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ESMARTCITY

Enabling Smarter City in the MED Area through Networking

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Priority Axis 1. Promoting Mediterranean innovation capacities to develop smart and sustainable growth

Specific Objective 1.1 To increase transnational activity of innovative clusters and networks of key sectors of the MED area

WP3 – Testing

Activity 3.2 – Testing preparatory activities

Deliverable 3.2.1 – Feasibility Study

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Responsible Author: **Luca Ferrarini (PP8 – POLIMI)**

Co-Authors : Athanasios Kalogeras, Christos Koulamas, Christos Alexakos, Panagiotis Foundas, Paraskevi Zisi, Adrijana Rac, Aleksandar Mastilovic , Gonzalo Esteban López, Maria Makri, Cristina Daniel, Orlando Paraiba, Cristoforo Massari, Carmine Pacente, Hervé Rivano, Oana Iova

Project Coordinator : **Iris Flacco (LP – ABREG)**

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RE	Restricted to a Group defined by the Partnership and MED Programme	
CO	Confidential, only for members of the partnership and MED Programme	

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1 Contents

2 Introduction

WP3 is related to the testing activities of the ESMARTCITY project. WP3 addresses a dual challenge: (i) to increase the level of innovation in MED cities enriching city infrastructure with reference to smart devices, IoT, embedded systems, sensors and actuators, and (ii) to enhance innovation potential of relevant clusters and SMEs in the MED area through related capacity building activities.

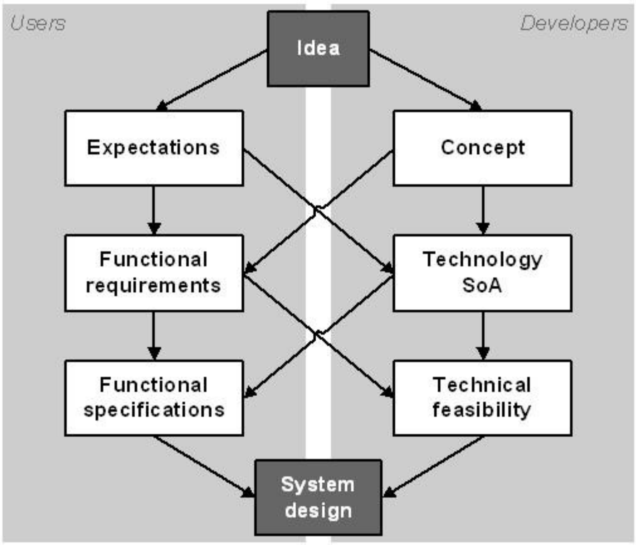
Activity 3.2 is related to the Testing Preparatory Activities of the ESMARTCITY project. The project intends to perform a transnational pilot testing including test use case deployment in the partner countries. Testing focuses on two different themes: energy efficient buildings and smart public lighting. Pilot deployments with reference to energy efficient buildings include the following regions and localities: Western Greece (EL) – {Patras, Messolonghi, Pyrgos}, Lisbon (PT) – {Palmela, Setubal, Sesimbra}, Lombardy (IT) – {Milan}. On the other hand pilot deployments with reference to smart public lighting include the following regions and localities: Abruzzo (IT) – {Pescara}, Auvergne-Rhône-Alpes (FR) – {Lyon}, Andalusia (ES) – {Huetor Tajar}, Bosnia and Herzegovina – {East Ilidza}.

Activity 3.2 is expected to provide three different deliverables: a Feasibility Study (D.3.2.1), a Methodology for Testing (D.3.2.2) and Pilot Deployment Operational Plan Framework (D.3.2.3).

Deliverable 3.2.1 is about conducting a Feasibility Study of the envisaged pilot testing and associated pilot deployments. The deliverable details the User Requirements for the different deployment use cases of the transnational pilot testing, reviews the Technology state-of-the-art with reference to building energy efficiency and smart public lighting technologies and solutions, and finally draws Functional Specifications for the transnational pilot testing. It is thus quite important for the replicability and scalability of the project in other sites in the MED area and beyond, along with Deliverables D3.2.2 and D3.2.3.

All three deliverables of Activity 3.2 provide the necessary input to Activity 3.3 dealing with Pilot Testing.

The schema depicted in below figure is representative of the structure of the present deliverable D.3.2.1. The idea that generated the project is associated with some expectations on the users side and a certain concept on the technical developers side. The combination of user expectation and technical concepts leads to functional requirements on the user side and a state-of-the-art survey on the technology side. In turn user requirements and technological state-of-the-art are combined to produce the project functional specifications and determine the project technical feasibility.



The deliverable is structured as follows. Chapter 3 presents an overall state-of-the-art review of the building energy efficiency and smart public lighting techniques. Chapter 4 presents the User Requirements of the different pilot deployment use cases grouped according to their theme. Finally, chapter 5 draws the Functional Specifications defined according to the user requirements classification proposed in the previous chapter.

3 Technological State of the Art

3.1 Building Energy Efficiency

This section is dedicated to an overall review of the state-of-the-art technologies involved in the building energy efficiency task. Since an incredible amount of technological discoveries has been carried out in the last years, these technologies will be categorized into five groups for the sake of simplicity:

- Thermal solutions
- Electrical solutions
- Human factor management
- Advanced control algorithms
- Data acquisition and storing

A sub-section is dedicated to each group.

3.1.1 Thermal solutions

Considering the energy consumption typical of a building, the largest amount of this cost is usually to be imputed to the control of the thermal comfort – namely for the operation of Heating, Ventilation and Air Conditioning (HVAC) systems. In [1] is estimated that a quote of 76% of the overall building energy consumption is used for this purpose. Considering that the same reference (Directive 2010/31/EU of the EU Parliament and of the Council of 19 May 2010 on the energy performance of buildings, 2010) attributes the 40% of the total European energy consumption to the residential and commercial buildings, tackling the efficiency of the HVAC systems is vital in order to reduce energy consumption in large cities.

Different alternatives to the conventional thermal comfort technologies have been developed in the last years. The focus of these solutions ranges from new insulating materials to different energy production systems and different ways to transmit this energy to the controlled thermal volumes. Although the consolidation of such technologies, the majority of the building realities still exploits outdated classic solutions.

In this section, the focus is given to some of the small-scale energy production system while neglecting the well-known district heating systems, which are beyond the project targets.

3.1.1.1 Thermal insulating coatings

From the building structural point of view, a way to reduce the overall energy consumption involved in the thermal comfort control is to reduce the thermal dispersion of the building itself. For this purpose, different thermal insulating coating have been developed. These coatings serve as an aid to the classic insulation material usually provided inside the external walls of a building – i.e. the walls constituting the external perimeter of the building. These external walls, being exposed to the action of the outside environmental conditions, are the main source of the constant thermal dispersion of the building. Different sources of thermal dispersion are represented by the ground of the building itself, or more trivially by the doors and windows: this latter dispersion factor will be tacked when considering the human factors involved in the thermal dispersion issue.

This thermal insulating coating solution sees the installation of a coating layer on the outside of the building itself. This layer is composed of materials designed to drastically reduce the convective heat exchange between the outside air and the building external walls. In this way, the energetic effort needed to guarantee a specific thermal comfort inside the building is reduced independently from the heating or cooling action needed.

3.1.1.2 Condensing boilers

The condensing boiler is an improved version of the classic boiler system. The functioning principle of this system is still focused on the production of hot water by exploiting the combustion of fuel – typically gas or oil. However, the improvement lays in the heat recovering system exploited to improve the energetic efficiency of this process. Thanks to this implementation, the achievable efficiency is typically greater than 90% - with respect to their classic counterpart, which usually reaches value in the range between 75% and 85% [2].

The focus is now posed on the heat recovering part of this system, since the heat generation part is well-known. The principle of this heat recover lays on the water vapor contained in the hot gases produced by the combustion part of the boiler. These water vapors are obtained from the combustion of the hydrogen part of the fuel. The latent heat of vaporization contained in this water vapor is recovered in the heat exchanger. The water returning from the heat load – i.e. the radiator or any other heating system installed in the building – is pre-heated by the combustion vapors, thus recovering the heat lost otherwise.

The usage of this kind of boiler system is widely spreading in Europe, since their installation is strongly advocated by government bodies whose aim is to reduce the domestic energy consumption.

3.1.1.3 Heat pumps

The domestic heat pump system exploits the heating power from the natural resources to guarantee the required thermal comfort in the controlled building. This system is able to exploit the classic thermodynamics principle of the heat pump both for heating or cooling purposes depending on the specific user requirements.

To quickly describe its functioning, an example of the heating case is considered. A first circulation pipeline is installed near to a heat source, which is typically represented by the ground or the outside air itself. The working fluid flowing into the pipeline is heated by the heat source. At the end of the pipeline, the fluid reaches an evaporator system. The working fluid contained in the evaporator absorbs the heat collected from the heat source by the working fluid contained in the pipeline. The fluid contained in the evaporator is usually a cold and low pressure mix of liquid and vapor. The transferred heat causes this fluid to evaporate and reach a compressor, which increases the pressure – and the temperature – of the vapor. This compressed vapor is collected into a condenser, which transfers the heat of this vapor to a second circulation pipeline connected to the building heat distribution system. The cold vapor condenses and is expanded by a condensation valve, which returns this working fluid in a cold and low pressure state to the evaporator system, thus closing the system loop.

Although the system requires an electrical source to power its compressor and the pipeline circulation system, this solution increases the overall efficiency up to four times with respect to a heating system exploiting the electrical source only – for example, electrical resistance heaters. Therefore, this heating strategy is able to drastically increase the efficiency of simple electrical-based heating systems while still preserving its independence from any other fuel sources.

3.1.1.4 Radiant panels

Considering the innovative ways to transmit thermal energy to the building, radiant panels are among the most trending ones. With respect to the classic radiator, the radiant panels are composed by a longer pipeline, which is in turn installed into a thermal screed. This screed has a function of thermal inertia, reducing the requested heat picks typical of a classic radiator and smoothing out the transferred heat profile, thus reducing the unnecessary thermal dispersions.

Depending on the building structure, radiant panels can be installed in different locations: the pavement, the walls or even the ceiling.

This system is usually endowed with a mixing valve, through which is possible to decide the inlet temperature of the pipeline itself. In this way, the system is not forced to work with the temperature provided by the generation system – typically, a boiler system. In this way, the obtainable performances in terms of consumption and thermal comfort are considerably increased.

3.1.2 Electrical solutions

The electrical load represents another relevant building energy consumption factor. With the advent of numerous innovation in the home automation and household appliances fields, new strategies are being developed to reduce the overall electrical consumption. These strategies act mainly on two fronts: reducing the electrical energy costs and reducing the consumption of any household appliance.

Solutions involved with the reduction of the energy cost itself are more focused on the large scale production. Concerning the building-scale solutions, the domestic solar panels will be presented. On the other hand, different solutions have been proposed to reduce the energy consumption of the building electrical loads. Beside the well-known common interest into making any electrical device more efficient possible, specific solutions can be found on the energy consumption reduction front.

3.1.2.1 Solar panels

Considering the field of renewable energy, the solar panel is the most widely adopted solution in the domestic building context. The reason behind this reality is the relevant power scalability of these systems, with respect to other renewable energy sources which cannot efficiently be replied in small scales.

The well-known functioning principle behind this system is based on collecting the solar radiation. However, because of the unpredictable climatic changes, this power source cannot guarantee a continuous and reliable power inlet for a building reality. The solar radiation is a highly varying natural input, and thus cannot be trusted to meet the baseline of the on-demand electrical consumption of our society. However, the aid of such technology should not be neglected since it definitely reduces the overall consumption. To overcome the problem of solar radiation discontinuity, new energy storage devices (batteries) are developed.

3.1.2.2 Household appliances efficiency

Different appliances contribute to the overall electrical consumption of a classic building. Considering the domestic reality, the highest consumption is caused by the typical appliances such as oven, washing machine, fridge and so on. To sensitize the industrial field to this efficiency topic, a classification based on energy labels have been imposed to the main household appliances. Remarkable improvements have been made on this front.

For what concerns the commercial building reality, a non-negligible consumption factor can be found in the lighting itself. To reduce this constant source of consumption, different technologies have been developed in the years. These new technologies aimed at reducing the required power while increasing – or at least maintaining – the same lighting power and lifespan. Considering the wideness of application of such technologies, particular focus has been posed on the environmental impact of the lighting devices manufacturing itself. The achieved consumption reduction in the last two decades hugely affected the building energy consumption. Considering the LED lamp technologies as an example, the consumption is reduces at one tenth of the consumption of a classic incandescent lamp [2].

3.1.3 Human factor management

A well-known source of energy inefficiency in a building realty is the human factor. The primary focus of the building inhabitant or visitor is usually its comfort, both in terms of thermal comfort and freedom of choice. For example, while opening a window for one minute can be seen as a decision of negligible impact from the building user, the actual impact of a simple action like this – depending on the external environmental conditions – could be drastic in terms of thermal dispersion and thus energy costs. It Is then clear that any expression of the simplest user freedom in a building can impact considerably on the overall building energy consumption.

This issue can be tackled mainly in two different fashions:

- Reducing the impact of such actions by taking specific countermeasures to minimize the energy losses
- Making the user more aware of its impact on the overall energy consumptions

Different strategies have been developed concerning the former path of cost reduction, some of which will be presented in this section. The latter one can be described as a “cost monitoring” procedure. Any tool to increase the awareness towards the energy impact of each user decision is a form of monitoring and represents a passive approach to the cost reduction issue, fueled by the financial benefit of the single consumer.

3.1.3.1 Smart user countermeasures

The extension of these countermeasures is mostly limited by the availability of the sensors installed in the building, and thus on their cost. The increased use of these sensors – consequent to the price reduction observed in the last years – opened the way to the development of different smart user countermeasures. Different simple techniques have been developed to drastically reduce the impact of the user freedom of choice.

The most known techniques exploit the presence sensors. These sensor are usually coupled to the lighting system. The classic lighting switch is removed and substituted with the presence sensor, which turns the light on only when a presence is detected. Then, the lights are usually turned off after no presence has been detected for a specific time span. With this solution, the lights will eventually be turned off when no one is occupying the room, thus preventing the scenario in which the lights are uselessly left switched on.

These presence sensors can be coupled to different devices to reduce the energy waste, such as HVAC systems. In fact, sophisticated sensors are able to estimate the number of occupants in one room. Exploiting this information it is possible to estimate the thermal impact of the occupant – that is, the people-related internal gain – and compensate it by acting on the HVAC system. In this way, the thermal stress of the room will be reduced, together with the consequent thermal dispersion and the impact of the possible human actions consequent to a considerable thermal stress (like opening the windows).

Other sensors can be deployed to support this smart interaction with the human interference. For example, sensors on the windows are usually exploited to detect the open/closed state of the window. Then, depending on the difference between the room temperature and the outside air temperature, the smart control system could decide to turn off the heating/cooling system in order to avoid an unnecessary energy waste.

Other solutions aim to the harmonization between the energy consumption objectives and the user desired comfort. Some controllers can be programmed to meet some user requirements on a time schedule. In this way, by forecasting the user requests it is possible to optimize the control action required to meet them.

3.1.3.2 Consumption monitoring

The most efficient and least expensive solution to reduce the overall building consumption is making the user aware of it. The user will then be primarily interested in the reduction of such costs, and will self-promote an intelligent behavior towards this objective.

The consumption monitoring is already an established practice for large commercial building and working building ensembles. However, the efficiency of this practice is usually reduced because of the lack of communication between the people who perform the consumption analysis and the people who are responsible of the majority of that consumption. To increase the benefic impact of such analysis, the administrations of some working groups are making their employees more aware about energy-saving shrewdness.

Focusing on the domestic field, wide maneuvering space is available for new technologies and solutions to make the everyday citizens more aware of their consumption. A common strategy used in new apartments is to have a digital display presenting the instantaneous electric power consumption. This simple device has the function of both signaling any form of unexpected energy waste and inform the user about its average electric consumption.

3.1.4 Advanced control algorithms

Once different technologies are available for the development of energy-saving systems, the implementation of specific control algorithms can further optimize this energy efficiency task. The focus here is posed mainly on the control of the thermal devices, which are the ones more characterize by optimizable system dynamics. A common and cost-effective strategy for energy analysis and design of innovative control strategies is based on an extensive simulation analysis. Through the results of such simulations, it is then possible to develop the aforementioned efficient control algorithms.

The simulations exploited for the development of such control strategies need a specific thermal model of the building. Based on the available standard handbooks, such as the 2009 ASHRAE Handbook [4] [5], the building modeling approaches are generally divided to two major categories. In the forward (classic) approach, the physical equations and the inputs of the system are known, and the goal is to predict the output. The accuracy of this approach increases as the model is more complex and detailed. This method is also called white-box modeling. On the contrary, once the inputs and outputs data measured from the system are available, data-driven (inverse) approaches will be utilized to define a mathematical description of the system.

Simulation tools are available to analyse in a white-box fashion the predicted behaviour of a given building. A class of models are derived through the physical approach (equations from conservation laws) [6] [7]. They allow to start from some physical parameters and quantities of the building and of the technological plants and to arrive to an estimation of energy consumption. An example of a wide-spread simulation environment is Energy Plus, developed in the USA as a joint effort of different entities (the National Renewable Energy Laboratory, the U.S. Department of Energy National Laboratories, academic institutions, and private companies) [6]. Another example is based on international standards, like the ISO 13790, which provides methods for the assessment of the annual energy needed for space heating and cooling in residential or non-residential buildings, based on quasi-static models [8].

On the application side, building automation systems are based on controllers (typically cascaded PID schemes with saturation and linear/nonlinear compensators), which are tuned by hand during the installation phase by some technicians. The results are that days, weeks or months later these systems must be retuned, manually, with users' discomfort in between. The variety of buildings types, materials, orientation and so on, makes the classic auto-tuning techniques ineffective, if proper actions are not taken. For these reasons, some advanced control algorithms exploiting the previous modeling approaches will be presented and described.

3.1.4.1 Adaptive PID building control

The need of advanced control algorithms – such as the one presented in this section – was highlighted by several groups of researchers, which carried out surveys on the thermal control strategies in buildings. Their studies were typically based on thermostatic valves on radiators (TVR). The authors revealed that most of the occupants fail to use TVR and thermostats as they were designed. After that PID controllers were used to improve these situations, but these strategies do not guaranty minimal energy consumption because they are not really designed for this purpose. Although PID controllers showed a reliable performance in many industries and in particular in building comfort control, they usually suffer from unforeseen disturbances both external (such as solar radiation, external temperature, external humidity, wind direction and speed) and internal (such as internal gains, user activities and occupancy) and even model uncertainties and unmodeled dynamics.

To better anticipate the effects of the disturbances on the system dynamics, researchers turned toward adaptive PID scheme. Adaptive controllers have the ability to self-regulate and adapt to the above-mentioned disturbances in the various buildings. Another approach to tackle with the problem is by using classic and advanced identification methods (Recursive Least-Squares estimation). Nesler [9] developed adaptive control of thermal processes in buildings. In this way, the standard PID control algorithm was adapted for the control of heating, ventilating, and air-conditioning (HVAC) processes. The gain, time constant and dead time of a process – which are the most vital system quantities to be known to guarantee excellent control performances – can be estimated accurately by this adaptive PID controller.

3.1.4.2 Building MPC

Model predictive control (MPC) is widely used in different application and mostly in large scale systems such as process industries with lots of control variables. The reason of the popularity of this control strategy is the potentially optimal performances obtainable with a reduced computational effort. Many works have been carried out using MPC in different areas to have an optimal decision such as energy management in electrical and thermal energy of buildings in both residential and commercial sector with different goals and different challenges to face.

Considering specific research works exploiting MPC controllers, in [10] the authors use MPC for building climate control where the approach utilizes RC model obtained from energy balance equation for a single thermal zone. The controller manipulates the actuators and its operation relies on the solar radiation and outside temperature prediction the compensation mechanism is implemented using feed-forward and dynamic matrix control. The approach can anticipate the performance of the controller in order to minimize the energy comfort. As it can be seen, this control system has been integrated with a weather prediction system: this kind of hybrid strategy represents another advantage the MPC structure can claim, which is in line with the trending vision of interconnected intelligence referred to as Internet of Things (IoT).

The flexibility of such control structure has been exploited even in [11] which is carried out by ETH research group of Automatic control laboratory. These researches utilize the weather prediction to have energy efficient climate control in buildings through multiple approaches. The key idea of the works is to keep the control variables such as temperature and lights inside their limits with a minimum amount of energy required. These kind of complex objectives can be implemented into an MPC structure more easily with respect to any traditional control structure.

3.1.5 Data acquisition and storing

All the previous sections describe different devices involved in the building energy consumption area together with some advanced control algorithms usually exploited in this field. Now, the focus must be set on the low-level components and connections that enable the previously described devices and control strategies to work. In fact, the development of complex control structures was made possible by the recent popularity level conquered by the sensors world in the Internet of Things age.

