.1 Communication Layer

The following table presents some key standards on the Communication Layer.

Table 1: Standards on the Communication Layer

Sensing Technology	
Standard	**Description**
ISO/IEC 29182	The purpose of the ISO/IEC 29182 series is to provide guidance to facilitate the design and development of sensor networks, improve interoperability of sensor networks, and make sensor network components plug-and-play, so that it becomes fairly easy to add/remove sensor nodes to/from an existing sensor network.
ISO/IEC 20005:2013	ISO/IEC 20005:2013 specifies services and interfaces supporting collaborative information processing (CIP) in intelligent sensor networks which includes: CIP functionalities and CIP functional model, common services supporting CIP, common service interfaces to CIP.
ISO/IEC 20005:2013	ISO/IEC 20005:2013 specifies services and interfaces supporting collaborative information processing (CIP) in intelligent sensor networks which includes: CIP functionalities and CIP functional model, common services supporting CIP, common service interfaces to CIP.
ISO/IEC 30101:2014	ISO/IEC 30101:2014 is for sensor networks in order to support smart grid technologies for power generation, distribution, networks, energy storage, load efficiency, control and communications, and associated environmental challenges. This International Standard characterizes the requirements for sensor networks to support the aforementioned applications and challenges. Data from

	sensors in smart grid systems is collected, transmitted, published, and acted upon to ensure efficient coordination of the various systems and subsystems. The intelligence derived through the sensor networks supports synchronization, monitoring and responding, command and control, data/information processing, security, information routing, and human-grid display/graphical interfaces. This International standard specifies interfaces between the sensor networks and other networks for smart grid system applications, sensor network architecture to support smart grid systems, interface between sensor networks with smart grid systems, and sensor network based emerging applications and services to support smart grid systems.
ISO/IEC 30128:2014	ISO/IEC 30128:2014 specifies the interfaces between the application layers of service providers and sensor network gateways, which is Protocol A in interface 3, defined in ISO/IEC 29182-5. This International Standard covers description of generic sensor network applications' operational requirements, description of sensor network capabilities, and mandatory and optional interfaces between the application layers of service providers and sensor network gateways
Wireless Transmission	
ISO/IEC/IEEE FDIS 8802-A	ISO/IEC/IEEE 8802-11:2012 defines one medium access control (MAC) and several physical layer (PHY) specifications for wireless connectivity for fixed, portable, and moving stations (STAs) within a local area.
ISO/IEC 9798-6:2010	SO/IEC 9798-6:2010 specifies eight entity authentication mechanisms based on manual data transfer between authenticating devices. Four of these mechanisms are improved versions of mechanisms specified in ISO/IEC 9798-6:2005 since they use less user input and achieve more security. Such mechanisms can be appropriate in a variety of circumstances where there is no need for an existing public key infrastructure, shared secret keys or passwords. One such application occurs in personal networks, where the owner of two personal devices capable of wireless communications wishes them to perform an entity authentication procedure as part of the process of preparing them for use in the network. These mechanisms can also be used to support key management functions. ISO/IEC 9798-6:2010 specifies mechanisms in which entity authentication is achieved by • manually transferring short data strings from one device to the other, or • manually comparing short data strings output by the two devices. In ISO/IEC 9798-6:2010, the meaning of the term entity authentication is different from the meaning applied in other parts of ISO/IEC 9798. Instead of one device verifying that the other device has a claimed identity (and vice versa), both devices in possession of a user verify that they correctly share a data string with the other device at the time of execution of the mechanism. This data string could contain identifiers (and/or public keys) for one or both of the devices.
SO/IEC 29180:2012	The recent advancement of wireless-based communication technology and electronics has facilitated the implementation of a low-cost, low-power sensor network. Basically, a ubiquitous sensor network (USN) consists of three parts: a sensor network consisting of a large number of sensor nodes, a base station (also known as a gateway) interfacing between the sensor network and an application server, and the application server controlling the sensor node in the sensor