In this section, an overview of the data acquisition and storing phase is given.

3.1.5.1 Internet of Things

The expression "Internet of Things" (IoT) is a neologism coined to describe a worldwide industrial/commercial phenomenon involving the interaction of numerous items of various nature. This interconnection trend has been propelled by the research of efficiency increases through big data analysis. Thanks to the interaction of different devices and the collection of huge amount of data it is possible to unveil complex mechanisms elsewhere hidden behind the limits of the small-scale analysis of the past. The market related to this kind of technological revolution is sky-rocketing, since the number of devices which can be referred to as "IoT devices" reached 8.4 billion on 2017 [12] and it is estimated that there will be 30 billion devices by 2020 [13] for an estimated market value of $7.1 trillion [14].

Thanks to the interconnection between devices of apparently different nature, it is possible to improve life quality as well as control and monitoring. By connecting any kind of home appliance – take the heating system as an example – to the internet, it is possible to communicate a control action even by distance. The benefit of such action is represented by the elasticity of the control structure, which has a longer time span to meet the user requirements and can thus find a more efficient way to complete its task. This example could be extended to contexts different from the one treated in this project. Focusing on the current topic, the IoT infrastructure allows a more careful monitoring of the building energy consumption together with a more efficient way of undertaking control actions to meet specific user requirements. The remote control possibilities are extended to almost any apparatus in the domestic appliance field, from the oven to a single light bulb. By interconnecting the energy loads of a group of buildings, it is possible to define a controlled smart grid. In such a grid it is possible to gather and act on energy and power-related information to improve the efficiency of the production and distribution of electricity [15]. Moreover, it is possible to act on the energy distribution itself to reduce dispersions and inefficiency phenomena [16].

Different communication protocols are being exploited to apply this technological imprint to the everyday reality. Most of these protocols possess a wireless nature in order to free the sensors and actuators from the spatial constraint represented by power and connection wires. The wireless protocols have been developed on short range (Bluetooth, Wi-Fi, Li-Fi, NFC, Z-Wave…), medium range (HaLow, Advanced-LTE…) and long range (Low-power WAN, VSAT satellite communication…). All these protocols aim at the reduction of the energy consumption needed for the data transfer. This requirement is justified by the expected huge amount of data that the sensors should transfer to a data storage and processing platform. Both for energy consumption and maintenance reasons, the communication protocols should be refined as much as possible to make these data collection system as economic and autonomous as possible.

3.1.5.2 Sensors

Thanks to the aforementioned advent of IoT technological revolution, the sensor have grown cheaper and smarter. Different functions have been integrated in a single sensor, together with some data pre-processing features to lighten the data collection and transmission. Together with the empowerment of the sensors role in the everyday technologies, new possibilities have been opened to almost any field now. Posing the focus on the current theme of building energy consumption, the availability of multiple measurements of different nature on different buildings allows the study of new techniques in this field. Large amounts of data can be exploited to develop consumption prediction models of the buildings. These models can be exploited by energy management bodies to evaluate the financial aspects of any investment on the building structure, on the energy generation system or even on the control algorithms. In conclusion, the knowledge of the energy consumption phenomena can be deepened thanks to the deployment of a large number of sensors and the consequent collection of real data.

To boost even more these possibilities, the sensors world is moving towards the production of multi-sensors, i.e. devices equipped with different sensors to measure different quantities. New correlations can be found when exploiting measurements of different nature quantities, opening the road to new control strategies.

3.1.5.3 Data storage

Once the interconnections of components is established thanks to the IoT concept and the data is collected thanks to the new sensors technologies, the acquired data need to be stored and eventually analyzed. The internet connection has become a vital a component to perform this kind of final and necessary task. Although many data storage devices have been developed to physically store large amount of data close to the sensor location, the relevant number of measurements coming from spatially distant locations and the necessity to process these measures together push the request toward different technological solutions. It is necessary to transmit all the measurements to a centralized storage center – which can be physical or on cloud – in order to manage correctly the data.

Once the data have been collected into a single location, different solutions are easily developed to display these data for monitoring purposes. Advanced real-time monitoring systems are able to exploit the data historicizing to display past data, usually for diagnosis purposes. Moreover, the overall quantity of measurements can be exploited to draw efficiency coefficients, performance indicators and consumption predictions. In fact, as presented in the previous section about advanced control algorithms, it is possible to exploit modeling techniques which are able to identify trends and intrinsic characteristics of a system, which can in turn be exploited to control the system towards specific user requirements.

3.2 Smart Lighting

3.2.1 Introduction

Smart lighting is a system initially designed to decrease energy consumption by adapting light intensity according to several parameters (e.g., natural light, occupancy) [17]. Progress in technology is considerably increasing the intelligence of lighting systems, by making it capable of communicating with its environment, drastically changing traditional uses, and improving the life of citizens. Indeed, research from **LightingEurope** (prepared by A.T. Kearney and the German Electrical and Electronic Manufacturers' Association (ZVEI)) found evidence that light-emitting diodes (LED) bulbs could present an array of health benefits [18], like:

- Increased employee or student motivation and commitment;
- Improved concentration and energy;
- "Mood support" in wellness and dining areas;
- Enhanced drug efficacy, e.g., of antidepressants (in hospitals);
- Reduced therapy times and capacity requirements.

Worldwide, there are over four billion public lamps, mostly consisting of high-intensity bulbs using mercury and other toxic substances. There are plans to pool this lighting network, territory by territory, by replacing current equipment with lower consumption connected sensors. Each lamp would be reconfigured as a node in a local network, constantly recording and sharing data with other local networks [17]. This prospect is made possible by the lowering cost of LEDs and by connecting each system on the network using cheap wireless communication devices. Indeed, smart lighting systems can be controlled through the Internet to adjust lighting brightness and schedules, e.g. through a smart lighting network that assigns IP addresses to light bulbs.

LEDs possess increased efficiency because energy of the bulb is utilized to produce light rather than wasteful heat; they last for an average of 40,000 hours, compared to incandescent bulbs that burn out in approximately 1,000. The US Environment Protection Agency has calculated that LED lights will save 88 terawatt-hours of electricity from 2010 until 2030 – enough to power seven million homes for an entire year. And in Britain it has been calculated that the country as a whole could save £1bn in energy bills every year – the equivalent of £50 per household – simply by switching to LEDs, and save around 5 million tones of carbon dioxide annually [18].

3.2.2 Motivation

3.2.2.1 Environmental

The last decade has seen growing interest in the study of light pollution, which extends from established areas of concern such as reduced visibility of the night sky or energy wastage, to an emerging emphasis on biodiversity loss, the disturbance of circadian rhythms, and the expansionary dynamics of global capital [19].

Light pollution encompasses several different phenomena including “light clutter,” when a myriad of different sources can cause disorientation, “light trespass” from unwanted light sources, and in particular “skyglow” produced by the scattering of light in the atmosphere where the cumulative impact can reduce night sky visibility over vast areas [19]. A recent study of satellite data by the pioneering investigator Fabio Falchi finds that around 83% of the global population is affected by “artificial skyglow,” rising to over 99 percent of the population of Europe and North America (see Figure 1) [20]. Hence, reducing the street lighting in cities is of uttermost importance.

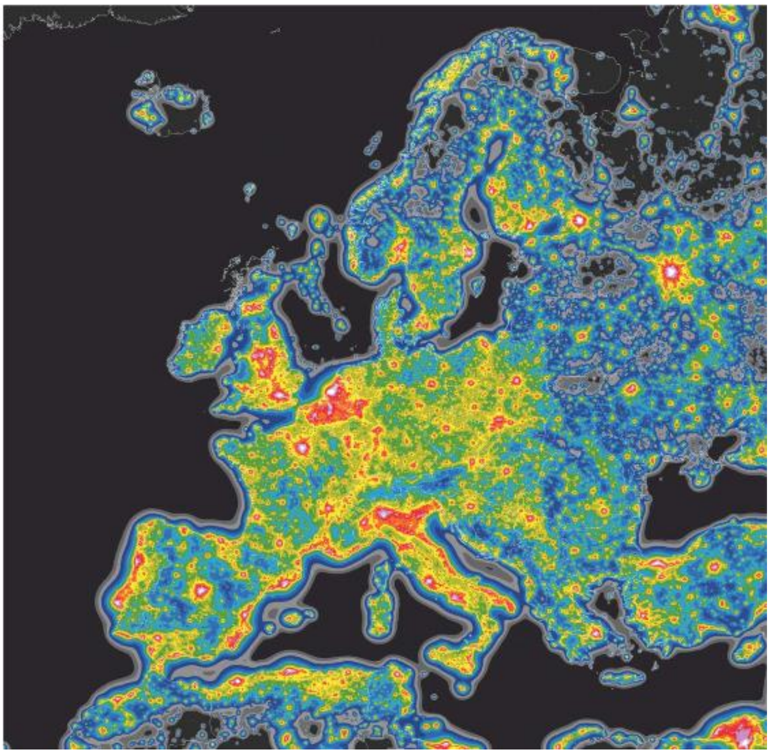


Figure 1 A cartographic representation of current levels of artificial sky brightness in Europe using low-light imaging data from the VIIRS DNB sensor on the Suomi National Polar-orbiting Partnership (NPP) satellite. The color scale identifies areas with a ratio of artificial light ranging from less than 0.1 (with no significant light pollution) to areas with more than forty one times the natural level of brightness. In those intermediate areas marked yellow and orange, with artificial brightness ratios of between 1.28 and 5.15, the Milky Way becomes gradually invisible [20].

3.2.2.2 *Economic*

Street lighting is an essential community service, but current implementations are not energy efficient and require municipalities to spend up to 40% of their allocated budget [21]. Replacing a legacy street lighting system with LEDs can reduce a municipality's energy bill by half. Integrating those lights with networking and intelligent controls can provide a further 30% in savings – and provide a platform for current and future smart city applications that can enhance public safety, traffic management, health, comfort, and more [22].

Assessing costs and benefits in adopting the new smart lighting solutions is a pillar step for municipalities to foster real implementation. A simulation of a lampost deployment in realistic urban environments for the city of Luxembourg, shows that replacing all existing lamps with LEDs and dimming light intensity in the absence of users in the vicinity of the lampposts is convenient and provides an economical return already after the first year of deployment [21].

3.2.3 Smart Lighting

The consumption of energy in conventional street light systems is consistent and has no concern with the activity and frequency of traffic. With the advancement of technology, numerous solutions like LED, illumination controller/dimmer, wireless, and Information and Communication Technology (ICT) based designs have been proposed. The authors in [23] propose a reliable, fast, and power efficient street light mechanism to switch off and dim the light by taking into account the pedestrian and vehicle speed and rate of flow. They showed through simulation that the proposed solution has potential to save the energy during the nights not only on the highways, but also in suburb and residential areas. However, one limitation is that in order to implement the proposed system a smart street light pole with multiple sensors is required.

Mustafa et al. introduced a preliminary design and simulation for a smart highway lighting management system based on road occupancy [28]. Wireless Sensors Network (WSN) detects the presence of vehicles along the road, and controls lamps accordingly. The system is simulated and optimized using a realistic probabilistic model for vehicles traffic, taking the advantage of simulation to provide estimation for expected energy saving rates; in contrary to previous works depending only on rough calculations or real-time results after implementation. According to simulation results, the proposed system can save up to 57.4% of power consumption compared to conventional lighting systems.

The main aim of smart streetlight systems is that lights turn on when needed and off when not needed. Yoshiura et al. propose a smart street light system consisting of LEDs, brightness sensors, motion sensors, and short-distance communication networks [27]. The lights turn on before pedestrians and vehicles come and turn off or reduce brightness when there is no one.

To mitigate the current excessive power consumption effects, smart cities should offer efficient support for global communications and access to services and information, e.g., by means of a homogenous and seamless machine to machine (M2M) communication. The authors in [24] present how to reach an interoperable Smart Lighting solution over the emerging M2M protocols such as CoAP built over REST architecture. This follows up the guidelines defined by the IP for Smart Objects Alliance (IPSO Alliance) in order to implement an interoperable semantic level for the street lighting, and describe the integration of the communications and logic over the existing street lighting infrastructure.

An intelligent streetlight management system can be an integral part of a Smart City platform. In [25], field bus technology is used at the field level. Control and monitoring strategies are implemented as web services in the central software, and interoperable interfaces to other parts of the platform are specified. Real-life use cases at test sites in Austria demonstrate increased energy efficiency without compromising public safety.

A cloud-based approach is proposed in [26], which integrates OpenStack, a widely used and competitive framework for infrastructure as a service. With its breadth in terms of feature coverage and expanded scope, OpenStack replaces current application-specific approaches with an innovative application-agnostic one. The authors focus on a park smart lighting example, featuring data collection, data visualization, event detection and coordinated reaction, as example use cases of such integration.

Visible Light Communication (VLC) is also fostering a lot of attention for adding smartness to light, be it denominated LiFi, optical wireless, or Free Space Optics (FSO) [41]. The main idea is to use the high reactivity of LEDs to modulate the emitted light in a manner that is undetectable by human eyes and can be exploited by a dedicated hardware. The aforesaid modulation is then used to transmit digital signal. The LiFi denomination actually refers to WiFi that the light industry aims at replacing. Both theoretical and practical performances can be impressive [42]. It is however controversial to use public street lighting to bear VLC communications. The energy reduction objective of most smart lighting projects is indeed in contradiction with the need for powering the LEDs to transmit information, even under daylight conditions. Consequently, many VLC/LiFi projects are addressing IoT issues or indoor settings where artificial lighting is legitimate [43]. In particular, no pilot of the eSmartCity project focuses on VLC.

3.2.4 Smart Lighting control

Adaptation of artificial light based on the available amount of daylight is known to be effective for energy savings. To achieve such daylight control, the state-of-the-art lighting systems use external photodetectors. The photodetector measures the combined contribution of artificial light and daylight, and closed-loop control schemes are used to determine the dimming levels of luminaires to produce the right amount of artificial light. Li et al. proposed LED luminaires that can perform the dual function of illumination and daylight sensing, obviating the need of additional photodetectors [30]. An open-loop control scheme is then considered for daylight control. They also propose system based on an open-loop control scheme, which they show it is more robust to reflectance changes in comparison with a photodetector-based closed-loop lighting control system.

Daylight-linked controls (DLCs) allow to reduce energy costs and to maximize users' comfort. Despite benefits it would provide, DLCs use is rather limited because of different factors [29]:

- Difficulties in design, as each phase of design process affects daylight-linked controls functioning;
- Knowledge about daylight-linked controls is not adequate to guarantee their spread;
- Software limits affect prediction of energy saving due to daylight-linked controls;
- Installation and calibration;
- Users' reluctance in accepting them.

Antchev et al. proposed an electronic ambient light controller, based on the open microprocessor system Arduino ProMini [31]. The main purpose is to reach a minimum time of the transient process within the initial turn on and regulation of the system.

Novak at al. propose an intelligent street lighting design known as integrated traffic-adaptive control [32]. In general, the strategy is that the luminance intensity of streetlights is either increased or reduced in multiple steps depending on the traffic flow. In a nutshell, higher traffic volume means higher luminance intensity, and vice versa, according to the method specified in the guideline of International Commission on Illumination CIE 115. Data on traffic flow comes from existing roadside infrastructure connected to other management systems, like traffic management, and is interfaced with streetlight management in a common platform. The benefit of such a holistic system approach is that energy consumption of public lighting is reduced without high investments in sensor infrastructure (since existing sensors are used) and without compromising road safety (due to the continuous adjustment of luminance intensity to the traffic volume).

The installation and operation of street lighting can be expensive: cables must be installed, and power is drawn from the grid, which is typically dominated, by non-renewable sources. A potential solution is the use of solar energy to power individual street lights locally. However, with limited energy storage and variable solar availability, existing lighting control strategies are unsuitable for this application. Lau et al. proposed TALiSMaN-Green, a scheme that achieves energy-neutral solar-powered operation [33]. It maintains a consistent level of usefulness of streetlights across a complete overnight period, regardless of the amount of energy stored at the beginning of the night. Unlike existing schemes, which may run out of energy during the night, it learns the dynamics of traffic volumes and sunrise times and budgets energy accordingly.

3.2.5 Networking for Smart Street Lighting

In order to improve energy efficiency, the traditional light posts are expected to be gradually replaced by smart systems able to adapt the features of the emitted light to different environmental, traffic, or crowdedness conditions. Power Line Communication (PLC) is the natural choice to support smart light control, since no additional communication infrastructure is needed. However, at the moment not so many simulation tools exist to guide the design and the deployment of smart lighting systems based on PLC. Sittoni et al. propose some suitable circuit models that can be used to analyze (through simulations at the physical layer) the behavior of narrowband PLC (NB-PLC) signals transmitted over low-voltage (LV) lines for street light control [34]. The proposed approach is quite simple from the computational point of view, and it is scalable enough to evaluate the quality of PLC signals in large networks with different topologies.

In the Triangulum smart city project, the proposed technology for streetlights monitoring and control is narrowband powerline communication (NPLC). Their results show that, with low power, NPLC can support a 3.5km network of streetlights without using a relay, and when the data packet size quadruples, latency can degrade by up to 22.63% (242.03ms) in the worst case [35].

Unlike classic lighting, the migration to smart lighting introduces the problem of power consumption of the intelligent infrastructure in standby mode. Golchin et al. showed how to eliminate the power consumption in listening mode with power line communication (PLC) infrastructure, by adding zero-power wakeup receivers to the modems [36]. This promising solution can be extended as a general technology for monitoring and controlling in a smart grid distribution. They show the design of the different hardware sections and, supported by simulations and experimental results, they discuss some considerations about the most efficient configurations and the best routing to wake up a remote PLC modem with the minimum power.

Besides PLC, wireless technology can be used to control street lighting systems. Perandones et al. proposed a LED-based smart street lighting system which allows both autonomous and on-demand control. The system has been tested in a real infrastructure at a University Campus, where every streetlight has been equipped with a wireless communication device that integrates a luminosity sensor, in order to maintain only the necessary light level, and a set of motion sensors, in order to increase the level just when there are pedestrians and vehicles around. Devices communicate through an IEEE802.15.4 radio interface and 6LoWPAN as network protocol, enabling external monitoring/control and between street lights interaction. When autonomously working, a state machine within the Contiki OS decides the most suitable dimming level according to sensor values and other programmable parameters such as illumination thresholds or neighbor configuration. On the other hand, since the system can be controlled remotely, luminosity levels, calibration and behavior parameters can be manually adjusted. Besides, the motion sensors may also be used during daylight to monitor citizen flow, offering additional features as people behavior patterns recognition and security assistance [37]. In another deployment using wireless communication, Jha Ashish et al. showed that deploying smart streetlight management system with the help of the LoRa technology saves energy, cost, and also helps save the environment [38].

3.2.6 Cloud/Fog/Edge for smart cities

Cloud computing and Internet of Things (IoT) are two very different technologies that are both already part of our life. Their adoption and use are expected to be more and more pervasive, making them important components of the Future Internet. A novel paradigm where Cloud and IoT are merged together is foreseen as disruptive and as an enabler of a large number of application scenarios, especially in smart cities. The new CloudIoT paradigm, which involves completely new applications, challenges, and research issues, is detailed by Botta et al. [39]. By analyzing the basics of both IoT and Cloud Computing, the authors discuss their complementarity, detailing what is currently driving to their integration. Thanks to the adoption of the CloudIoT paradigm a number of applications are gaining momentum: we provide an up-to-date picture of CloudIoT applications in literature, with a focus on their specific research challenges The authors also discuss what is already available in terms of platforms–both proprietary and open source–and projects implementing the CloudIoT paradigm.

Another new computing paradigm that offers location-awareness and latency-sensitive monitoring and intelligent control is Fog Computing, which extends the computing to the edge of network. Tang et al. introduce a hierarchical distributed Fog Computing architecture to support the integration of massive number of infrastructure components and services in future smart cities [40]. To secure future communities, it is necessary to integrate intelligence in our Fog Computing architecture, e.g., to perform data representation and feature extraction, to identify anomalous and hazardous events, and to offer optimal responses and controls. The authors analyze case studies using a smart pipeline monitoring system based on fiber optic sensors and sequential learning algorithms to detect events threatening pipeline safety. A working prototype was constructed to experimentally evaluate event detection performance of the recognition of 12 distinct events. These experimental results demonstrate the feasibility of the system's city-wide implementation in the future.

3.3 Smart cities – Internet of Things

3.3.1 Introduction

An acceptable definition of Smart City is the following: “A city can be defined as ‘smart’ when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic development and a high quality of life, with a wise management of natural resources, through participatory governance” [44].

With current rapid urbanization trends it is anticipated, according to Forrester Research, that by the year 2050 6.4 billion of the human population will live in cities outnumbering rural population expected to decrease to 2.8 billion people. This rapid urbanization creates new challenges for advanced services offered to the city population in a number of application areas, made possible by technological advancements. The main technological building blocks behind the Smart City paradigm comprise

- devices, smart devices and more generally “things” deployed at a large scale and having adequate embedded computational capabilities to contribute to a pervasive computing paradigm,
- Ubiquitous high speed networking infrastructure connecting people, places and things and utilizing its networking forerunners of the Semantic Web and the Social Web, and
- Data management, Ambient Intelligence and Data Analytics enabling highly autonomous decision making.

Networked things represent the cornerstone of this evolution making available their data for data analysis and offering their computational resources for computing and decision making at the network edge. It is estimated (Statista 2018) that the installed base of networked devices will grow to 31 billion by year 2020 reaching 75.5 billion by 2025.

The Internet of Things (IoT) is the term used as an umbrella keyword for covering various aspects related to the extension of the Internet and the Web into the physical realm, by means of the widespread deployment of things, i.e. spatially distributed devices with embedded identification, sensing and/or actuation capabilities [45]. The term things refers to anything from sensors and machines to entire buildings, and can include any device capable of participating in a communicating–actuating network, wherein sensors and actuators blend seamlessly with the environment, and the information is shared across platforms in order to develop a common operating picture [46]. Most IoT devices are connected together to form purpose-specific systems, meaning that they are less frequently used as general-access devices on a worldwide network [47].

The IoT pertains a very wide range of applications and helps drive towards a unification of different domains with reference to their conceptualization and applied solutions. One of the primary sectors for IoT application is the manufacturing sector which is already characterized by a high level of automation, digitization and customization. Furthermore, building automation and smart buildings use IoT applications to monitor and adapt building operation. Smart buildings along with city infrastructure (sensing devices, smart public lighting, smart garbage bins, smart parking slots, smart traffic lights, etc) can contribute to the Smart City paradigm leading to city operation optimization and better quality of life. Smart vehicles can self-monitor the health of the vehicle or collaborate with other vehicles and road infrastructure, while IoT medical systems and devices can help monitor patient's condition and offer assistive living anywhere and anytime. These are just some of the potential applications of the IoT in real life applications. Other sectors where IoT is spreading also mapping to the Smart City paradigm include smart grid and energy, smart agriculture, security and safety of critical infrastructures, and smart environment. Understandably the potential economic impact of IoT systems is huge, estimated between 900 billion USD and 2.3 trillion USD on a yearly basis up to 2025 [48].

3.3.2 Reference Architectures

The extreme heterogeneity of application environments for IoT systems makes it very difficult to identify solutions that can satisfy the requirements of all possible scenarios. The systems novelty and varying complexity only add difficulty to the establishment of best practices in the realization of an IoT system [49].

To solve this problem, reference architectures are developed. A reference architecture provides guidance for the development of system, solution and application architectures. It provides common and consistent definitions in the system of interest, its decompositions and design patterns, and a common vocabulary with which to discuss the specification of implementations so that options may be compared [50].

Reference architectures need to fulfill some general requirements. To support the broad applicability of IoT systems, an architecture must be generic and remain at a high level of abstraction, so as not to enforce unnecessary restrictions to system applications. Ideally it should intend to transcend today's available technologies and so be able to identify technology gaps based on the architectural requirements [51].

Architectures must be highly scalable to be able to support a number of devices ranging from a few to millions, while remaining affordable for small deployments. An architecture must also be able to support device management for different types of devices as well as data collection, analysis and actuation for all these devices. Data must be collected, stored, analyzed and acted upon. It is obvious that overtime the amount of data will become extremely high, which calls for a scalable storage system as well.

Connectivity and communication between all physical components is of utmost importance to ensure the proper operation of the IoT network. Since most IoT systems are event driven, communication should be done using protocols that support event-style communication. Finally, since we are talking about an Internet system, security is vital in all parts of the network: devices, physical network and middleware.

A general organization of an IoT system is presented in Figure 2.

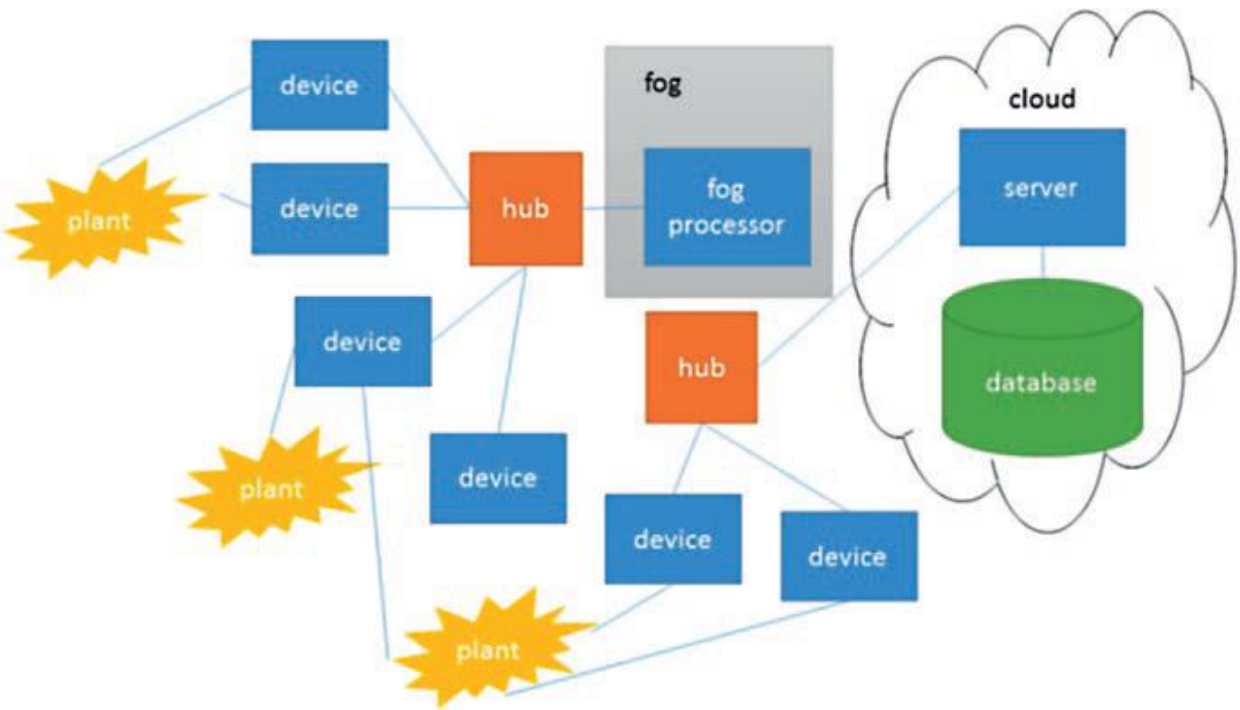


Figure 2 Organization of an IoT system

A general reference architecture for IoT systems is presented in [52]. The outline of the architecture is shown in Figure 3. The different layers of the architecture are briefly explained below.

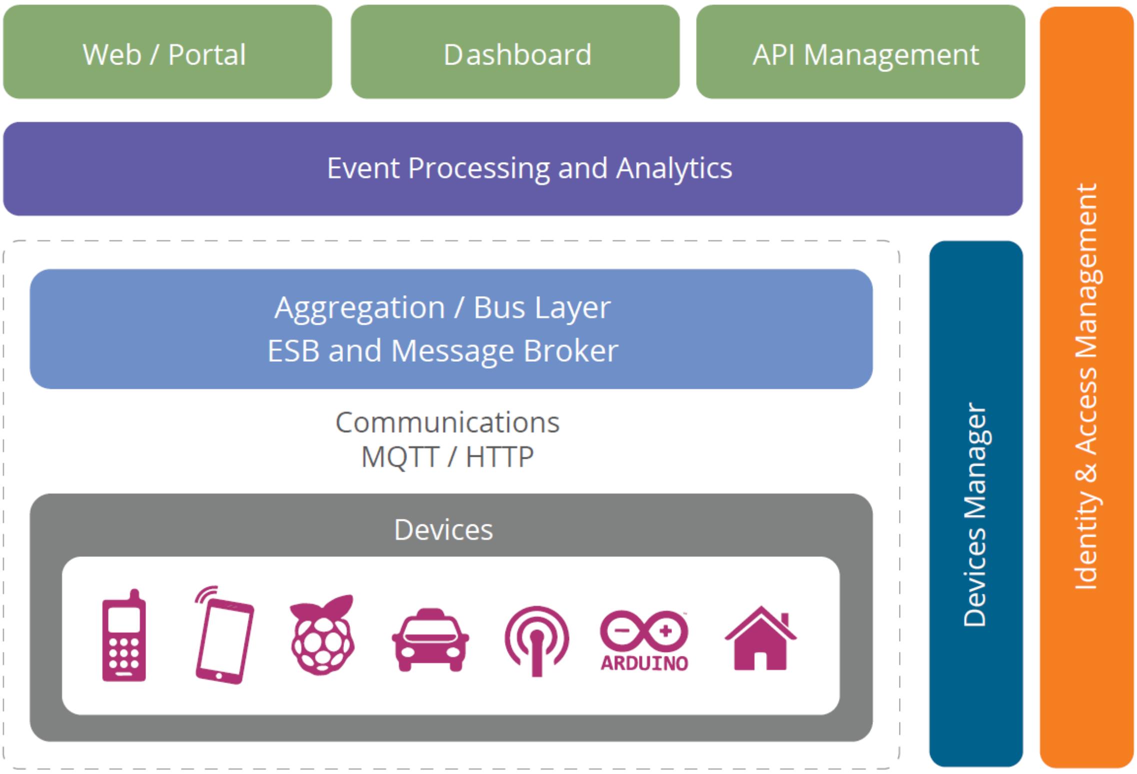


Figure 3 Reference architecture for IoT

The bottom layer of the architecture is the device layer. Devices in the layer can be of various types, under the condition that each device can either directly or indirectly attach to the Internet. IoT devices should operate at extremely low power levels but often not operate continuously. They must integrate processors, memory and storage, communication, and sensors. Each device must be discoverable in the system through a unique identifier, often in the form of a hardware manufacturer code.

The communications layer connects all physical devices. There are several communication protocols that can be used to this end, with no single standard having been reached yet. In the presented architecture two protocols are suggested. HTTP uses a request/response pattern, while MQTT is a publish/subscribe protocol which leads to less coupling between client and server and has a very low overhead.

The aggregation/bus layer aggregates and brokers communications from different devices and routes communications to a specific device. It can also transform and bridge between different communication protocols.

The event processing and analytics layer takes the events from the bus and provides the ability to process and act upon these events. A core capability here is the requirement to store the data into a database.

The external communications layer provides a way for the devices to communicate outside of the device-oriented system.

The device management crosscutting layer communicates with devices via various protocols and provides both individual and bulk control of devices while maintaining the list of device identities and map these into owners.

Identity and access management layer provides identity and validation services to the system.

Apart from the general architecture requirements and the basic outline presented above there have been several initiatives and efforts to create IoT reference architectures that are targeted towards more specific sectors where IoT systems apply. Some of these reference architectures are presented in the following section.

3.3.2.1 Application specific reference architectures

3.3.2.1.1 Industrial Internet of Things

The Industrial Internet of Things is part of the general IoT evolution. However, it faces challenges that are unique and differentiate it from the other systems and services of IoT, mainly due to the need to integrate the infrastructure of the Operation Technology (OT) with the typical Information Technology (IT). This will create an integrated system that can manage the complete manufacturing hierarchy, from business processes to sensors, which provides significant flexibility and presents new opportunities to enterprises. Although the manufacturing environment is the primary and most important application domain of the IIoT, it is applicable in other domains as well, which characteristics and challenges are similar, including for instance critical infrastructure protection, transportation, energy and healthcare, being identified by the common term "industry". In this context relevant reference architectures could be valuable for the Smart City paradigm.

Several initiatives deal with the adoption of IoT in industry, i.e. Industrial IoT (IIoT). The Industrial Internet Consortium (IIC) and the Industrie 4.0 Platform are two of the mainstream initiatives towards standardization of IIoT systems, supplemented by further initiatives such as Japan's Society 5.0 and Made in Chine 2025. The two aforementioned mainstream initiatives that have already produced Reference Architectures are briefly presented below.

3.3.2.1.1.1 Reference Architectural Model Industrie 4.0 (RAMI 4.0)

Platform Industrie 4.0 (I4.0) [53] is a high-tech strategy of the German Government, promoting computerization in manufacturing. It connects / merges production (OT) with information and communication technology (IT) and merges customer and machine data to enable higher, more flexible and efficient productivity and new services. In order to do this, it is essential to create a reference architecture that will serve as a common language to all stakeholders. This led to the creation of RAMI 4.0, a three dimensional map that shows how to approach the issue of Industrie 4.0 in a structured manner. The reference model of the architecture is shown in figure 3.

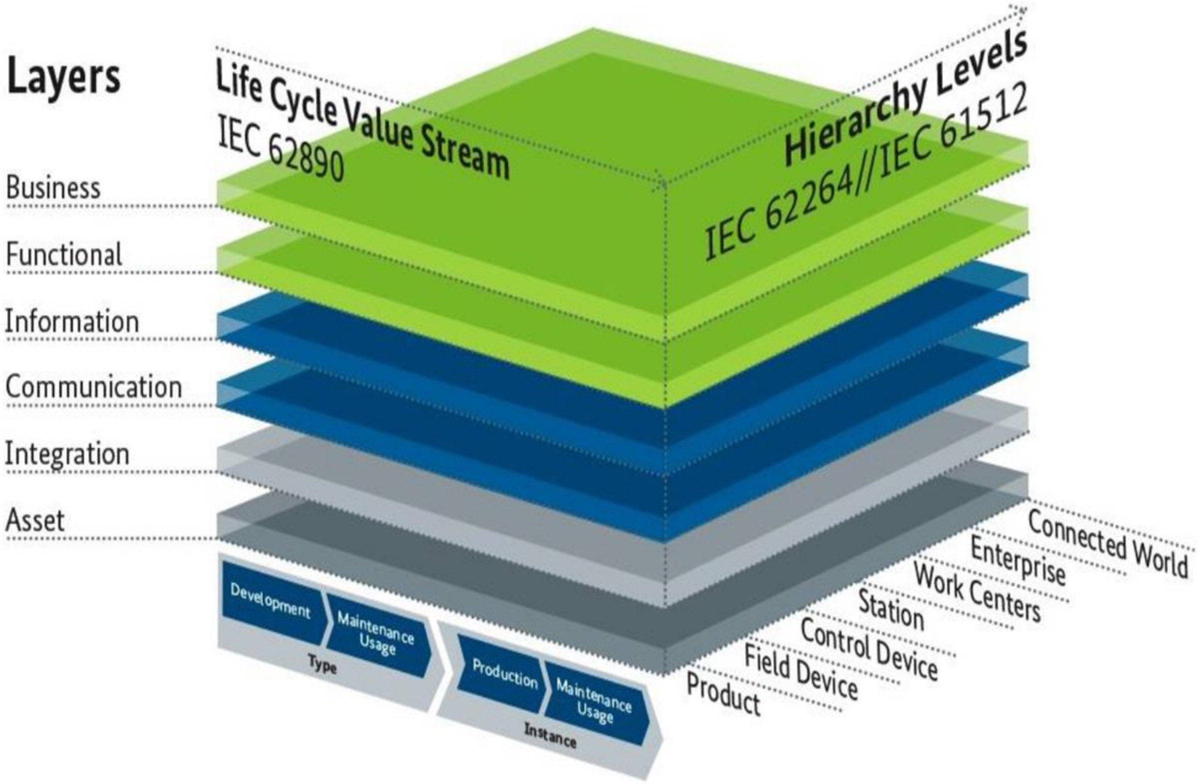


Figure 4 RAMI 4.0 model

As we can see RAMI 4.0 is a three dimensional service oriented architecture that combines all elements in a layer and life cycle model. The three dimensions are Hierarchy, Architecture and Product Life Cycle.

The first axis, Hierarchy, highlights the different approach that IIoT takes compared to previous models. Industrial IoT does not follow the hardware based classical industrial environment hierarchy (figure 4) but instead presents a flat and flexible hierarchy that distributes functions and integrates smart products (figure 5).

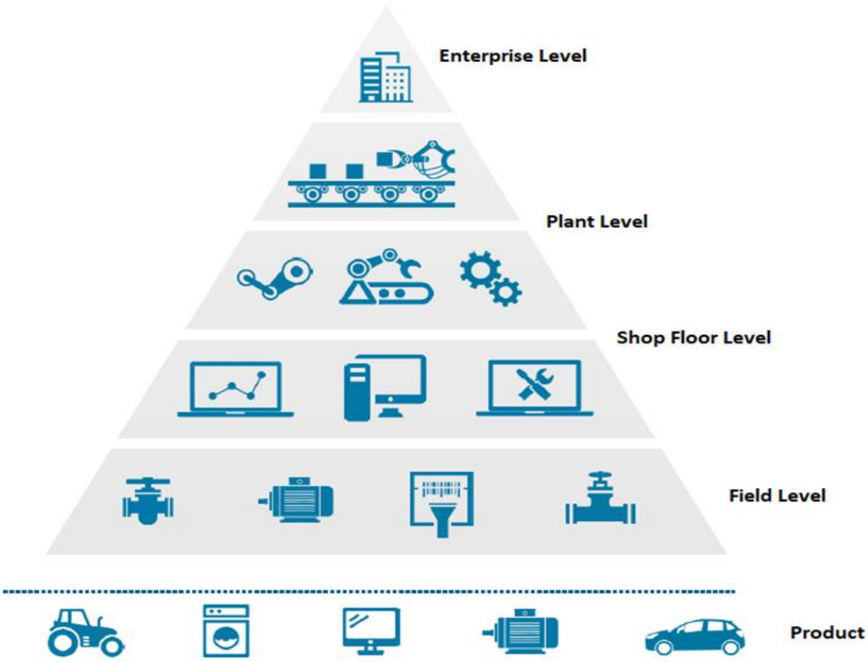


Figure 5 Classical industrial environment hierarchy

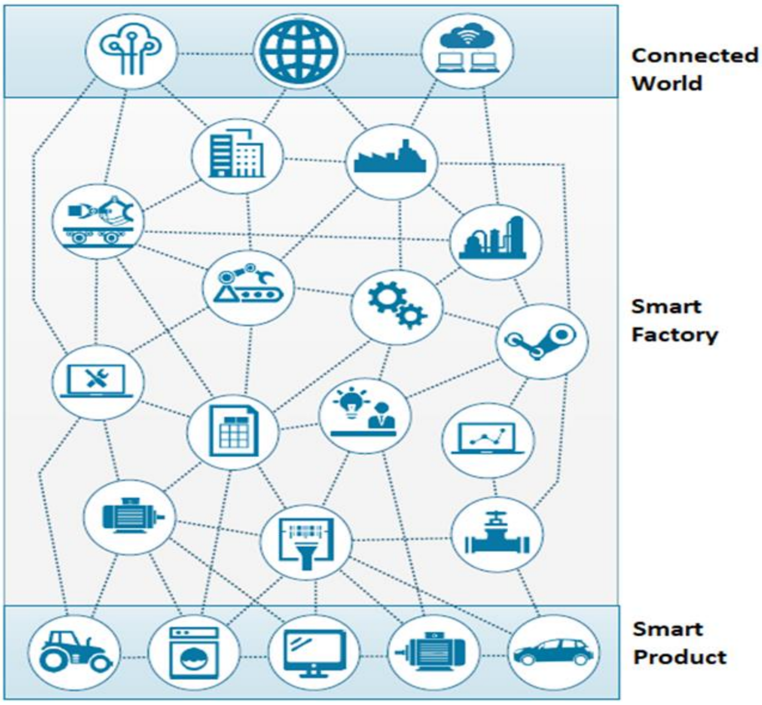


Figure 6 RAMI 4.0 hierarchy axis

The architectural axis comprises of six layers which are shown in figure 6.

Figure 7 RAMI 4.0 architecture axis

Finally, the third axis is product life cycle. The life cycle of a product is broken down into 2 methods with two phases in each one. The first method, Type, refers to a product in the development or re-design phase. The second method, Instance, covers the production and facility management phases of the product life cycle. These are presented in figure 7.