	network or collecting the sensed information from the sensor nodes in the sensor network. ISO/IEC 29180:2012 describes the security threats to and security requirements of the USN. In addition, it categorizes the security technologies according to the security functions that satisfy the said security requirements and where the security technologies are applied in the security model of the USN. Finally, the security functional requirements and security technologies for the USN are presented.
EN 13757	Communication systems for meters and remote reading of meters
CEN/TR 16674:2014	The scope of this Technical Report (TR) is to identify methodologies that are used for, or have been considered applicable to, wireless technologies. These methodologies are analyzed to identify features that are applicable to RFID. Based on the Industry RFID PIA Framework endorsed by the Article 29 Data Protection Working Party, the Technical Report focuses on proposing risk analysis methodologies suitable for the data capture area of an RFID system. This includes the RFID tag, the interrogator, the air interface protocol used for communication between them, and the communication from the interrogator to the application. The Technical Report also proposes risk management features based on the inherent capabilities of a number of RFID technologies that conform to standardized RFID air interface protocols. This should provide enough information to enable the proposed privacy control features to be applied to other RFID technologies including those with proprietary air interface protocols and tag architectures. The risk management features exclude fundamental privacy by design features because these should be the subject of revisions and enhancements to technology standards. The risk management features defined in this Technical Report are considered applicable to current and future implementations of RFID based on existing technology. As such, this Technical Report is considered as input into a standard procedure for undertaking an RFID Privacy Impact Assessment.

7.2.2 Data Layer

The following table presents some key standards on the Data Layer.

Table 2: Standards on the Data Layer

Cloud Technology	
ISO/IEC 27017	Guidange on the information security elements of cloud computing, recommending and assisting with the implementation of cloud-specific information security controls supplementing the guidance in ISO/IEC 27002 and indeed other ISO27k standards including ISO/IEC 27018 on the privacy aspects of cloud computing, ISO/IEC 27031 on business continuity, and ISO/IEC 27036-4 on relationship management, as well as all the other ISO27k standards.
ISO/IEC 27018	This standard provides guidance aimed at ensuring that cloud service providers (such as Amazon and Google) offer suitable information security controls to protect the privacy of their customers' clients by securing PII (Personally Identifiable Information) entrusted to them.
ISO/IEC 27001	formally defines the mandatory requirements for an Information Security Management System (ISMS). It uses ISO/IEC 27002 to indicate suitable information security controls within the ISMS, but since ISO/IEC 27002 is merely a code of practice/guideline rather than a certification standard, organizations are free to select and implement other controls, or indeed adopt alternative complete suites of information security controls as they see fit. ISO/IEC 27001 incorporates a summary (little more than the section titles in fact) of controls from ISO/IEC 27002 in Annex A. In practice, most organizations that adopt ISO/IEC 27001 also adopt ISO/IEC 27002.
ISO/IEC 27002	Like governance and risk management, information security management is a broad topic with ramifications throughout all organizations. Information security, and hence ISO/IEC 27002, is relevant to all types of organization including commercial enterprises of all sizes (from one-man-bands up to multinational giants), not-for-profits, charities, government departments and quasi-autonomous bodies - in fact any organization that handles and depends on information. The specific information security risk and control requirements may differ in detail but there is a lot of common ground, for instance most organizations need to address the information security risks relating to their employees plus contractors, consultants and the external suppliers of information services. The standard is explicitly concerned with information security, meaning the security of all forms of information (e.g. computer data, documentation, knowledge and intellectual property) and not just IT/systems security or "cybersecurity" as is the fashion of the day.
CWA 16871-1	Requirements and Recommendations for Assurance in Cloud Security. Contributed recommendations from European projects
Data Storage	
ISO/IEC 27040	The purpose of ISO/IEC 27040 is to provide security guidance for storage systems and ecosystems as well as for protection of data in these systems. It supports the general concepts specified in ISO/IEC 27001.