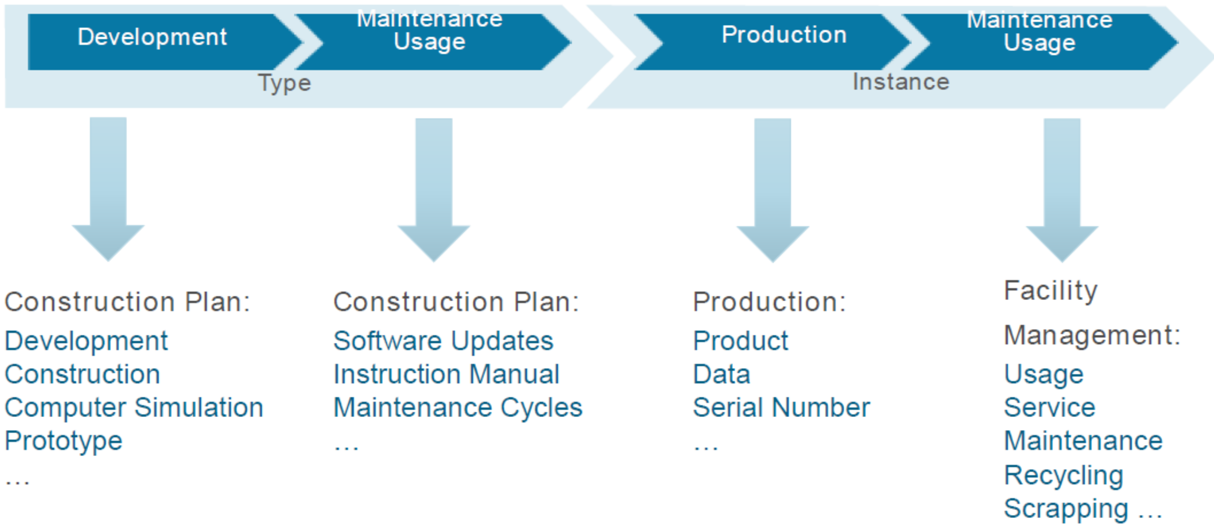


Figure 8 RAMI 4.0 product life cycle axis

At the core of the RAMI 4.0 application is the I4.0 component. Between the physical asset and the communication layer of I4.0 lies the Administration Shell. The Administration Shell is the interface connecting I4.0 to the physical thing, which stores all data and information about the asset and serves as the network's standardized communication interface. It is possible for a shell to refer to multiple assets that are related to each other.

The Administration shell consists of the Manifest, which stores all data about the assets and the Component Manager which includes all necessary APIs to make services externally available. The structure of the administration shell is presented in figure 8.

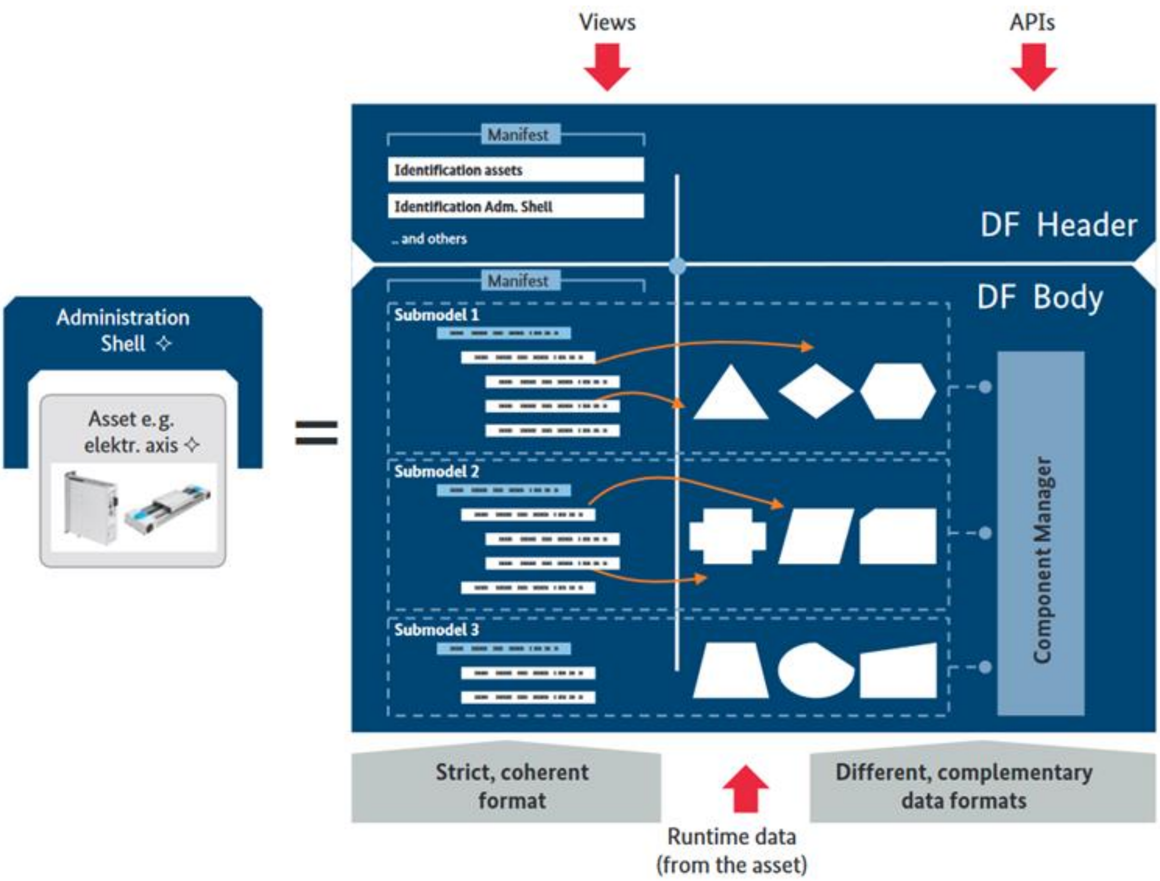


Figure 9 Administration shell structure

3.3.2.1.1.2 Industrial Internet Reference Architecture

The Industrial Internet Contortium (IIC) [54] was founded in 2014 as an open membership organization aiming to bring together industry players to accelerate the development, adoption and widespread use of Industrial Internet technologies. As a result the Industrial Internet Reference Architecture (IIRA) was developed.

IIRA deals with different industrial sectors ranging from manufacturing and transportation to energy and healthcare.

The architecture is based on four viewpoints, each one associated with particular stakeholders and their concerns. It can also be related to product lifecycle process and specialized according to the industrial sector in question. This is all presented in figure 9.

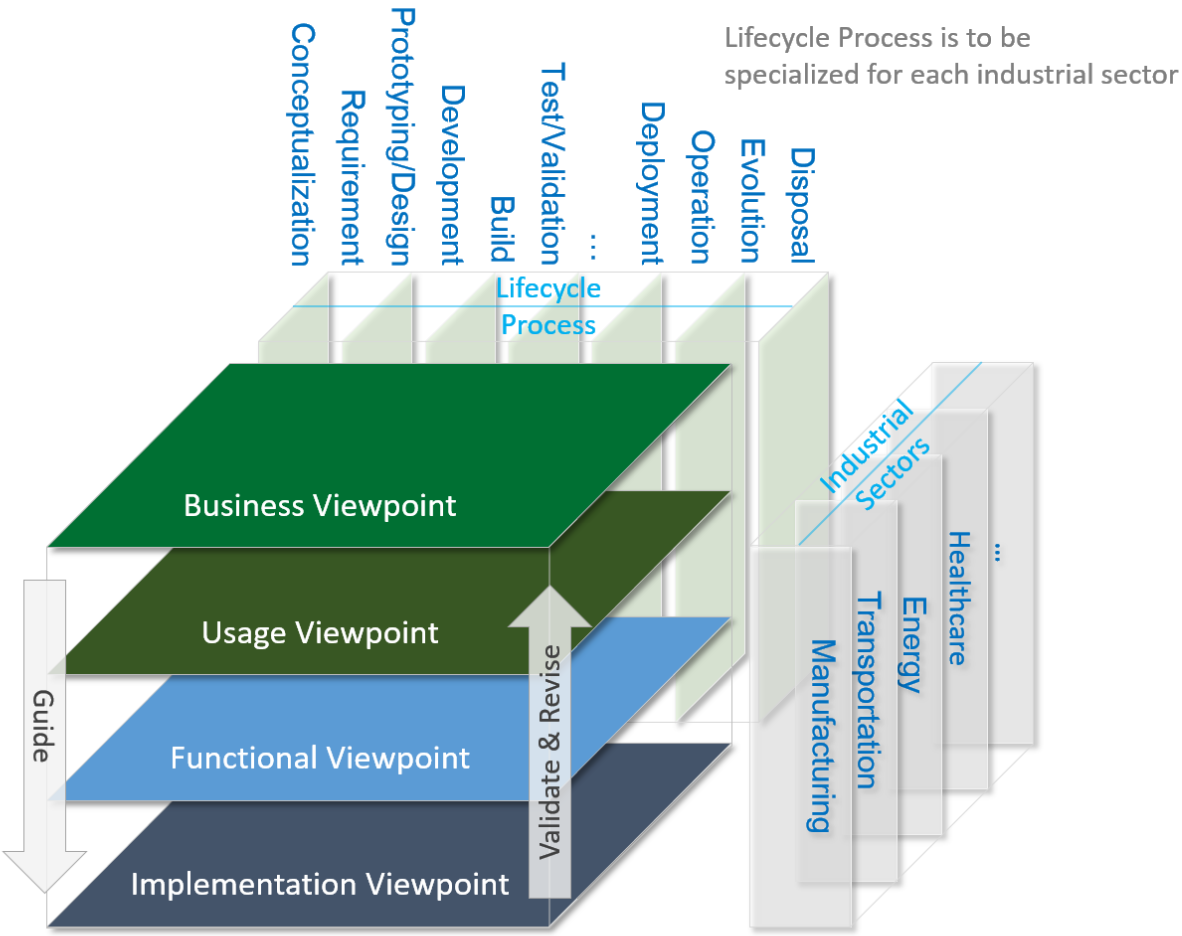


Figure 10 IIRA viewpoint architecture

Business viewpoint refers to business-oriented concerns such as business value, expected return on investment, cost of maintenance and product liability. The viewpoint can be seen in figure 10, while major components of the viewpoint are explained below.

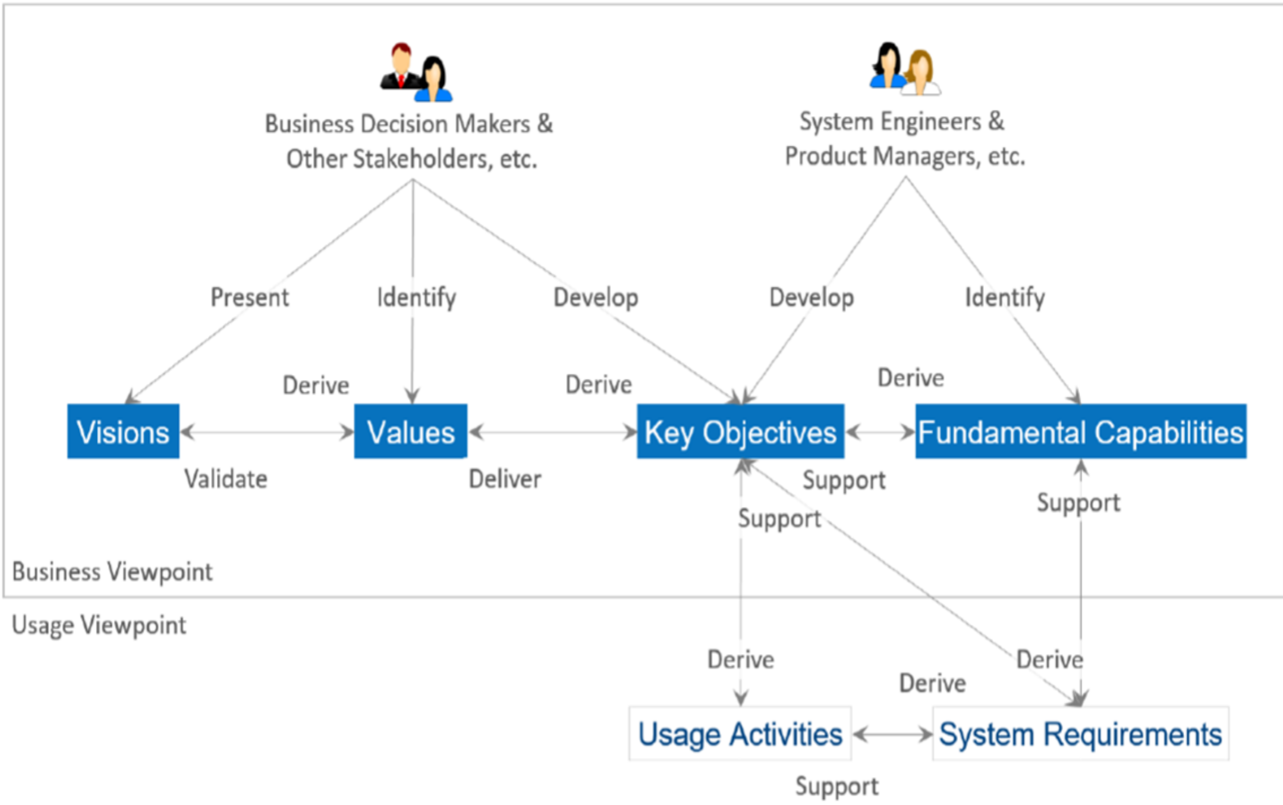


Figure 11 IIRA Business viewpoint

Stakeholders have a major stake in the business and strong influence in its direction. They include those who drive the conception and development of IIoT systems in an organization. Vision describes a future state of an organization or an industry and provides the business direction toward which an organization executes. Values reflect how the vision may be perceived by the stakeholders who will be involved in funding the implementation of the new system as well as by the users of the resulting system. Key objectives are quantifiable high-level technical and ultimately business outcomes expected of the resultant system in the context of delivering the values. Key objectives should be measurable and time-bound. Fundamental capabilities refer to high-level specifications of the essential ability of the system to complete specific major business tasks.

Usage viewpoint (figure 11) is concerned with how an IIoT system realizes the key capabilities identified in the business viewpoint. The usage viewpoint describes the activities that coordinate various units of work over various system components. The basic unit of work is a task which is carried out by a party assuming a role. A role is a set of capacities assumed by an entity to initiate and participate in the execution of, or consume the outcome of, some tasks or functions in an IIoT system as required by an activity. Roles are assumed by parties. A party is an agent, human or automated, that has autonomy, interest and responsibility in the execution of tasks. A party executes a task by assuming a role that has the right capacities for the execution of the task. An activity is a specified coordination of tasks (and possibly of other activities, recursively) required to realize a well-defined usage or process of an IIoT system.

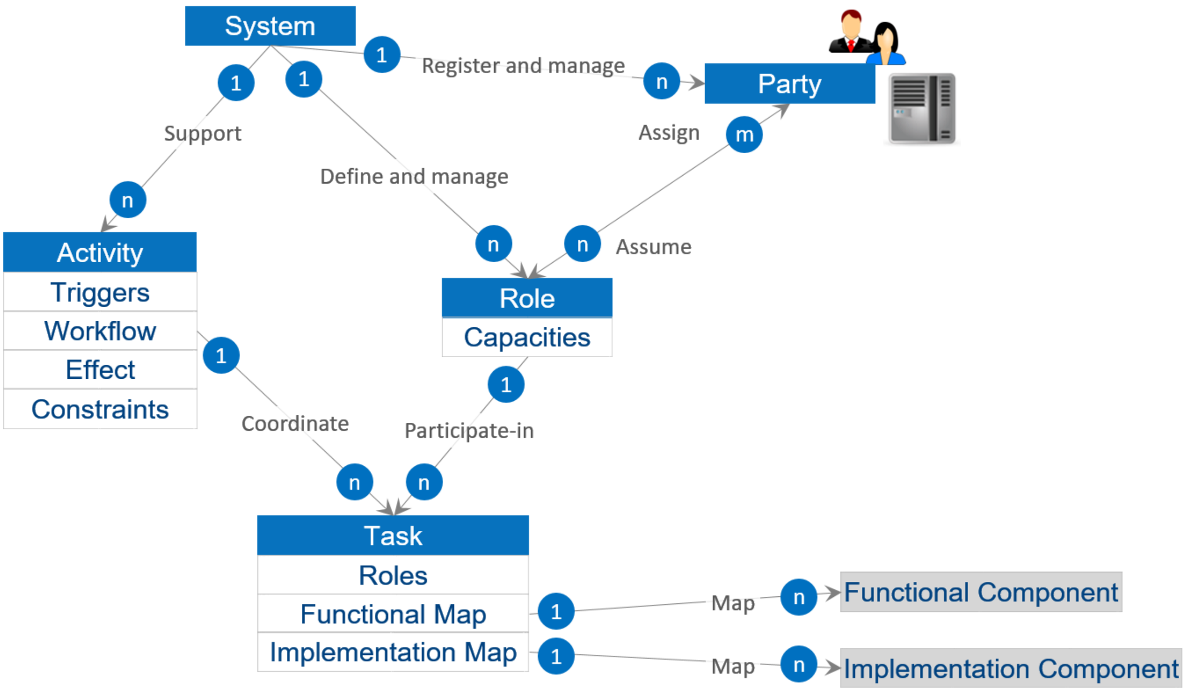


Figure 12 IIRA Usage viewpoint

Functional viewpoint focuses on IIoT System functional components, structure and interrelation, interfaces and interactions. It can be decomposed into five functional domains:

- Control domain which represents the collection of functions that are performed by industrial control systems. The core of these functions comprises reading data from sensors, applying rules and logic, and exercising control over the physical system through actuators.
- Operations domain which represents the collection of functions responsible for the provisioning, management, monitoring and optimization of the systems in the control domain.
- Information domain which represents the collection of functions for gathering data from various domains, most significantly from the control domain, and transforming, persisting,

and modeling or analyzing those data to acquire high-level intelligence about the overall system.

- Application domain which represents the collection of functions implementing application logic that realizes specific business functionalities. Functions in this domain apply application logic, rules and models at a coarse-grained, high level for optimization in a global scope.
- Business domain which includes functions that enable end-to-end operations of the industrial internet of things systems by integrating them with traditional or new types of industrial internet systems specific business functions including those supporting business processes and procedural activities.

The entire picture of the functional viewpoint is shown in figure 12.

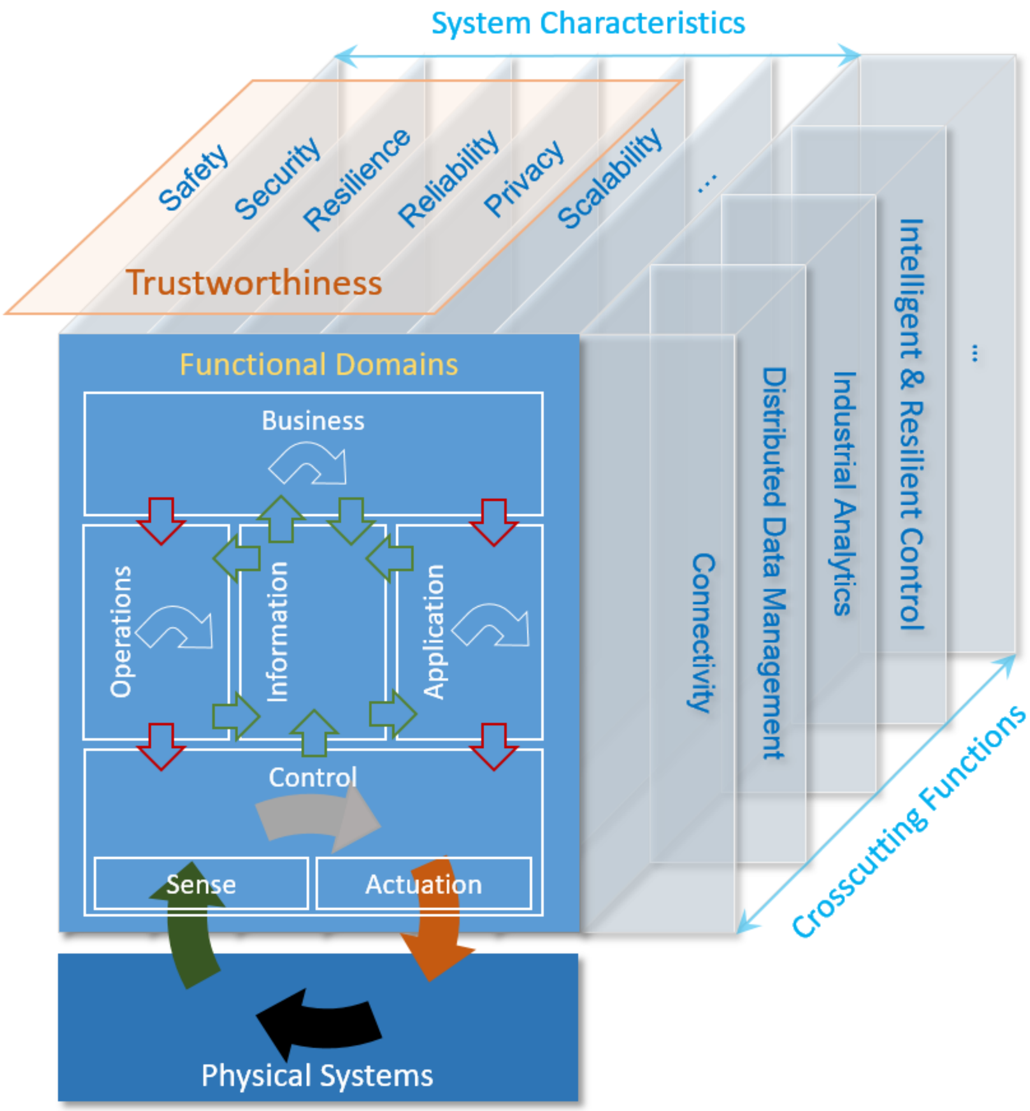


Figure 13 IIRA functional viewpoint

Finally the implementation viewpoint is concerned with the technical representation of an IIoT system and the technologies and system components required implementing the activities and functions prescribed by the usage and functional viewpoints. IIoT system implementations follow certain well-established architectural patterns, such as:

- Three-tier architecture pattern
- Gateway-Mediated Edge Connectivity and Management architecture pattern
- Layered Databus pattern.

These patterns are presented below.

The three-tier architecture pattern comprises edge, platform and enterprise tiers. These tiers play specific roles in processing the data flows and control flows involved in usage activities. They are connected by three networks, as shown in Figure 14.

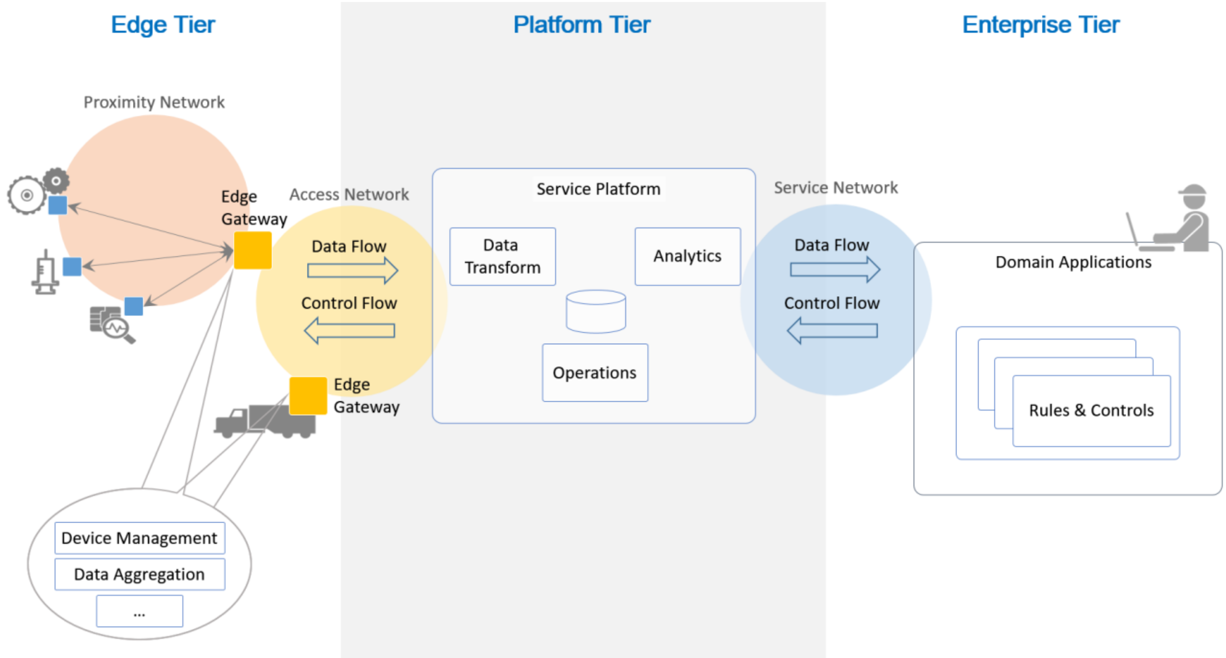


Figure 14Three-Tier IIoT System Architecture

The edge tier collects data from the edge nodes, using the proximity network. The architectural characteristics of this tier, including the breadth of distribution, location, governance scope and the nature of the proximity network, vary depending on the specific use cases.

The platform tier receives, processes and forwards control commands from the enterprise tier to the edge tier. It consolidates processes and analyzes data flows from the edge tier and other tiers. It provides management functions for devices and assets. It also offers non-domain specific services such as data query and analytics.

The enterprise tier implements domain-specific applications, decision support systems and provides interfaces to end-users including operation specialists. The enterprise tier receives data flows from the edge and platform tier. It also issues control commands to the platform tier and edge tier.

Tiers are connected via different networks:

The proximity network connects the sensors, actuators, devices, control systems and assets, collectively called edge nodes. It typically connects these edge nodes, as one or more clusters related to a gateway that bridges to other networks.

The access network enables connectivity for data and control flows between the edge and the platform tiers. It may be a corporate network, or an overlay private network over the public Internet or a 4G/5G network.

Service network enables connectivity between the services in the platform tier and the enterprise tier, and the services within each tier. It may be an overlay private network over the public Internet or the Internet itself, allowing the enterprise grade of security between end-users and various services.

The three-tier architecture pattern combines major components (e.g. platforms, management services, applications) that generally map to the functional domains (functional viewpoint) as shown in Figure 15. From the tier and domain perspective, the edge tier implements most of the control domain; the platform tier most of the information and operations domains; the enterprise tier most of the application and business domains.

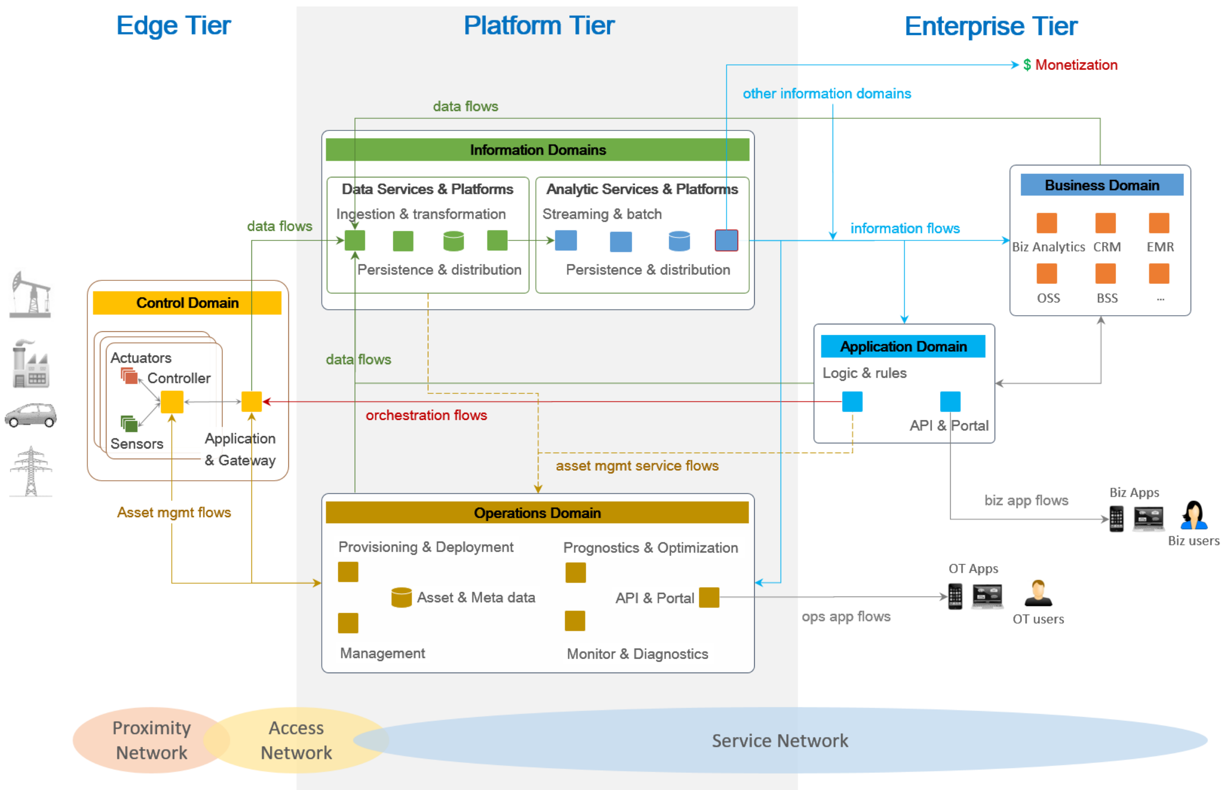


Figure 15 Mapping between a three-tier architecture to the functional domains

The Gateway-Mediated Edge Connectivity and Management architecture pattern comprises a local connectivity solution for the edge of an IIoT system, with a gateway that bridges to a wide area network as shown in Figure 16. The gateway acts as an endpoint for the wide area network while isolating the local network of edge nodes. This architecture pattern allows for localizing operations and controls (edge analytics and computing). Its main benefit is in breaking down the complexity of IIoT systems, so that they may scale up both in numbers of managed assets as well as in networking.

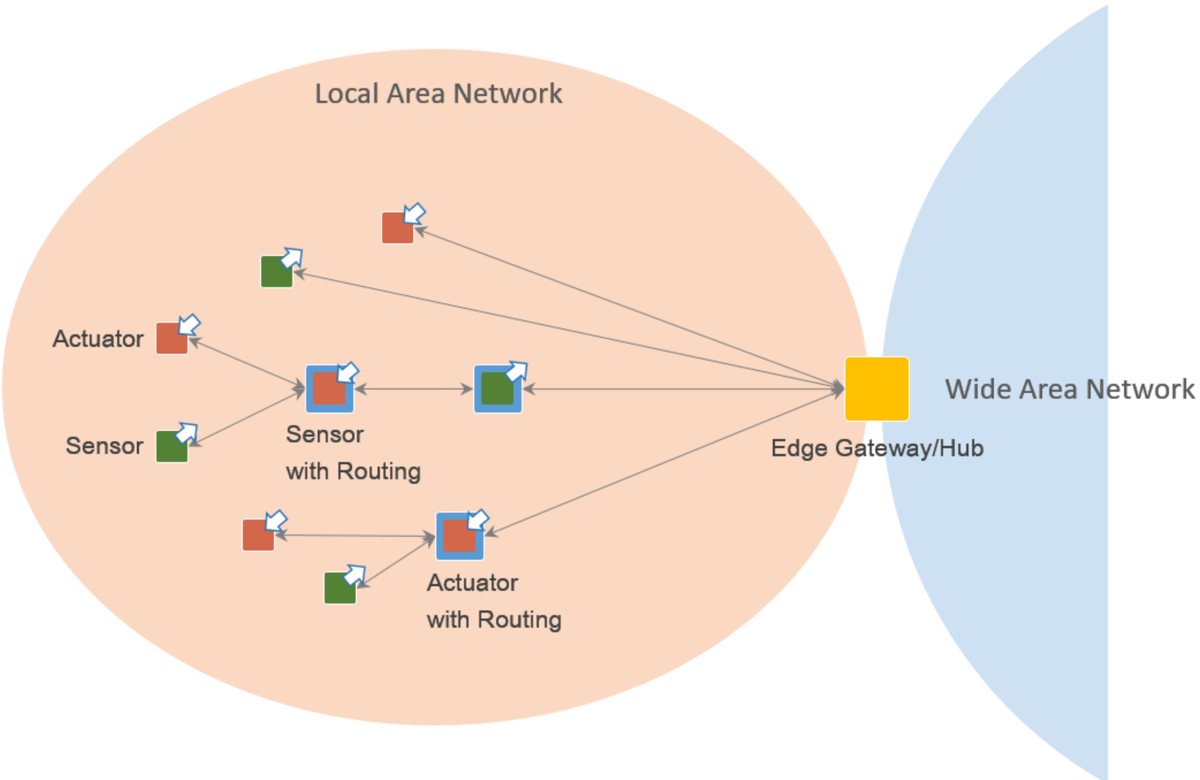


Figure 16 Gateway-Mediated Edge Connectivity and Management Pattern

The edge gateway may also be used as a management point for devices and assets and data aggregation point where some data processing and analytics, and control logic are locally deployed.

The local network may use different topologies.

In a hub-and-spoke topology, an edge gateway acts as a hub for connecting a cluster of edge nodes to each other and to a wide area network. It has a direct connection to each edge entity in the cluster allowing in-flow data from the edge nodes, and out-flow control commands to the edge nodes.

In a mesh network (or peer-to-peer) topology, an edge gateway also acts as a hub for connecting a cluster of edge nodes to a wide area network. In this topology, however, some of the edge nodes have routing capability. As result, the routing paths from an edge node to another and to the edge gateway vary and may change dynamically. This topology is best suited to provide broad area coverage for low-power and low-data rate applications on resource-constrained devices that are geographically distributed.

In both topologies, the edge nodes are not directly accessible from the wide area network. The edge gateway acts as the single-entry point to the edge nodes and as management point providing routing and address translation.

The edge gateway supports the following capabilities:

- Local connectivity through wired serial buses and short-range wireless networks. New communication technologies and protocols are emerging in new deployments.
- Network and protocol bridging supporting various data transfer modes between the edge nodes and the wide area network: asynchronous, streaming, event-based and store-and-forward.
- Local data processing including aggregation, transformation, filtering, consolidation and analytics.
- Device and asset control and management point that manages the edge nodes locally and acts an agent enabling remote management of the edge nodes via the wide area network.
- Site-specific decision and application logic that are perform within the local scope.

The layered databus is a common architecture across IIoT systems in multiple industries (Figure 17). This architecture provides low-latency, secure, peer-to-peer data communications across logical layers of the system. It is most useful for systems that must manage direct interactions between applications in the field, such as control, local monitoring and edge analytics.

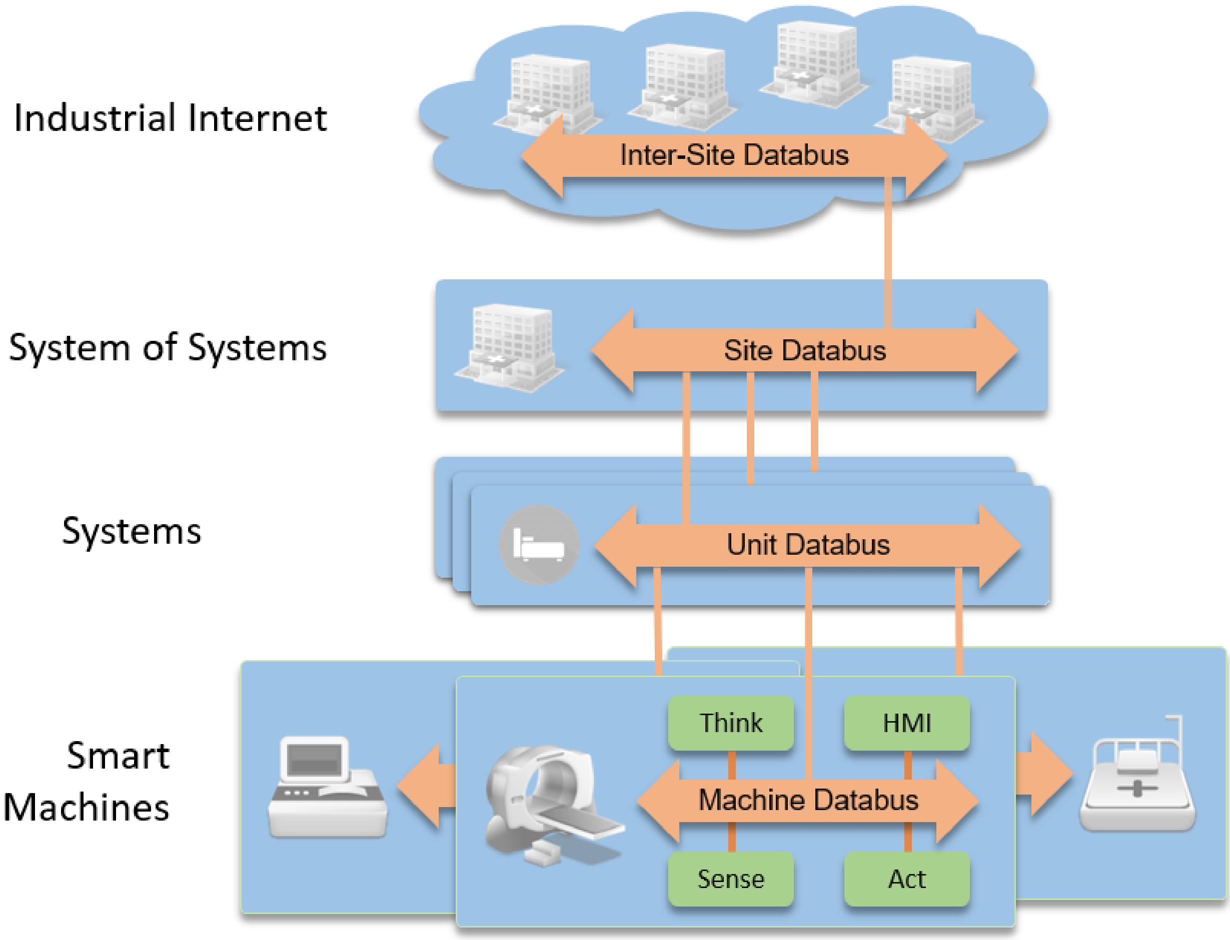


Figure 17 Layered Databus Architecture

At the lowest level, smart machines use databuses for local control, automation and real-time analytics. Higher-level systems use another databus for supervisory control and monitoring. Federating these systems into a “system of systems” enables complex, Internet-scale, potentially-cloud-based, control, monitoring and analytic applications.

A databus is implements a common data model, allowing interoperable communications between endpoints at that layer.

The databus supports communication between applications and devices. For instance, a databus can be deployed within a smart machine to connect its internal sensors, actuators, controls and analytics. At a higher smart system level, another databus can be used for communications between machines. At a system of systems level, a different databus can connect together a series of systems for coordinated control, monitoring and analysis. Each databus may have a different set of schema or data model. Data models change between layers, as lower-level databuses export only a controlled set of internal data. a logical connected space that implements a set of common schema and communicates using those set of schema between endpoints. Each layer of the databus therefore implements a common data model, allowing interoperable communications between endpoints at that layer.

The databus supports communication between applications and devices. For instance, a databus can be deployed within a smart machine to connect its internal sensors, actuators, controls and analytics. At a higher smart system level, another databus can be used for communications between machines. At a system of systems level, a different databus can connect together a series of systems for coordinated control, monitoring and analysis. Each databus may have a different set of schema or data model. Data models change between layers, as lower-level databuses export only a controlled set of internal data.

3.3.2.1.1.3 RAMI 4.0 and IIRA mapping

There are efforts for a mapping between IIRA and RAMI 4.0 that recognize the commonalities between the two Reference Architectures. The functional mapping of IIRA to the RAMI 4.0 architecture layers is shown in figure 13.