Data Processing	
ISO/TR 9007:1987	Information processing systems - Concepts and terminology for the conceptual schema and the information base.
ISO/IEC TR 10032:2003	ISO/IEC TR 10032:2003 defines the ISO Reference Model of Data Management. It establishes a framework for coordinating the development of existing and future standards for the management of persistent data in information systems. ISO/IEC TR 10032:2003 defines common terminology and concepts pertinent to all data held within information systems. Such concepts are used to define more specifically the services provided by particular data management components, such as database management systems or data dictionary systems. The definition of such related services identifies interfaces which may be the subject of future standardization. ISO/IEC TR 10032:2003 does not specify services and protocols for data management. ISO/IEC TR 10032:2003 is neither an implementation specification for systems, nor a basis for appraising the conformance of implementations. The scope of ISO/IEC TR 10032:2003 includes processes which are concerned with handling persistent data and their interaction with processes particular to the requirements of a specific information system. This includes common data management services such as those required to define, store, retrieve, update, maintain, backup, restore and communicate applications and dictionary data. The scope of ISO/IEC TR 10032:2003 includes consideration of standards for the management of data located on one or more computer systems, including services for distributed database management. ISO/IEC TR 10032:2003 does not include within its scope common services normally provided by an operating system including those processes which are concerned with specific types of physical storage devices, specific techniques for storing data, and specific details of communications and human computer interfaces.
95/46/EG	Directive 95/46/EC of the European Parliament and the Council on the protection of individuals with regard to the processing of personal Data and on the free movement of such data.
EC 45/2001	Regulation (EC) No 45/2001 of the European Parliament and of the Council on the protection of individuals with regard to the processing of personal data by the Community institutions and bodies and on the free movement of such data.
2002/58/EC	Directive 2002/58/EC concerning the processing of personal data and the protection of privacy in the electronic communication sector (Directive on privacy and electronic communications).

7.2.3 Application Layer

Application Layer	
ISO/IEC 9545:1994	Refines the description of the application layer contained in the basic reference model for OSI (ITU-T Rec. X.200 / ISO/IEC 7498-1). Provides a framework for coordinating the development of existing and future application layer recommendations and standards. Is provided for reference by application layer

	recommendations and standards. The purpose is to facilitate a coherent and modular approach to the structuring of specifications for application layer behaviour.
ISO/IEC 13249	Information technology - Database languages - SQL multimedia and application packages
ISO/IEC 27034	ISO/IEC 27034 offers guidance on information security to those specifying, designing and programming or procuring, implementing and using application systems, in other words business and IT managers, developers and auditors, and ultimately the end-users of ICT. The aim is to ensure that computer applications deliver the desired or necessary level of security in support of the organization's Information Security Management System, adequately addressing many ICT security risks.
ISO/IEC 30128:2014	ISO/IEC 30128:2014 specifies the interfaces between the application layers of service providers and sensor network gateways, which is Protocol A in interface 3, defined in ISO/IEC 29182-5. This International Standard covers - description of generic sensor network applications' operational requirements, - description of sensor network capabilities, and - mandatory and optional interfaces between the application layers of service providers and sensor network gateways

7.2.4 Data Security

The following table presents some key standards related to aspects of Data Security.

Table 3: Standards related to Data Security

Data Security	
ISO/IEC JTC 1/SC 27	ISO/IEC JTC 1/SC 27 IT Security techniques is a standardization subcommittee of the Joint Technical Committee ISO/IEC JTC 1 of the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC), that develops and facilitates International Standards, Technical Reports, and Technical Specifications within the field of IT security techniques.
ISO/IEC 27001:2013	ISO/IEC 27001 is an internationally recognized best practice framework for an information security management system. It helps you identify the risks to your important information and put in place the appropriate controls to help reduce the risk.
ISO/IEC 27002:2013	ISO/IEC 27002:2013 gives guidelines for organizational information security standards and information security management practices including the selection, implementation and management of controls taking into consideration the organization's information security risk environment(s). It is designed to be used by organizations that intend to: 1. select controls within the process of implementing an Information Security Management System based on ISO/IEC 27001; 2. implement commonly accepted information security controls; 3. develop their own information security management guidelines.

ISO/IEC 15408	ISO/IEC 15408-1:2009 establishes the general concepts and principles of IT security evaluation and specifies the general model of evaluation given by various parts of ISO/IEC 15408 which in its entirety is meant to be used as the basis for evaluation of security properties of IT products. It provides an overview of all parts of ISO/IEC 15408. It describes the various parts of ISO/IEC 15408; defines the terms and abbreviations to be used in all parts ISO/IEC 15408; establishes the core concept of a Target of Evaluation (TOE); the evaluation context; and describes the audience to which the evaluation criteria are addressed. An introduction to the basic security concepts necessary for evaluation of IT products is given. It defines the various operations by which the functional and assurance components given in ISO/IEC 15408-2 and ISO/IEC 15408-3 may be tailored through the use of permitted operations. The key concepts of protection profiles (PP), packages of security requirements and the topic of conformance are specified and the consequences of evaluation and evaluation results are described. ISO/IEC 15408-1:2009 gives guidelines for the specification of Security Targets (ST) and provides a description of the organization of components throughout the model. General information about the evaluation methodology is given in ISO/IEC 18045 and the scope of evaluation schemes is provided.
ISO/IEC 29100:2011	ISO/IEC 29100:2011 provides a privacy framework which • specifies a common privacy terminology; • defines the actors and their roles in processing personally identifiable information (PII); • describes privacy safeguarding considerations; and • provides references to known privacy principles for information technology. ISO/IEC 29100:2011 is applicable to natural persons and organizations involved in specifying, procuring, architecting, designing, developing, testing, maintaining, administering, and operating information and communication technology systems or services where privacy controls are required for the processing of PII.
ISO/IEC 29101:2013	ISO/IEC 29101:2013 defines a privacy architecture framework that • specifies concerns for information and communication technology (ICT) systems that process personally identifiable information (PII); • lists components for the implementation of such systems; and