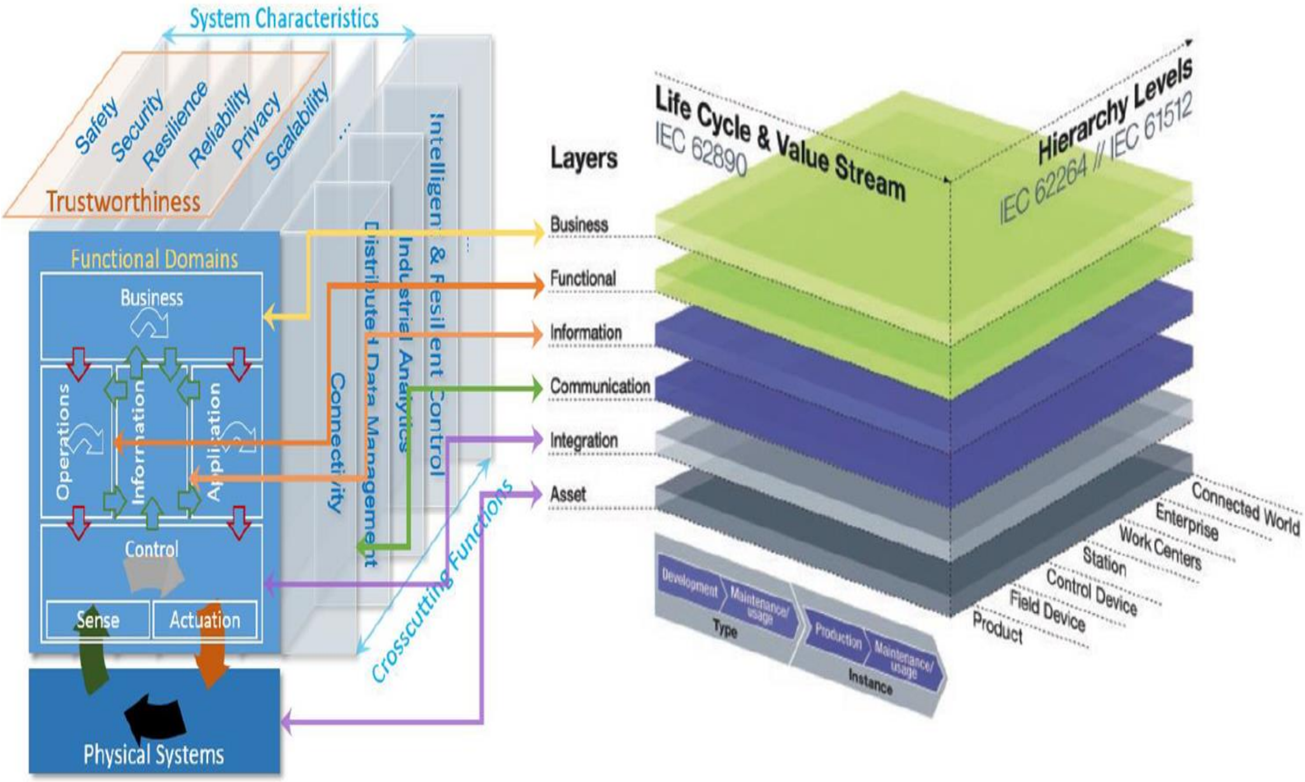


Figure 18 Functional mapping between IIRA and RAMI 4.0

3.3.2.1.2 Smart City sector

In this section a reference architecture for urban IoT systems is presented. Urban IoT systems are designed to support the Smart City vision, which aims at exploiting the most advanced communication technologies to support added-value services for the administration of the city and for the citizens. In their paper, Zanella et al. provide a reference architecture specifically targeted to Smart City applications. The goal of IoT in smart cities is to create a communication infrastructure that provides unified, simple, and economical access to a plethora of public services, thus unleashing potential synergies and increasing transparency to the citizens. A Smart City IoT infrastructure integrates all the different technologies and already existing communication infrastructures to support the interconnection of other devices and produce new services. Another fundamental aspect is the necessity to make (part of) the data collected by the urban IoT easily accessible by authorities and citizens, to increase the responsiveness of authorities to city problems, and to promote the awareness and the participation of citizens in public matters [55].

The IoT network is based on a web service approach and the general architecture is shown in Figure 19. IoT services in the proposed architecture are designed in accordance with the ReST paradigm, which means that they exhibit very strong similarity with traditional web services, thus greatly facilitating the adoption and use of IoT by both end users and service developers. A reference protocol architecture is presented in Figure 20.

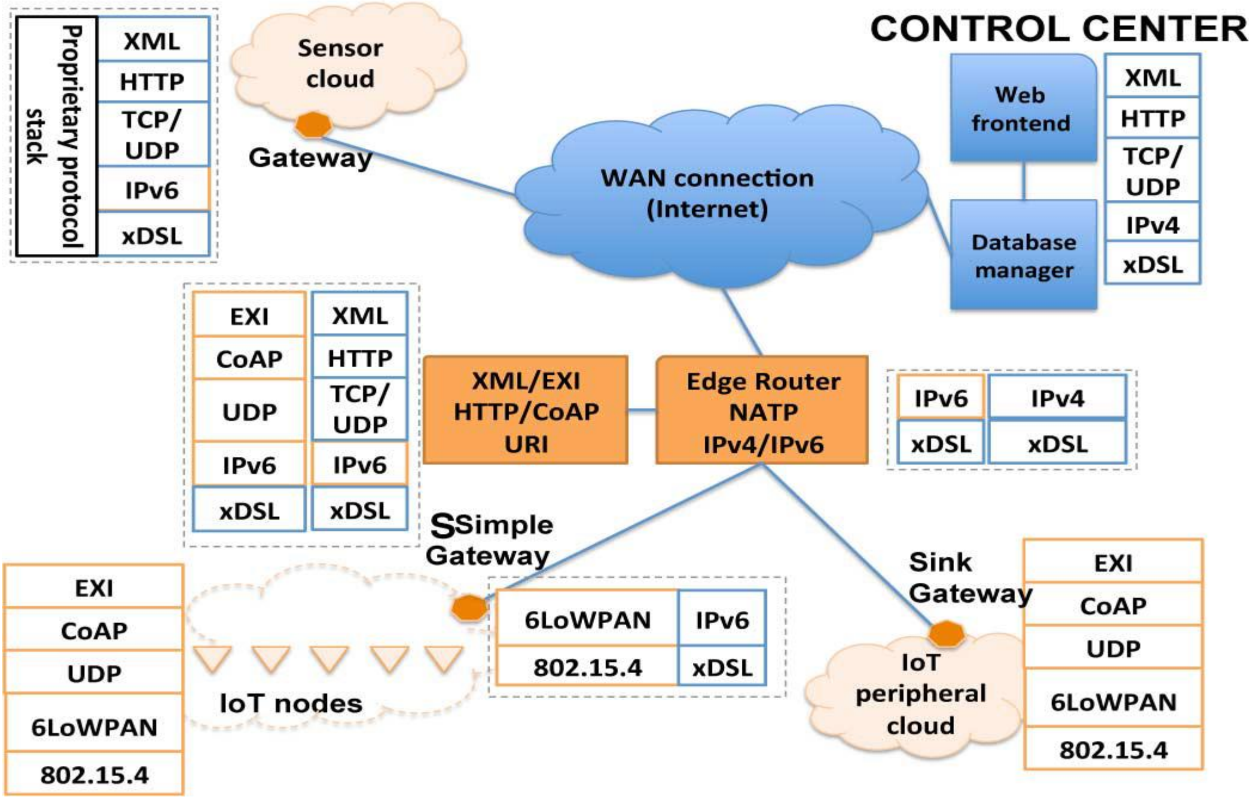


Figure 19 Smart City IoT network representation

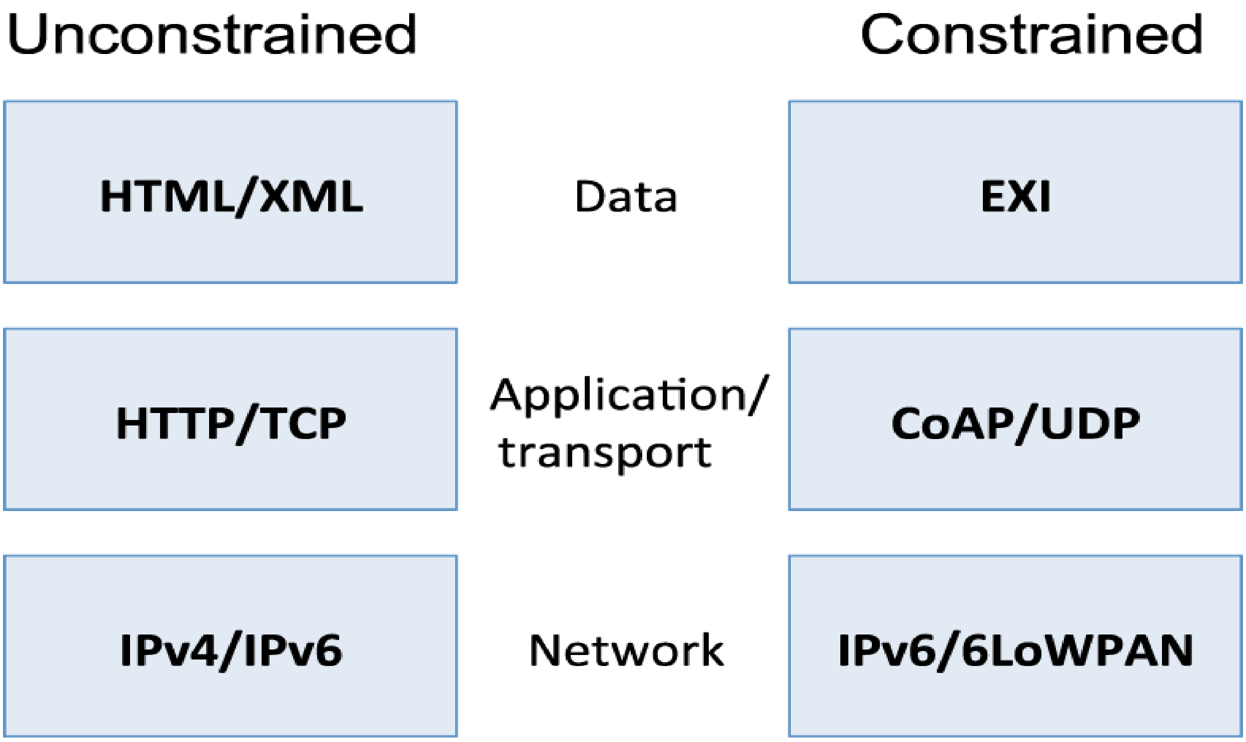


Figure 20 Reference protocol architecture

The data layer uses Efficient XML Interchange (EXI) for data exchange. By using EXI instead of XML, even the most constrained devices can natively support and generate messages using an open data format compatible with XML, without sacrificing their limited capacity to the large size of XML messages.

Application and transport layers rely on the Constrained Application Protocol (CoAP). CoAP reduces the amount of data required when using the typical HTTP protocol while still supporting the ReST methods. Even though regular Internet hosts can natively support CoAP to directly talk to IoT devices, the most general and easily interoperable solution requires the deployment of an HTTP-CoAP intermediary, also known as cross proxy that can straightforwardly translate requests/responses between the two protocols, thus enabling transparent interoperation with native HTTP devices and applications [56].

In network layers, while the adoption of IPv6 addressing would be possible, the introduced overhead is not compatible with the scarce capabilities of constrained nodes. For this reason the adoption of 6LoWPAN, which is an established compression format for IPv6 and UDP headers over low-power constrained networks is proposed in this architecture.

An urban IoT system, due to its inherently large deployment area, requires a set of link layer technologies that can easily cover a wide geographical area and, at the same time, support a possibly large amount of traffic resulting from the aggregation of an extremely high number of smaller data flows. Due to the constrained characteristics of the system nodes, the proposed technologies are generally characterized by low energy consumption and relatively low transfer rates. Some solutions in this category are IEEE 802.15.4, Bluetooth and Bluetooth Low Energy, IEEE 802.11 Low Power, PLC , NFC and RFID.

At the lowest layer which represents the physical devices of the system we find all the essential devices for the realization of an Urban IoT system. Backend servers are in charge of collecting, storing and processing data to produce added-value services to the system. Database management systems store the collected data while web sites and Enterprise resource planning systems (ERP) act as the final interconnecting nodes between the system and the users.

Towards the edge of the system gateways are used to interconnect the end devices to the main communication infrastructure of the system. Gateway devices shall also provide the interconnection between unconstrained link layer technologies, mainly used in the core of the IoT network, and constrained technologies that, instead, provide connectivity among the IoT peripheral nodes.

Finally, at the periphery of the IoT system, we find the devices in charge of producing the data to be delivered to the control center, which are usually called IoT peripheral nodes. These devices can be anything from a sensor/actuator to a mobile device like a smartphone used to interact with the IoT.

3.3.3 IoT Middleware Platforms

The Platform tier in the Smart City paradigm is intended to provide an intermediate tier between the Edge tier dealing with connected devices and things and the Cloud tier. Its primary role is to provide the necessary middleware for data aggregation; the data analytics part being allocated primarily on the Cloud tier. There are different solutions for this tier both open and proprietary. The most important among them and their characteristics are presented in this section. Esmartcity project focuses primarily on open solutions, yet for the sake of completeness of the current state-of-the-art both open source and proprietary solutions are presented.

3.3.3.1 Open Source solutions

Kaa (https://www.kaaproject.org/) is a multi-purpose middleware platform for the Internet of Things that allows building complete end-to-end IoT solutions, connected applications, and smart products. Kaa provide an endpoint SDK in C, C++, Java, Objective-C for all platforms allowing programming devices to connect to the Kaa Server. For devices with implemented interfaces such as MQTT or OPC UA proxies must be developed. Kaa Server manages the connected devices through configuration and programmable application by Kaa SDK. Also, REST API is provided. Kaa Server is scalable, it can be applied in clustered mode. Security in Kaa is limited to hybrid encryption with RSA and AES at the connection between SDK and server. The aggregated data can be used by pre-integrated data processing systems, like MongoDB, Cassandra (NoSQL), Apache Spark (Big Data Analytics) and Apache Fume (Streaming) or by any other system after creating interface using SDK.

Thingsboard (https://thingsboard.io/) is an Open source IoT platform and can host it as a SaaS or PaaS solution. IT provides device management, data collection, processing and visualization for IoT projects. The standard protocols it supports for providing device connectivity are MQTT, CoAP and HTTP. Also, it can connect with PLCs over OPC UA and supports both sandbox and cluster deployments. ThingsBoard provide REST API for device, gateway, server, application configuration and management. It supports device security through authentication tokens. Also, it has a native functionality of data visualization and rule based data filtering. Finally, it can be integrated with Apache Spark for advanced data analytics and Apache Kafka for streaming data.

DeviceHive (https://devicehive.com/) is an open source platform which provides instruments for smart device communication and management. It consists of the communication layer, control software and multi-platform libraries and clients to bootstrap development of smart energy, home automation, remote sensing, telemetry, remote control and monitoring software and much more. DeviceHive provides REST, Websocket APIs by default + MQTT API as an additional plugin. All communication is performed via JSON messages. Through DeviceHive API, a RESTful service, and GUI administration panel, the user can configure the resources and the server. DeviceHive behavior may be customized by running custom python, java or javascript code. It supports Big data solutions such as ElasticSearch, Apache Spark, Cassandra and Kafka for real-time and batch processing. It comes with Apache Spark and Spark Streaming support. It allows running batch analytics and machine learning on top of your device data.

OpenHab (https://www.openhab.org/) is an IoT framework capable of running on any device that can run a Java Virtual Machine and is focused on home automation. It is mainly based on the Eclipse Smarthome framework. It uses Apache Karaf alongside with Eclipse Equinox to create an OSGi environment. It provides a modular architecture that can be extended through add-ons.

Eclipse IoT (https://iot.eclipse.org/) is a stack of open source projects suggested by Eclipse IoT Working Group that provides technology specifically suited for Industry 4.0 applications. For Industry 4.0 open standards there are the Eclipse Milo (OPC UA), Eclipse Paho and Eclipse Mosquitto (MQQT), Eclipse Unide (PPMP) and Eclipse OM2M(oneM2M). For PLC Development the Eclipse 4diac. For IoT Gateway, the Eclipse Kura. For security Eclipse Kura (Code signing), Eclipse Leshan (Device Authentication) and Eclipse Keti (Access Control). Eclipse Leshan, Eclipse Wakaama and Eclipse Kapua are used for Device Management and Configuration. Also, Eclipse Hono, Eclipse

Kapua, Eclipse Vert.x and Apache Spark are used for Event Management. Apache Hadoop, Apache HDFS, Apache Kudu and Apache HBase are used for Data Storage and analysis.

Mainflux (https://www.mainflux.com/) is a highly-scalable open-source platform that can be deployed on-premises or in the cloud. It is written in Go and deployed in Docker. Features of this platform include a set of clean APIs (RESTful, MQTT, Websocket, CoAP), a SDK, highly secured connections via TLS and DTLS, enhanced and fine-grained security via deployment-ready Mainflux Authentication and Authorization Server with Access Control scheme based on customizable API keys and scoped JWT, device management, device provisioning, and OTA updates.

SiteWhere (http://www.sitewhere.org/) provides a system that facilitates the ingestion, storage, processing and integration of device data. The platform presents an IoT server that can be installed either on the cloud or on a local host and acts as a controller for the processing of the data. The server provides service provider interfaces (SPIs) which allow third parties to extend and customize the system. The platform also provides an end-to-end device management model. It uses many well-known and established open source technologies like Apache Tomcat 7, Spring Framework, Spring Security, Hazelcast, MongoDV, Apache HBase, InfluxDB, Apache Spark, and Mule AnuPoint platform.

Zetta (http://www.zettajs.org/) is a platform built on Node.js. It combines REST APIs, WebSockets and reactive programming for building real-time applications. It can be deployed in the cloud, on PCs or on single-board computers. Its architecture is optimized for data-intensive, real-time applications. It generates a Hypermedia HTTP API for devices modeled in Javascript. The APIs are expressed using the Siren notification.

WSO2 IoT Server (https://wso2.com/iot) provides the essential capabilities required to implement a scalable server-side IoT Platform. It supports almost all known hackers board devices such as Raspberry Pi, Arduino Uno, etc. and supports complete API driven device type definition eliminating the necessity to create deployable plugins. The supported protocols for device communication are MQTT, HTTP, Websockets and XMPP protocols. Through WSO2 Data analytics server (DAS) it supports batch, interactive, real-time and predictive analytics. Group, manage, monitor and identity management is supported for connected devices. It provides stats-API to write custom visualization. There is an API store for easy discovery of all product/device APIs for app development. It performs both Stream Processing and Complex Event Processing through WSO2 Siddhi.

Distributed Services Architecture (DSA) (http://iot-dsa.org/) is another open source IoT platform that enables the communication between devices at every layer of IoT infrastructure. It unifies applications, services, and devices into a structured and adaptable real-time model. It consists of three core components. The DSLink is responsible for wrapping domain specific functionalities and publishing their capabilities on a DSA network via the nodeAPI protocol. The nodeAPI protocol is the communication protocol between all the DSA entities. The DSBroker which is an Apache 2.0 licensed implementation written in Dart among others is responsible for managing node attributes and permissions, managing connections from DSLinks, implementing DSA queries DSL, exposing http/webssocket endpoints for subscribing to value changes, and dictating M2M authorization livecycle.

IoT Platform	Device Management	Integration	Security	Data collection	Data Analytics	Data Management
Kaa	Yes	REST API, SDK for integrating new technologies	SSL, RSA 2048 key, AES 256 key	MQTT, CoAP, XMPP, TCP, HTTP	Real-time IoT data analytics and visualization with Kaa, Apache Cassandra, and Apache Zeppelin	Mongo DB, Cassandra, Hadoop, NoSQL
Thingsboard	Yes	REST API	SSL/TSL	MQTT, CoAP, HTTP	Real-time analytics. Can be integrated with i.e. Apache Spark, Kafka	MongoDB
DeviceHive	Yes	REST APIs, MQTT APIs	Basic Authentication using JSON Web Tokens (JWT)	REST API, WebSockets or MQTT	Real-time analytics (ElasticSearch, Apache Spark, Cassandra and Kafka)	PostgreSQL ,SAP Hana DB
OpenHab	Yes	REST APIs	SSL, https	Large number of addons	Yes, third parties	MySQL, MongoDB, InfluxDB, DynamoDB and others
Eclipse	Yes	REST APIs	TLS	CoaP, MQTT,	Yes	Apache Hadoop,

IoT				OPC-UA, LWM2M, IEC 61499 and more		Apache HDFS, Apache Kudu and Apache HBase
Mainflux	Yes	Rest APIs	TLS, Authentication	HTTP, MQTT, WebSocket, CoAP	Yes	PostgreSQL, MongoDB, InfluxDB
SiteWhere	Yes	REST APIs	SSL, TLS	MQTT, AMPQ, Stomp and others	Yes	MongoDB Influx, HBase
Zetta	No	REST APIs	Basic authentication	HTTP , Websockets	Yes (Splunk)	Unknown
WSO2	Yes	REST APIs	SSL/TSL, basic authentication	HTTP, WSO2 ESB, MQTT	Yes	Oracle, PostgreSQL, MySQL, MS SQL
DSA	No	REST APIs	SSL, basic authentication	http, fieldbus protocols, zigbee and others	Yes, third party	MySQL, MS SQL, PostgreSQL, Cassandra, Oracle, Hadoop, ETSDB

3.3.3.2 Proprietary Solutions

Amazon Web Services (AWS) IoT (https://aws.amazon.com/iot/) allows the integration of millions of devices from the edge to the cloud. One of its major components is the AWS IoT Core which is a managed cloud platform that acts as the connecting glue between intelligent devices, like sensors, actuators, embedded microcontrollers or smart appliances, and the AWS Cloud. The AWS Greengrass is another software that implements the notion of edge computing and lets you run local compute, messaging and data caching. In addition, FreeRTOS is a real-time operating systems for microcontrollers that is suitable for time-critical applications. Other features include device registry, SKD, rules for inbound messages, and device shadows. Finally, it integrates directly with other AWS services like Amazon Kinesis, Amazon Simple Service, Amazon Simple Queue Service etc. providing huge data processing capabilities.

Microsoft Azure IoT (https://azure.microsoft.com) is one of the most complete offerings in the market. The Azure IoT Hub acts as the connecting point between the deployed devices and the services that reside into the cloud. It provides secure and reliable two-way communication over popular open protocols (MQTT, Https, and AMQPS). It provides a REST API and an open source SDKs for service and application development. Moreover, a number of source samples and preconfigured solutions can be obtained. Features include device shadowing, a rules engine, identity registry, and information monitoring.

General Electric's Predix (https://www.predix.io) is built on Pivotal's Cloud Foundry, an open source Platform-as-a-Service (PaaS). Predix uses software-defined infrastructure (SDI) as an abstraction layer above the hardware, allowing services to evolve over time, with minimal disruption to the applications. Predix can connect with new or old machines and capture, analyze and distribute their data. Predix uses microservices which are reusable software modules and act as building blocks in order to create applications rapidly.

Siemens MindSphere (https://www.siemens.com/) is a cloud-based, open IoT operating system that connects products, plants, systems, and machines, enabling to harness the wealth of data generated by the Internet of Things with advanced analytics. It is offered in the form of a platform as a service. The applications developed for the platform can run on the customer's preferred cloud infrastructure, including Amazon's AWS, Microsfot Azure, and SAP Cloud Platform. MindShere stores data that are gathered from the devices and makes it accessible through digital applications (MindApps).

Bosch IoT Suite (https://www.bosch-iot-suite.com**)** is another IoT platform provided as PaaS. It is based on open standards and open source projects, mainly derived from Ecliplse IoT. The Bosch IoT Hub service is responsible for the easy and secure connectivity of the IoT devices. Bosch IoT Remote Manager among others provides the device and gateway lifecycle management, remote device configuration and control, remote provision and remote diagnostics. An OSGi-based gateway middleware stack, Bosch IoT Gateway Software, supports the indirect connection of device via gateways. The platform supports the creation of digital twins in the cloud and Bosch IoT Analytics is responsible for the domain and problem specific analysis of device data.

Carriots by Altair (https://www.carriots.com/**)** is a cloud-based platform that offers an end-to-end solution. The platform allows to connect a large variety of heterogeneous devices and employs a HTTP RESTful API to push and pull XML or JSON data. Furthermore, it offers a rules engine which can implement either simple if-then-else control flow or more complex scenarios using Groovy scripts. The Carriots SDK allows users to execute custom code for listeners and rules.

PTC's thingworx (https://www.ptc.com/en/thingworx8) offers the ability of managing an IoT application from one centralized place. ThingWorx Analytics is a powerful data analytics suite that offers tools for applying machine learning algorithms to collected data and embedding smart advanced analytics insights into the IoT applications. The platform offers Augmented Reality Capabilities and a Rest API which fully exposes properties, functions, services, and subsystems. The ThingWorx WebSocket-based Microserver (WS EMS) supports edge devices and allows the fast and secure communication of these devices with the platform. It is accompanied by a set of ThingWorx Edge SDKs for the development of applications for the edge.

The IBM Watson IoT Platform (https://www.ibm.com/internet-of-things) provides you flexible toolkit for device management, application access, and deploying device gateways. Concerning data management, it offers access to either real time or stored data. Rules reacting quickly to critical changes can be defined. These rules monitor conditions and trigger automated actions such as email, Node Red flows, alerts, and external services. MQTT over TLS ensures the secure communication between devices and the provided services. It can be combined with IBM Bluemix platform for the rapid composing of analytics applications, intuitive dashboards, and mobile IoT apps.

M2X IoT Platform (https://m2x.att.com) is developed by AT&T and provides cloud-based time-series data storage, device management, message brokering, event triggering, alarming, geo-fencing, and data visualization. Through the AT&T M2X developer tools and RESTful APIs, real time data can be retrieved and further analyzed in order to extract meaningful information for quick decisions. The RESTful API streamlines the connection between devices and the M2X service and is accessed over HTTPS. All data are received as JSON while MessagePack format is also supported. It supports a range of device platforms, software and other services and in addition M2X is compatible with any device or application that can communicate over HTTP with our RESTful API.

Seebo (https://www.seebo.com/why-seebo/) is a SaaS platform focused on Industry 4.0 concept, which includes solutions for predictive maintenance, condition monitoring, remote asset monitoring, machine learning, digital twins, and IoT simulation among others. The Seebo IoT Modeler is used to create digital models of the actual industrial equipment. The IoT model created by the Modeler automatically generates a digital prototype which can be simulated for analysis and verification purposes by the Seebo IoT Simulator. Seebo IoT Analytics utilizes data produced by the industrial IoT devices, like PLCs, sensors etc., and generates useful insights.

Google Cloud IoT (https://cloud.google.com/solutions/iot/) is an IoT platform that is provided as PaaS. The heart of this solution is the Google IoT Core which is responsible for gathering, analyzing, and visualizing data. It uses REST APIs for automatically managing the registration, deployment, and operations of devices. It ensures the secure two-way transmission of data using asymmetric key authentication over TLS 1.2. Two different types of protocol bridges (MQTT and HTTP) for connecting devices with the platform.

Ayla's IoT Platform (https://www.aylanetworks.com/products/iot-platform) comprises three primary components, namely Ayla Embedded Agents, Ayla Cloud Services, and Ayla Application Libraries. It is offered as a cloud Platform-as-a-Service (PaaS). The embedded agents run on IoT devices or gateways and incorporate a fully optimized network stack along with the additional protocols needed to integrate the devices into the Ayla Cloud. Ayla Cloud Service is the heart of the platform and host several business intelligence and analytics services. The Application Libraries contain rich APIs to develop iOS or Android applications to communicate with the platform.

Lumada by Hitachi (https://www.hitachivantara.com/en-us/products/internet-of-things.html) is another IoT industrial focused platform which promises the seamless integration of IT and OT technologies. It is a three-tiered IoT ecosystem which can be deployed in a variety of platforms (e.g. cloud, premises, Hyper-V, VMware). The base layer of architecture consists of the connected device, gateways, storage etc. The central layer is the Core layer which includes services performing tasks like security, advanced analytics, and predictive maintenance. The upper layer consists of the actual digital business solutions created for smart businesses and industrial applications.

C3 IoT platform (https://c3iot.ai/products/c3-iot-platform/) delivers a PaaS for developing and operating big data, predictive analytics, AI/machine learning, and IoT SaaS applications. Users and developers access the platform, the C3 Apps, and the microservices through the C3 Type System. The platform provides extensive connectivity options which include support for a variety of streaming platforms (MQTT, SFTP, AWS Kinesis, etc.), databases (Apache HBase, MapR DB, Apache Cassandra, AWS DynamoDB, Azure Cosmos DB NoSQL), relational databases (Oracle, Postgres, SAP Hana, AWS RedShift, Azure SQL), distributed file systems (S3, HDFS, Azure HDInsight, and Azure Blob Stor), delimited file formats (Apache Avro, Apache Parquet, and JSON), and application connectors (Salesforce, Marketo, SAP ERP, OSISoft Pi, Microsoft Dynamics). Other features include stream processing, batch processing, iterative processing (train and re-train AI / machine learning models by iterating over data in-memory rather than on disk), compatibility with data science platforms and tools (e.g. AWS ML, Spark MLlib, TensorFlow, scikit-learn, cuDNN etc.), deployment of AI models and custom methods accessible by REST APIs.

Artik (**https://www.artik.io/**) by Samsung is a new platform that brings together hardware IoT devices with cloud services. The platform is accessed through an API which supports protocols like REST, Websockets, MQTT, and Coap. The platform uses a virtual representation of each device, which is called Device Mirror, and via the LWM2M protocol manages their properties. The communication is secured with the use of TLS protocol. The Rules UI, which resides in the cloud, allows the quick and intuitive definition of rules between the smart devices. The platform gives the opportunity of connecting devices that cannot directly communicate to ARTIK cloud services via the Proxy Hyb.

Cisco Jasper Control Center (https://www.jasper.com/) is and IoT service platform which provides a rich library of 100+ APIs for exchanging data between devices and internal systems and for managing the device's lifecycle, monitoring data, sending messages to the device, and assigning a rate plan to a device.

SAP Cloud Platform for the Internet of Things (https://www.sap.com/products/iot-platform-cloud.html) along with SAP Leonardo IoT Bridge delivers an end-to-end solution for integrating, monitoring, and managing devices inside or outside the premises of an enterprise. SAP Leonardo Machine Learning Foundation enriches the platform with functionalities such as image processing, natural language processing, tabular and time-series processing, and development of custom machine learning models.

IoT Platform	Device Management	Integration	Security	Data collection	Data Analytics	Data management
AWS	Yes	REST API	Link Encryption, Authentication	MQTT, HTTP	Real-time analytics (Rules engine, AWS Kinesis, AWS Lambda)	Relational DBs (MySQL, PostgreSQL etc.), Non-relational DBs (DynamoDB, ElastiCache, Amazon Neptune)
Azure	Yes	REST API	SSL/TSL	HTTP, AMQP, MQTT	Real-time analytics	MySQL, PostgreSQL, Cosmos DB, MariaDB and others
Predix	Yes	REST API	TLS, authentication	AMPQ	Real-time analytics (Analytics Library), third parties	PostgreSQL, RabbitMQ
Bosch IoT	Yes	REST API	TLS, authentication	MQTT, CoAP, AMQP, STOMP	Bosch IoT Analytics	MongoDB
Carriots	Yes	REST API	HTTPS,TLS	MQTT	Third party	unknown

thingworx	Yes	REST API	Identity Management	MQTT, XMPP, CoAP, Websockets, DDS	Real-time analytics	PostgreSQL, H2, Hana, Neo4J
IBM Watson	Yes	REST and real-time APIs	TLS, Authentication, Identity Management	MQTT, HTTPS	Real-time analytics (IBM Real-time insights)	IBM Infomix, NoSQL
M2X	Yes	REST API	TLS	MQTT, HTTP	Real-time analytics	unknown
Google Cloud	Yes	REST API	TLS	MQTT, HTTP	Real -time analytics (Google BigQuery)	RDBMS, NoSQL
Ayla	Yes	REST APIs	unknown	unknown	Real-Time analytics	unknown
Lumada	Yes	REST APIs	TLS	AMQP, MQTT	Real-time analytics	unknown
C3	Yes	REST API	HTTPS	HTTPS, MQTT, SFT etc.	Real-time analytics	Relational DBs, NoSQL
Artik	Yes	REST API, websocket APIs	SSL	LWM2M, CoAP, MQTT, http	Real-time analytics	Unknown
Jasper	Yes	REST API	Unknown	Unknow	Unknown	Unknown
SAP Cloud Platform	Yes	REST APIs	Authentication, encryption, digital signature	HTTPS, MQTT, IoT gateway	Real-time analytics	PostgreSQL

4 User Requirements

This chapter presents the user requirements for the transnational pilot deployment use cases. The envisaged pilot deployments are presented in the table below, differentiated on their theme. As previously exposed, the proposed themes are Building Energy Efficiency and Smart Public Lightning.

<table>
<tr><th rowspan="2">Country</th><th rowspan="2">Region</th><th rowspan="2">Locality</th><th colspan="2">Theme</th></tr>
<tr><th>Building Energy Efficiency</th><th>Smart Public Lighting</th></tr>
<tr><td>BiH</td><td>Republic of Srpska</td><td>East Ilidza</td><td></td><td>X</td></tr>
<tr><td rowspan="2">EL</td><td rowspan="2">Western Greece</td><td>RWG</td><td>X</td><td></td></tr>
<tr><td>Patras</td><td>X</td><td></td></tr>
<tr><td>ES</td><td>Andalusia</td><td>Huetor Tajar</td><td></td><td>X</td></tr>
<tr><td>FR</td><td>Auvergne-Rhône-Alpes</td><td>Lyon</td><td></td><td>X</td></tr>
<tr><td rowspan="3">IT</td><td>Abruzzo</td><td>Pescara</td><td></td><td>X</td></tr>
<tr><td rowspan="2">Lombardy</td><td>Milan city</td><td>X</td><td></td></tr>
<tr><td>Milan PoliMi</td><td>X</td><td></td></tr>
<tr><td>PT</td><td>Lisbon</td><td>ENA</td><td>X</td><td></td></tr>
</table>

Pilot Deployment Use cases

Each section is dedicated to the description of a specific pilot deployment use case. In the final section, an overall codification for the User Requirements issued in the use cases is developed.

4.1 Building Energy Efficiency

This sub-chapter presents the User Requirements of the deployment use cases dealing with building energy efficiency.

4.1.1 Building energy efficiency in public buildings in Region of Western Greece-RWG located in the three Regional Units of RWG, Aitoloakarnania, Achaia and Ileia

4.1.1.1 Introduction

Region of Western Greece (RWG) is a public authority, which acts as the Local representation of Central Government in Western Greece. RWG is one of the 13 Regions of Greece and consists of three Regional Units: Former Prefectures of Aitoloakarnania, Achaia and Ileia. RWG extends over an area of 11.350 square kilometres (8,6% of Greece total surface), with a population of 680.190 inhabitants (2011). As a public authority, RWG deals with all matters affecting local/regional development. For year 2018, the strategic priorities of RWG presented in order of significance are:

- Development of an Energy Planning
- Development of Digital Convergence
- Agricultural Development Plan
- Tourism

For the Development of an Energy Planning, the first approach is to organize Energy Communities with other public authorities such as Municipalities, Universities, Technical Chambers of Western Greece etc… and to construct an Energy Observatory for public buildings in Western Greece in cooperation with University of Patras, University of Applied Sciences (TEI of Western Greece) and Technical Chambers of Western Greece. The basis for the Energy Observatory for public buildings in Western Greece is set through the deployment of the presented pilot project and the installation of energy metering controllers in public buildings. The target is improving Energy Efficiency in RWG Buildings and in a school (Pilot school of the University of Patras).

4.1.1.2 Site Description

RWG Pilot Testing involves installing Smart Energy Metering Controllers in public buildings located in the three Regional Units of RWG – Aitoloakarnania, Achaia and Ileia – as follows (Cases A, B,C):

A. For two buildings RWG owns:
    a. RWG Public Building in Messolonghi - capital town of Aitoloakarnania prefecture
    b. RWG Public Building in Pyrgos – the capital town of Ileia prefecture

   Smart Energy Metering Controllers will be installed in order to get energy measuring consumption data per use.

RWG Public Building in Messolonghi: The building has two floors, all of it about 5.000 m^2 and 100 employees. Many people are visiting the building daily to carry out procedures with RWG directorates and services.

RWG Public Building in Pyrgos: The building has five floors, all of it about 9.500 m^2 and 175 employees. As for the previous building, the occupants affluence is relevant each day.

B. Smart Energy Metering Controllers will be also installed in other 15 buildings, which are rented from RWG to host her services. These buildings are located in the three Regional Units: Aitoloakarnania, Achaia and Ileia.
C. Smart Energy Metering Controllers will be also installed in a school, the Pilot School of the University of Patras located in the area of Rio, Patras. There are three main buildings in this school used for Primary and High School.

4.1.1.3 Pilot Deployment Description

The specific goals of the pilot project is to improve Energy Efficiency in public buildings and to deliver solutions based on this monitoring in order to decrease energy consumption. According to literature, measuring electricity consumption is the first step in order to take actions that will lead to Energy Efficiency of Buildings. The outcome of this pilot will be transferred to other public authorities and private companies. The pilot enables the usage of high-performance and affordable IOT technology to monitor electrical energy consumption in buildings in real time.

<u>Case A:</u>

For these two buildings, one Smart Electrical Energy Meter will be installed in the general electric panel for the whole building. Then, according to the wiring diagram of the building, a

Smart Energy Metering Controller (sub-meter) will be installed for each electricity line (e.g. lighting, heating, air-conditioning, elevator etc.) to collect electricity consumption data depending on the use. Approximately five (5) smart electrical energy meters will be used for each building.

Case B:

One Smart Energy Metering controller will be installed in the central electric unit of each of the fifteen buildings to monitor total electricity consumption. A total of fifteen (15) smart electrical energy meters will be used.

Case C:

Smart Energy Metering Controllers will be also installed in a school, the Pilot School of the University of Patras located in the area of Rio, Patras. There are three main buildings in this school for Primary and High School, so three (3) smart electrical energy meters will be used.

Data from all smart energy meters will be collected on an initial premise basis every 15 minutes. Using wired and wireless technology, all data will be delivered to the main server, which will be installed in Patras through the National Public Administration Network –Syzefxis. As a result, all data from all smart energy meters will be accessible using an IP address and thus will be on line monitored.

4.1.1.4 User Requirements specification

In order to implement the specific goal of the pilot project –Improvement of Energy Efficiency in public buildings, the following user requirements are needed:

- Gather information about electric energy consumption using Smart Electrical Energy Meters.
- Store Data collected from smart meters in a server.
- Deploy a Wireless network to easily access the stored data.

4.1.2 Building energy efficiency at Industrial Systems Institute's premises in Patras, Western Greece

4.1.2.1 Introduction

The ESMARTCITY pilot testing deployment undertaken by ISI focuses on its own premises at the Patras Science Park (PSP) building in Platani, Patras, Greece. It more specifically addresses two concepts: the concept of **energy efficiency** and the concept of the building as a **living lab**. In this context, the pilot testing will utilize different types of sensing / actuating equipment in order to perform some testing / experimentation with different scenarios. More precisely, the strategic aims of the pilot testing deployment at ISI are:

- **Experiment with Energy Efficiency scenarios.** Deployment and execution of scenarios that will conclude to the better and more efficient energy management of the offices. These scenarios include the monitoring of power consumption and other parameters, their data analysis and the manual or automatic response of the overall system in order to decrease power consumption.
- **Experiment with Living Lab scenarios.** The pilot in ISI will follow the Living Lab concept. The installation of a smart building infrastructure at the premises of ISI, in offices where actually people work, will provide the basis for the exploration, experimentation and evaluation of innovative ideas, scenarios, concepts and related technological artefacts in real life use cases.
- **Deploy the necessary infrastructure** for monitoring, controlling, optimizing and testing energy efficiency and smart urban living. The aim is the purchase or creation and installation of the appropriate equipment that provides the ability to monitor power consumption, environmental variables, lighting utilization and office space occupation. Furthermore, actuating devices along with analytics and decision making software will be used for controlling power consumption. Thus the pilot infrastructure comprises:
    - Smart devices, IoT, smart embedded systems
    - Wireless connectivity
    - Edge computing, Cloud computing
    - Big data analytics

4.1.2.2 Site Description

The Industrial Systems Institute (ISI) premises utilize building resources of about 300 sq.m. at the building of the Patras Science Park (PSP), Platani, Patras, Greece. This space is distributed among 5 different offices. Two of the offices are located on the building 1st floor (Director's office and Accounting Department) while the rest three of the offices / laboratories are located on the building 2nd floor.

PSP's main building has a total area of approximately 4.700 sq m with large multipurpose auxiliary spaces and 1.940 sq m available for the hosted enterprises. The whole complex rests on 3 acres of autonomous ground in a marvelous green surrounding.

Fig.1 Aerophoto of the main building of Patras Science Park

ISI offices are distributed in the two floors of the PSP's main building. In the first floor there is the office of director (area A6), the offices of the administration staff and the meeting room (area A7).

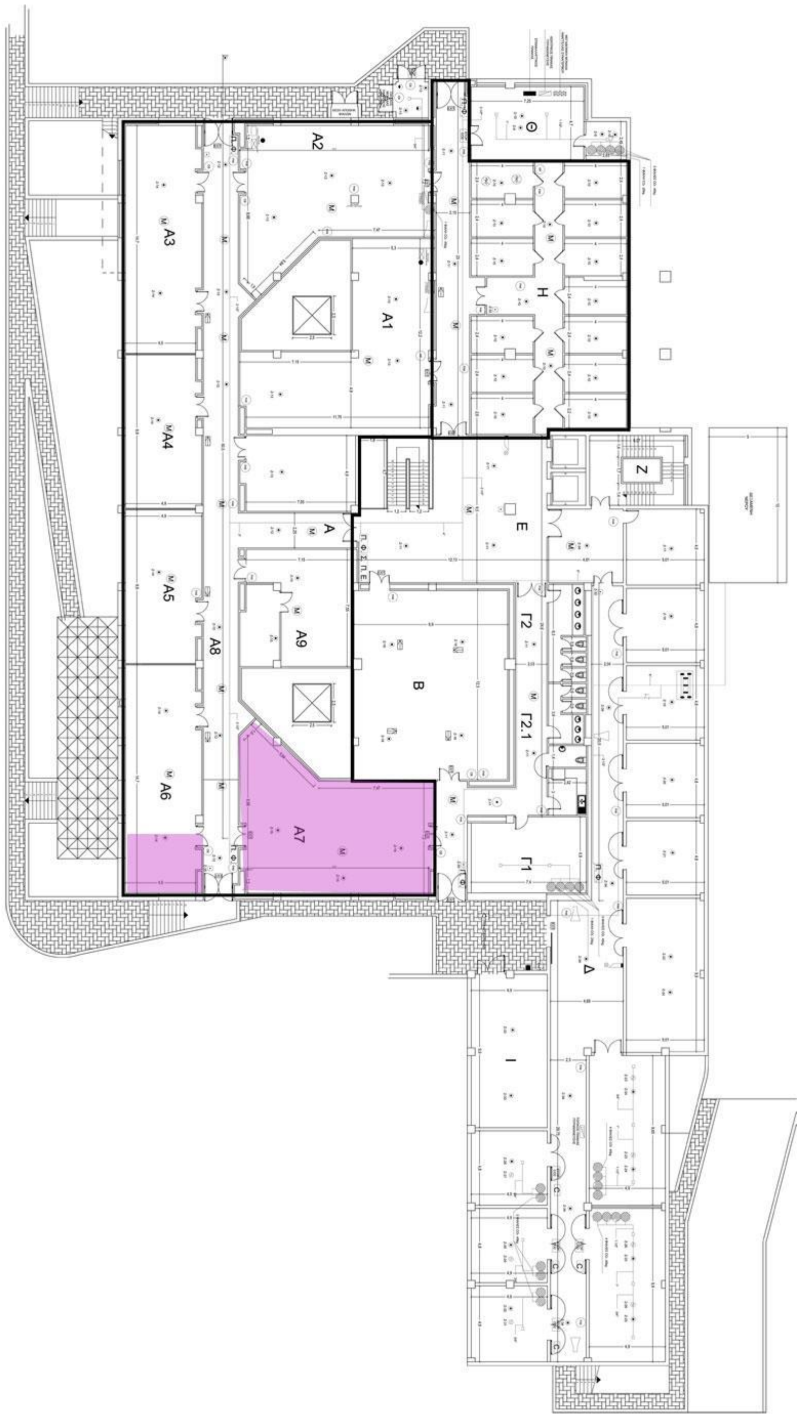


Fig. 2 Schematic Top View of the 1st Floor of PSP main Building. ISI's space is denoted with purple.