	• provides architectural views contextualizing these components. ISO/IEC 29101:2013 is applicable to entities involved in specifying, procuring, architecting, designing, testing, maintaining, administering and operating ICT systems that process PII. It focuses primarily on ICT systems that are designed to interact with PII principals.
ISO/IEC TS 30104:2015	Physical security mechanisms are employed by cryptographic modules where the protection of the modules sensitive security parameters is desired. ISO/IEC TS 30104:2015 addresses how security assurance can be stated for products where the risk of the security environment requires the support of such mechanisms. This Technical Specification addresses the following topics: - a survey of physical security attacks directed against different types of hardware embodiments including a description of known physical attacks, ranging from simple attacks that require minimal skill or resources, to complex attacks that require trained, technical people and considerable resources; - guidance on the principles, best practices and techniques for the design of tamper protection mechanisms and methods for the mitigation of those attacks; and - guidance on the evaluation or testing of hardware tamper protection mechanisms and references to current standards and test programs that address hardware tamper evaluation and testing. The information in ISO/IEC TS 30104:2015 is useful for product developers designing hardware security implementations, and testing or evaluation of the final product. The intent is to identify protection methods and attack methods in terms of complexity, cost and risk to the assets being protected. In this way cost effective protection can be produced across a wide range of systems and needs.
ISO/IEC 30111:2013	ISO/IEC 30111:2013 gives guidelines for how to process and resolve potential vulnerability information in a product or online service. ISO/IEC 30111:2013 is applicable to vendors involved in handling vulnerabilities.
EC	The Charter of Fundamental Rights recognises a range of personal, civil, political, economic and social rights of EU citizens and residents, enshrining them into EU law.
2006/24/EC	Directive 2006/24/EC of the European Parliament and of the Council on the retention of data generated or processed in connection with the provision of publicly available electronic communications services or of public communications networks and amending Directive 2002/58/EC

8 Conclusions & Next Steps

The current document presented our considerations regarding the topic of an ICT Reference architecture for Smart Cities, which were discussed and worked out in the first six months of the Triangulum project. The goal of such an architecture is to provide an abstract model for complex, distributed and integrative ICT solutions, which should be at the heart of Smart Cities.

Especially, within the Triangulum project, the goal of such an ICT architecture is to provide a unified reference platform, based on which different ICT products can be combined and solutions can be created based on the needs of the different stakeholders. The platform is further expected to enable the creation of eco-systems of products and business models, which can bring sustainable solutions for various urban domains (e.g. Energy, Mobility, Building Automation …).

Data is at the heart of the proposed ICT reference architecture. For that reason a classification of data sources is conducted and the reference architecture is motivated in a way as to define components along the paths on which data is processed thereby involving various technological layers – starting from sensor networks and reaching to data portals/platforms and mobile applications/services on top. Seeing data as the key enabler for Smart Cities allows specifying different abstract components and layers around it, thereby addressing the different needs. Therefore, the proposed architecture comes with different views on its core, which include the Technical, Information and Organizational perspectives. The current document deals with each of these perspectives and explains the relations among the various abstract layers, components and concepts. Finally, a case study is presented which shows the instantiation of the proposed ICT reference architecture for an integrated and distributed solution from the domain of Mobility.

With respect to further steps: The architecture will be subsequently refined in a series of discussions with the relevant stake-holders in the lighthouse and follower cities. The goal is to meet all the ICT needs of the solutions which are emerging within Triangulum whilst at the same time accommodating as many as possible of the existing legacy solutions. For the latter, a template was prepared (please refer to Appendix C), which will allow capturing the key characteristics of a legacy ICT solution and potentially adapting the reference architecture accordingly. In that line of thoughts, the ultimate goal is to have an abstract model that will enable the replication and interoperability of ICT solutions among the lighthouse and follower cities within Triangulum.

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Appendix A

Table 4: Examples of Sensor Networks providing (real-time) Data Streams in Cities across the World

Area	Application	Source	Recording	RT	Format	Public
Mobility	Public Transport Arrivals App (VBB Livekarte[5])	GPS in Busses and Trains, Shedules provided by company	Location, Manual	yes	MR[6]	yes
	PT Smart Ticketing Info, Redirecting/Multi-modal Route Planning, Peak Hour Statistics	"Smart Dust" in trains	Distance, Acoustic, Vibrations	yes	MR	yes
	Smart Traffic Lights Control, Car Route Planning according to Occupancy, Navigation	"Smart Dust"[7] in pavement	Vibrations, Magnetic Field, Acoustic, Velocity, Material Type	yes	MR	yes
		CCTV, Smartphone GPS	Visual, Location	yes	MR	no
	Carsharing (Zipcar[8])	Sensors on rental sites	Manual (Slots), Internal (Availability)	yes	MR	yes
	Parking Space Monitoring (SfPark[9])	Sensors on parking space	Distance, Light		MR	yes
	Bike-Rental-Info (Nextbike[10], Call a bike[11])	Sensors on rental sites	Manual (Slot location), Internal (Availability)	yes	MR	yes
	Event Detection, Crowd Monitoring	"Smart Dust" in pavement	Vibrations, Distance, Acoustic, Velocity	yes	MR	yes

5

6 MR = machine readable, HR = human readable

7 Smart dust are tiny devices of a size in the scales of millimeters, which can record a multitude of properties/measurements and are interconnected with each other by wireless connections and thus allow for inter-device communication and data forwarding.

8 http://www.zipcar.com/

9 http://sfpark.org/

10 http://www.nextbike.de

11 https://www.callabike-interaktiv.de/

Environment / Safety	Tsunami/Earthquake-Predetection (German Indonesian Tsunami Early Warning System[12])	Seismographs, Satelites	Vibrations, Visual (relative Suface Heights, e.g. Waves)	yes	MR	yes
	Snow Level / Snow Disposal Service	"Smart Dust" in pavement	Brightness, Close Distance, Temperature	yes	MR	yes
	Micro-Weather Information, Fire (Danger) Detection (manet-projekt[13])	Crowd source sensors	Temperature, Humidity	yes	MR	maybe
	Bridge Integrety Monitoring (VIVE, FU-Berlin[14])	Sensors in Bridges	Pressure measurements	no	MR	no
Water/Energy Needs	Tap Water Quality Overview	"Smart Dust"	Particle Type & Concentration	semi	both	yes
	Water Leakage Detection	"Smart Dust"	Pressure	yes	MR	no
	Night Lights Dimming	"Smart Dust" in pavement	Brightness, Vibration, Acoustic	yes	MR	no
	Lamp function Monitoring	Sensors on Lamp	Brightness, ID	semi	MR	maybe
	Detection of Energy peaks and downtimes (see Smart Grid Projects Outlook 2014[15])	Sensors on Grid		yes	MR	no
	Environmental Zones/Car restrictions	Governance		yes	both	yes

[12] http://www.gitews.de/homepage/

[13] http://www.manet-projekt.de/

[14] http://www.mi.fu-berlin.de/inf/groups/ag-tech/projects/VIVE/

[15] http://ses.jrc.ec.europa.eu/smart-grids-observatory

Appendix B

The following contains additional information regarding the related work that was reviewed whilst preparing the current document. The review was conducted by gathering a number of publications, standards, presentations etc. that seemed of relevance for the current topic. Subsequently, the aspects upon which the works were to be reviewed were discussed and the following template was laid down. This template was filled for the most relevant works from those that were initially put together.

Reference: <Name of the Material + Autors>
Type of the Material: <Scientific Paper| White Paper | Standard | Presentation …>
Type of Contribution: <Architecture |Use Cases| Implementation|Vocabulary| …>
Deployment: <Testbed | Simulation | Living Lab | Cities – list the cities in which the architecture was deployed>
Technical Aspects: <Open Data| Data Portal| Decentralized vs. Centralized Storage| Sensor Network| Linked Data| Cloud based System| Machine-2-Machine| Ontologies>
System Architecture: <Reference Model| Layered Architecture| holisitic vs. adressing only particular aspects – which aspects>
Use Cases: <are use cases defined>
Interfaces and APIs: <are interfaces and APIs clearly defined, if not how are these aspects addressed>
Data Model/Format: <what data models and formats are used – JSON, XML, particular standards e.g. OMA NGSI-10, DCAT …>
Data Sources: <sensors| governmental data| harvesting| social networks …>
Openness: <Open Ecosystem| Open Source| Open Data vs. Billing and Charging for Data or „Closed Data in general" | Public vs. Private Cloud>
Domains: <Mobility | eHealth | Buliding Automation | Environment | Garbage Management | Water Management …>
Applications: <are there any significant Apps available>
Integration of Legacy Systems: <can legacy systems be easily integrated>
Related Standards: <list any related standards here>
Description of Further Aspects: <free text describing other important aspects>

We screened a total of **26 research works and 3 standardization activities**. Out of these, **13 were selected** for a more detailed review. The results in the form of the above template are presented on the following pages.

Reference: Smart Cities Design using Event-driven Paradigm and Semantic Web. Liviu-Gabriel Cretu
Type of the Material: Journal (*Informatica Economica* 16.4 (2012))
Type of Contribution: Architecture
Deployment: None
Technical Aspects: Linked Open Data, Ontologies, Rules, Event-driven, Cloud based System

System Architecture: Reference Model
Use Cases: No
Interfaces and APIs: No, only high level
Data Model/Format: RDF, OWL, RIF (Rule Interchange Format), SPARQL
Data Sources: Not explicitly specified; data providers may be: sensors, smart devices, people, services
Openness: Open Data
Domains: Not explicitly specified
Applications: No
Integration of Legacy Systems: Not explicitly specified
Related Standards:
Description of Further Aspects: *high-level* approach towards a reference model for Smart Cities

- based on Data, Events and Listeners („Smart Community Space" as core of architecture)
- Semantic Web

Reference: iCore - Internet Connected Objects for Reconfigurable Ecosystem. Partner: TCS, ALU...
Type of the Material: Report (Deliverable)
Type of Contribution: Architecture
Deployment: Testbed
Technical Aspects: Open Data, Sensor Network, Semantic Web
System Architecture: Layered Architecture
Use Cases: Yes, e.g. „smart home living assistant", „smart urban security"
Interfaces and APIs: No
Data Model/Format: XML
Data Sources: sensors,governmental data
Openness: Some parts Open Source
Domains: Not explicitly specified
Applications: No
Integration of Legacy Systems: should be possibile with „The need to create a virtual counterpart of a real object"
Related Standards:
Description of Further Aspects: mainly use cases and their execution → lessons learned

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Reference: Smart Cities at the Forefront of the Future Internet. José Hernández-Muñoz et al
Type of the Material: Section in Book „The Future Internet" (based on the research that is carried out within the Future Internet Assembly (FIA))
Type of Contribution: Architecture
Deployment: None, maybe Living Lab within SmartSantander Project
Technical Aspects: Ubiquitous Sensor Network
System Architecture: Layered Architecture (holisitic approach)

Use Cases: examples for SmartSantander Project
Interfaces and APIs: No
Data Model/Format: Sensor Modeling Language (SensorML), OGC O&M Language
Data Sources: sensors, governmental data
Openness: Open Ecosystem
Domains: Not explicitly specified
Applications: No
Integration of Legacy Systems: quite hard
Related Standards:
Description of Further Aspects: 3 basic principles
Unified information modeling
Unified communication protocol
Horizontally layered approach

Reference: A Smart World: A Development Model for Intelligent Cities. Azamat Abdoullaev
Type of the Material: Keynote
Type of Contribution: Vocabulary
The true Smart City is committed to the following Value Propositions:

- Eco-Intelligent Infrastructure
- Sustainable Living, Well Being and Quality of Life
- Ecopolis (smart environment/natural capital and resources, eco-health, safety and security, engineering and
- Sanitation, conservation and protection, landscape integrity, and awareness; re-use, reduce, recycle and recover of resources, materials and energy);
- Smart People, Communities, and Society, Social and Human Capital;
- Future Proof Smart Technologies;
- Network Integrated Township (Smart Connected Communities, Ubiquitous Eco City);
- City Intelligence (Knowledge and Health Triangles, Intelligent Management Urban Platform);
- Environmental Infrastructure, Smart Utilities and Energy Networks;
- Smart Mobility (innovative transportation, FO ICT networks);
- Intelligent Green Lifestyle and QoL Facilities (cultural, health, safety, housing quality, education, touristic, and entertainment);
- Smart Governance (i-services, social, cultural and political cohesion);
- Innovation Economy and Knowledge Industry
- Sustainability Standards;
- Private, Public and Civil Society Partnership; financing schemes: BOT, BOOT, BOO, BLT, DBFO, or DCMF (Design, Build/Construct, Own, Operate, Transfer, Manage, Finance, Lease);
- Intelligent Investment Projects (Impact/Socially Responsible Investment)

Reference: Real-Time IoT Stream Processing and Large-scale Data Analytics for Smart City Applications. Partner: ERIC, NUIG..
Type of the Material: Report (Deliverable)
Type of Contribution: Architecture
Deployment: No
Technical Aspects: Open Data, Data Portal, Sensor Network, Linked Data
System Architecture: Reference Model
Use Cases: No
Interfaces and APIs: interfaces are defined
Data Model/Format: XML, machine-readable format („xml-like")
Data Sources: sensors, governmental data, social networks
Openness: Not explicitly specified, but charging and billing are considered
Domains: Not explicitly specified
Applications: No
Integration of Legacy Systems: Should be possible, they considered this ‚problem'
Related Standards:
Description of Further Aspects: definition of problem → how to solve the problem with existing technologies

- presenting an architecture using multiple views and perspectives with the exception that we limit the presented views for SCF since it is mainly a framework and not a concrete system architecture
  - Functional View
  - Interface and Information View
  - Security and privacy View

Reference: Smart City Info Architecture and Functional Platform. IBM , NTUA (University of Athens)
Type of the Material: Report(Deliverable)
Type of Contribution: Architecture
Deployment: Testbed
Technical Aspects: Data Portal, Sensor Network
System Architecture:
Use Cases: No
Interfaces and APIs: No, but interfaces are somehow available..
Data Model/Format: Not explicitly specified, but can handle GML, KML
Data Sources: sensors, governmental data
Openness: Not explicitly specified
Domains: Not explicitly specified
Applications: No
Integration of Legacy Systems: Integration is possible, but did not mention how the integration can be done
Related Standards:
Description of Further Aspects: detailed description of their platform architecture, based on WebSphere Application Server

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Reference: New Services Design for Smart Citites: A Planning Roadmap for User-driven Innovation. Nicos Komninos
Type of the Material: Scientific Paper (Proceedings of the 2014 ACM international workshop on Wireless and mobile technologies for Smart Cities)
Type of Contribution: Roadmap for making cities smart
Deployment: District in the city of Thermi, Greece
Technical Aspects: Linked Open Data
System Architecture: Layered Architecture
Use Cases: Yes, smart marketplace with air pollution, available parking
Interfaces and APIs: No
Data Model/Format: RDF, JSON
Data Sources: Sensors, citizens
Openness: Open Source, Open Data
Domains: Environment, Garbage Management , Mobility (Parking)
Applications: http://smartcity.thermi.gov.gr/
Integration of Legacy Systems: integrated existing systems in their architecture (small use case!)
Related Standards:
Description of Further Aspects: „key challenges [...] should be, first, the identification of existing technologies, secondly, the embedding of technology into urban activities and projects, and, finally, the interoperability between e-services across different domains.“

Reference: Smart Cities and Smart Communities Concepts. Alcatel-Lucent
Type of the Material: Presentation
Type of Contribution: Overview
Description of Further Aspects:

- Smart governance
- Smart people
- Smart environment
- Smart mobility
- Smart economy
- Smart living
- „Ultra broadband networks are essential“

Reference: Reliable, resilient and secure IoT for Smart City applications. Jorge Cuellar (Siemens AG)
Type of the Material: Report (Deliverable D2.2)
Type of Contribution: Requirements of Architecture
Description of Further Aspects: developed a lot of requirements

- security-by-design, privacy-by-design (non-functional req.)
- Support a large number of attached devices/objects (network and QoS req.)
- Centralised management of constrained networks
- Filtering and Decision making (middleware req.)

Reference: Reliable, resilient and secure IoT for Smart City applications. Elias Tragos (FORTH)
Type of the Material: Report (Deliverable D2.3)
Type of Contribution: Architecture
Deployment: Testbed
Technical Aspects: Sensor Network
System Architecture: Layered Architecture
Use Cases: Yes, Smart Transportation, Environmental Monitoring
Interfaces and APIs: interfaces are defined
Data Model/Format: JSON, WSDL, XML
Data Sources: sensors, governmental data
Openness: Not explicitly specified, but billing is mentioned
Domains: Not explicitly specified
Applications: No
Integration of Legacy Systems: Not explicitly specified
Related Standards:
Description of Further Aspects: some more paper pointers:

Internet of Things - Architecture, IoT-A EU-FP7 project, http://www.iot-a.eu/
Empowering the IoT with Cognitive Technologies, EU-FP7 project iCore, www.iot-icore.eu
uBiquitous, secUre inTernet-of-things with Location and contEx-awaReness, EU-FP& project BUTLER, http://www.iot-butler.eu/
Open Source cloud solution for the Internet of Things, EU-FP7 project OPENIOT, www.openiot.eu
FI-WARE, Core Platform of the Future Internet, http://www.fi-ware.org

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Reference: Creating Municipal ICT Architecture - A reference guide from Smart Cities, Gunnar Kartman, Arild Sandnes and Gjill Smit
Type of the Material: SmartCities project: Research Report
Type of Contribution: ICT Architecture Metamodel
Deployment: Lessons and experiences derived from three cities ICT architecture implementations: Karlstad (Sweden), Kristiansand (Norway), and Groningen (Netherlands)
Technical Aspects: Service Oriented Infrastructure
System Architecture: Architecture Metamodel, a holistic approach. Three architecture domains based on TOGAF (business, information systems and technology), their characteristics (Interoperability, Service Orientation, Information Security), and Governance domain.
Use Cases: Not defined

Interfaces and APIs: Interfaces roughly defined as dependencies between domains and their characteristics.
Data Model/Format: None
Data Sources: None
Openness: not clearly specified
Domains: none specified
Applications: None
Integration of Legacy Systems: not clear
Related Standards: TOGAF Enterprise Architecture Framework (Open Group standard)

Reference: "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0", US National Institute of Standards and Technologies
Type of the Material: Standard
Type of Contribution: Architecture, Use Cases, Vocabulary, related standards
Deployment: Not applicable
Technical Aspects: Sensor Network, Cloud based System, Machine-2-Machine, Ontologies
System Architecture: Reference Model, Layered Architecture, holistic
Use Cases: Yes
Interfaces and APIs: interfaces roughly defined
Data Model/Format: none specific
Data Sources: sensors, governmental data, social networks
Openness: not clearly addressed
Domains: Smart Grid (Energy)
Applications: Not applicable
Integration of Legacy Systems: not clearly addressed
Related Standards: list of related standards
Description of Further Aspects: none of relevance

Reference: "Smart City Architecture for Community Level Services Through the Internet of Things", R. Jalali, K.l El-khatib, C. McGregor
Type of the Material: Scientific Paper
Type of Contribution: Architecture
Deployment: (small) Testbed – Smart Community Healthcare
Technical Aspects: Sensor Network, Cloud Computing
System Architecture: Layered Architecture – sensing layer, network layer and control layer
Use Cases: None
Interfaces and APIs: None
Data Model/Format: None
Data Sources: Sensors, RFIDs, crowd sourcing
Openness: Individual vs. Community control center

Domains: eHealth, transportation, public safety
Applications: Case study in smart healthcare. eHealth, transportation, public safety
Integration of Legacy Systems: Not described
Related Standards: None
Description of Further Aspects: presents a general reference architecture for the design of Smart Cities and its services.

Appendix C

Aspects for mapping solutions of legacy IT-Provider to the proposed ICT reference architecture:

Technology Application Area: <please list area of application of your solution>
Interfaced Third Party Systems: <any third party systems your system interfaces with>
Own Interfaced Components: <any of your components which interfaces the described solution>
Code and Executables Openness: <Open Source | Free | Licensed | Commercial>
Open Interfaces: <based on standards | based on community established technology | proprietary>
Relation to Open Data: <generates open data | consumes open data>
Characterization of the Interfaces: <Programmable APIs | REST | SOAP | …|Used Protocols – e.g. ZigBee, IP>
Server/Cloud vs. Local Installation/Deployment: <describe the deployment constellation>
Database Technology: <describe the used data base technology>