On the second floor, ISI has three offices (areas Δ3.1, Δ3 and E) where ISI researchers' offices and other facilities (servers, manufacturing emulator, laboratories) are located.

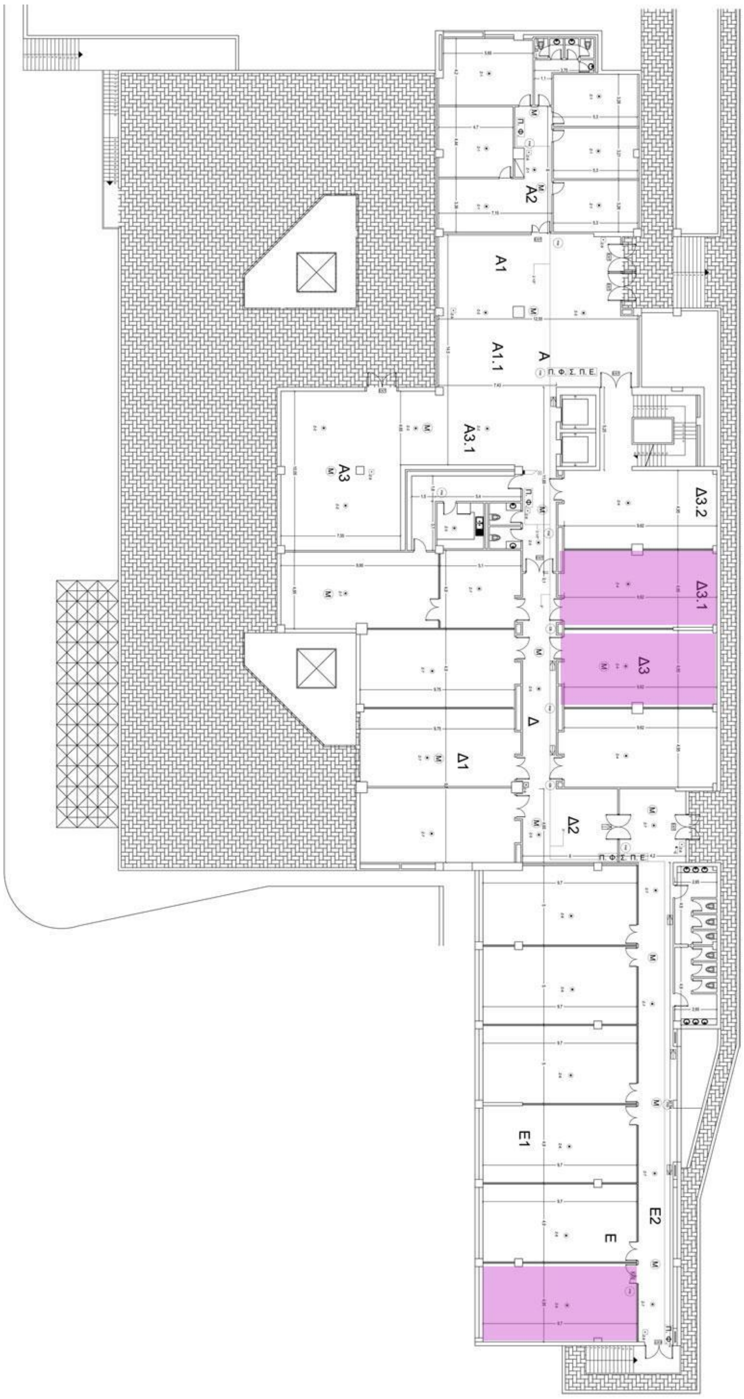


Fig. 2 Schematic Top View of the 2nd Floor of PSP main Building. ISI's space is denoted with purple.

Power Consumption

The devices that mainly consume power at the ISI premises are:

- About 30 PC, laptops and Monitors
- 4 Servers
- 6 Electric oil heaters
- 2 Refrigerators
- 1 Coffee machine
- 1 Television

The above are taking power from about 30 power plugs installed at ISI's offices.

Also every office has two rows of lights that are controlled by an analog switch each.

Regarding air conditioning / central heating, ISI is using the central infrastructure provided by the PSP and has no access to its control.

Networking

The PSP building provides a Structured cabling for data and voice networks. All the spaces of ISI are connected to a single Ethernet LAN which is isolated by a switch from the other networks of ISI. Also, the last two years, wireless access points have been installed to all the areas of ISI so each office provides WiFi connection to ISI's LAN.

4.1.2.3 Pilot Deployment Description

ESMARTCITY pilot in ISI includes the installation and operation of a smart building infrastructure aiming to the **specific goals**:

- To take advantage of high-performance affordable IOT technology to monitor and analyze buildings in real-time
- To integrate diverse devices increasing the overall level of heterogeneity
- To exploit open source solutions and standard protocols wherever possible
- To adopt a suitable distributed embedded infrastructure
- To exploit edge and cloud computing as potential solutions
- To utilize and test IIoT data acquisition platforms
- To finalize and deliver smart monitoring and control solutions integrating big data analytics for energy consumption and user comfort optimization
- The solution should be scalable and replicable, so as to be transferable to other sites.

4.1.2.4 User Requirements specification

Based on the above description the pilot deployment User Requirements are the following:

- Exploiting cutting-edge intelligence to test different control and actuation scenarios, aiming at building energy consumption optimization while maintaining the user's required comfort level.
- Derive occupancy behavioural characteristics.
- Deploy a highly heterogeneous net of devices and manage their interconnection and real-time communication through different network protocols.
- IoT platform must provide a Graphical User Interface for devices management, data visualization and actuators control. Data visualization include graphic charts and colorful alert messages that can be managed by the user.
- Provide a solid data management plan to perform of statistical and machine learning analysis in order to detect anomalies or patterns that will provide knowledge for optimizing energy consumption.

4.1.3 Building energy efficiency in public buildings in Milan, Lombardy, Italy

4.1.3.1 Introduction

The Metropolitan City of Milan, through the deployment of its pilot project, aims at creating an ecosystem of smart devices in order to enhance applications and services for final users and citizens. The pilot will allow for the finalization of an innovative telecommunication infrastructure (about 2500 km of optic fiber) which will be used to monitor, control, optimize and test energy and environment parameters. The beneficiaries of this innovative infrastructure will be the public buildings of the Metropolitan City of Milan and some schools in the metropolitan area, thus the pilot deployment will not only affect the efficiency of buildings in the PA, but also create the conditions for smart urban living in the metropolitan area.

4.1.3.2 Site Description

Palazzo Isimbardi, in via Vivaio 1, Milan, hosts the headquarters of the Metropolitan City of Milan, and it contains offices and meeting rooms of different sizes. It is actually composed of different buildings dating back to different periods – the most ancient one was built in the XVI century – all integrated among them. The buildings also contain internal courtyards and an internal garden. The optic fiber of the pilot project will be used in specific rooms of Palazzo Isimbardi in order to monitor and control environment parameters: Sala Affreschi (Frescoes' room) and Sala Giunta (Board room). Sala Affreschi stands between the main courtyard and the garden and it derives its name from the two large frescoes placed here: "La Vittoria" (The victory) and "La resa dei Re vinti" (The surrender of the conquered kings), attributed to Pierfilippo Mazzuccelli, known as Il Morazzone. Sala Giunta represents the most important room in the buildings, and it is used for the meeting of the executive body of the entity. It contains the famous painting "Apotheosis of Angelo della Vecchia in virtues' sign" by Giovanbattista Tiepolo. The painting was purchased by the Province of Milan in 1954 and expertly restored in 1982, when the paint layering of previous restorations was removed and the damaged parts of the painting were integrated. Besides Tiepolo's painting, numerous other paintings and antique furniture are located in the room. Guided visits are organized regularly to visit Sala Giunta.

Interventions will also take place in one school building in the metropolitan area. The pilot deployment will be similar in nature to that taking place in the buildings of the Metropolitan City.

4.1.3.3 Pilot Deployment Description

The specific goals of the pilot project are various. First of all, the pilot aims at exploiting the high speed infrastructure to enhance energy management in public buildings, improve coordination services and guarantee the safeguard of the artistic and cultural heritage of the Metropolitan City of Milan. Secondly, in coordination with the pilot developed by Politecnico di Milano, it allows for the development of smart control algorithms to optimize energy consumption and user's comfort. Thirdly, the pilot enables the usage of high-performance and affordable IOT technology to monitor and analyze buildings in real time. Fourthly, it gives the possibility to adopt a suitable and well-distributed embedded infrastructure. Finally, one of the specific objectives of the pilot is also that of creating a replicable and scalable project, which could then be applied to other public entities in Italy or in the EU.

4.1.3.4 User Requirements specification

The user requirements can be summarized as follows:

- Enhancing energy monitoring and management through advanced customized energy monitoring tools.
- Examine different control strategies aiming at minimizing the impact of environmental factors in public buildings, to optimize energy consumption and user's thermal comfort.
- Study the impact of environmental factors in public buildings
- Enabling innovative technologies for the optimization of energy consumptions and user' comfort.
- Testing a pilot that could be replicated in other public entities.

4.1.4 Building energy efficiency over an advanced thermal network in a school building in Milan, Lombardy, Italy

4.1.4.1 Introduction

Recent years has witnessed significant progress in innovative comfort control strategies in context of small to large buildings in order to increase the overall building energy efficiency and improve the comfort level of building occupants. Due to the fact that air conditioning systems contain a considerable portion of energy consumption in building sectors, it is important to improve the efficiency of plants and building's structure in order to optimize the required energy for heating and cooling systems.

An analysis of existing approaches, research works, scientific papers and applications regarding building thermal modeling, control strategies for buildings and energy control is performed in state of the art section with the aim of understanding the main points for practical improvement to be developed in the context of this project.

DAISY aims at developing an efficient and scalable control strategy to manage the heating and cooling systems for complex thermal networks. Different modeling approaches will be explored for building thermal energy analysis, while several control solution will be deployed and tested in the context of classic to advance methods. The main targets of this proposal are performing experiment with energy efficiency scenarios in a real PoliMi smart building where different control methodologies can be experimentally tested. Considering different heating and cooling systems provide us the capability of analyzing the effectiveness of different plant algorithms on energy consumption and comfort level in building sectors. Moreover, the real occupancy of the testing building will give us the opportunity of experiencing with the real operating condition to develop new strategies for dealing with possible parametric and structural uncertainties in both modeling and control.

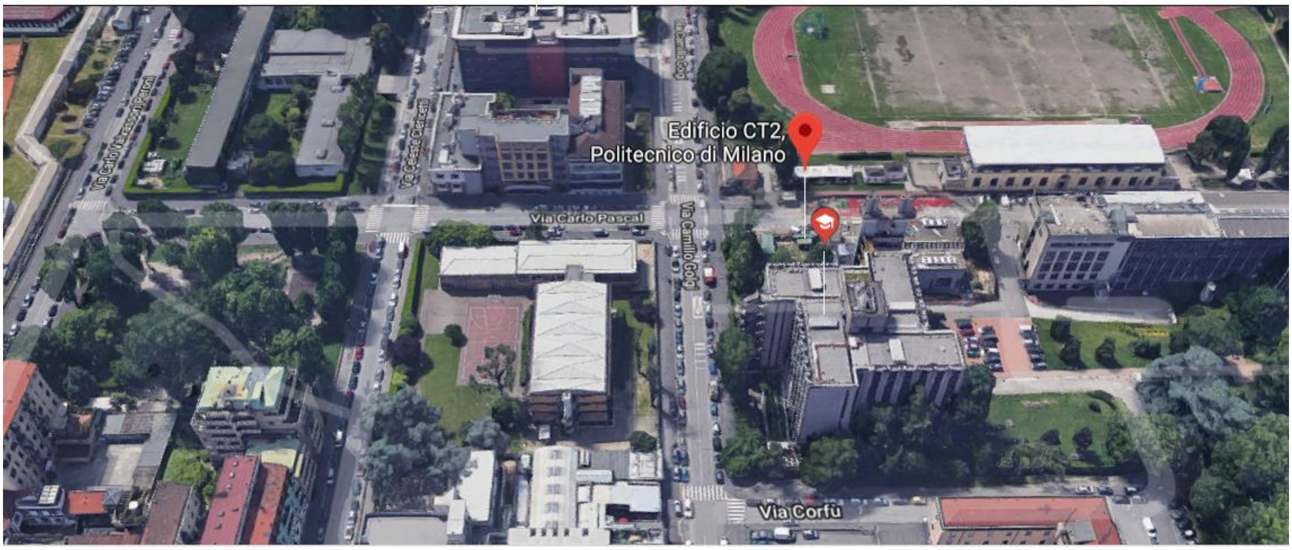
4.1.4.2 Site Description

Politecnico di Milano is a scientific-technological university which trains engineers, architects and industrial designers. The University has always focused on the quality and innovation of its teaching and research, developing a fruitful relationship with business and productive world by means of experimental research and technological transfer.

The Milano Leonardo campus is the oldest of Politecnico di Milano's campuses. It was inaugurated in 1927 in the buildings located in Piazza Leonardo da Vinci. Over the course of the decades the campus has been expanded to encompass new campuses and given rise to a real and genuine university quarter commonly dubbed "Città Studi" (City of Studies). The Milano Leonardo campus hosts the University's main management and administrative structures.

DAISY research group, which is an acronym for Distributed AutomatIon Systems, is a group of researchers working at the Department of Electronics and Computer Science of Politecnico di Milano. It contains offices and meeting room of different sizes, office of the director, offices of researchers and PhDs and post docs. Its main research interests are control, supervision and monitoring for automatic systems, automatic diagnostics algorithms, modular and hierarchical control code generation, advanced system integration, monitoring systems for energy sector and smart Energy grid. DAISY recently turns toward the design of energy management systems with the aim of developing a complete end-to-end innovative green solution for the manufacturing of Building Integrated Photovoltaics (BiPV). Also, thermal energy analysis and modeling of buildings with the aim of deploying several heating and cooling systems together with advanced control approaches has been significantly investigated with the researchers and PhDs in DAISY lab.

The PoliMi school building which will be exploited as testing building is located in the aforementioned university quarter “Città Studi”. As a result of previous renovation PoliMi projects, one of the recently built school building has been endowed with a complex network of thermal devices. This complexity allows the testing of different and innovative control strategies, which in turn could encourage the installation of particular thermal systems in different contexts.



4.1.4.3 Pilot Deployment Description

The pilot testing building is equipped with different type of heating and cooling systems together with several energy resources ranging from thermal to electrical energy generators and storages. It is also supplied by a collection of software and hardware that lets us measure or control physical characteristics of the proposed smart building. The pilot will allow this building to be endowed with a data acquisition system which will include all required sensors, actuators, data loggers, computers and also interfaces for communicating with different part of the system.

The specific goals of such a lab-scaled smart building is listed as follows:

- Experimental analysis of proposed modeling and control strategies
- Energy analysis in buildings affected by a variable and relevant occupancy factor
- Performance analysis of different heating and cooling systems, such as radiant panels, radiators, fan coils, heat pumps, air handling units etc
- Monitoring of all possible variables in real time for validation of developed modeling and control techniques
- Testing both winter and summer days to analyze and develop different heating and cooling modes respectively
- To exploit the advantages of using both thermal and electrical energy resources for dynamic pricing purposes

- To manage different type of energy generators and storages increasing the overall energy efficiency in building
- To utilize the renewable energies for energy management purposes
- To attack the problem of real time communication between programmable PC and real components
- To finalize and deliver smart monitoring and control solutions integrating energy consumption and user comfort optimization

4.1.4.4 User Requirements specification

Generally speaking, DAISY pilot is developing with the aim of:

- Testing and analyzing several heating and cooling systems
- Compare different control strategies and control algorithms
- Analyze the effect of different thermal devices on the behavior of buildings
- Proposing innovative energy management programs in building sectors in presence of renewable energies and redundant thermal devices

Several scenarios will be defined to better analyze the energy behavior in buildings. As a starting point, a what-if analysis can be performed based on following scenarios:

- Analyzing the behavior under different weather conditions, or summer and winter days, to develop efficient thermal management strategies under different case scenarios.
- Considering different heating and cooling systems, e.g. radiant floor heating, fan coils, radiators, air handling units etc. for energy analysis purposes and for the development of reliable models for energy prediction and estimation purposes.
- The optimal usage of a thermal energy storage (TES) for load shaping in demand side management can be investigated.
- Investigation of the effects of source of uncertainties, such as coefficient of performance of heat pump or thermal characteristics of the building, in performance of different control approaches.
- Application of different control strategies in the context of classic to advanced methods will be experimentally tested.

4.1.5 Building energy efficiency in public buildings in Lisbon Metropolitan Area, Portugal

4.1.5.1 Introduction

The main goal is to install energy consumption smart metering system in public buildings in ENA's Municipalities (Palmela, Setúbal and Sesimbra).

A system will be installed to monitor, control, optimize and test energy parameters enhancement through an ecosystem of smart devices for smart urban living. Those systems will provide data for the Municipalities and their citizens.

The targets of this project are public buildings.

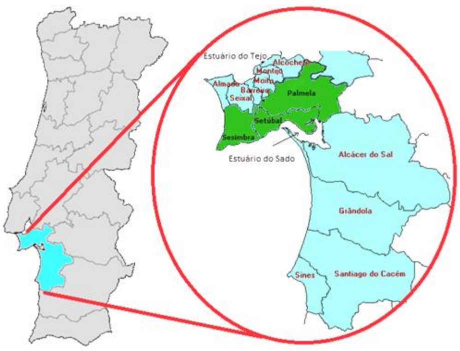


Figure 1 - Location of ENA`s Municipalities

4.1.5.2 Site Description

The pilot is planned for Smart Energy Metering.

The main sites will be on 24 Municipalities' buildings in Palmela, Setúbal and Sesimbra.

They contain offices and meeting rooms of different sizes and they are actually composed of different buildings with different characteristics. They all are public service buildings and therefore they are opened to public.

Figure 2 – Some of pilot buildings (Town hall – Palmela; Municipal Library and theatre – “Cineteatro João Mota”; and Sesimbra Municipal Culture Hall – “Casa da Baía”, Setúbal)

The metering equipment will be installed in the energy entering point in each building.

4.1.5.3 Pilot Deployment Description

The specific goals are:

- To obtain and systematize energy consumption data to enable energy management and coordination services
- To take advantage of affordable Information Communication Technology to monitor and analyze buildings in real time
- To plan interventions and investments based on real needs
- To prepare and deliver energy patterns to optimize the energy consumption

The solution will be scalable and replicable to other Municipalities’ buildings, other partners, other public entities in Portugal and EU.

4.1.5.4 User Requirements specification

Considering the aforementioned pilot deployment nature, its related user requirements can be declined in the following list:

- Collect energy consumption data
- Provide a real-time analysis tool aiming at planning interventions and investments based on evident needs
- Define energy patterns to optimize the energy consumption
- Develop the previous solutions in a scalable and replicable fashion

4.2 Smart Public Lighting

This sub-chapter presents the User Requirements of the deployment use cases dealing with smart public lighting.

4.2.1 Smart Street Lighting in East Ilidza, BiH

4.2.1.1 Introduction

According to the public information, there are 282 million installed units of public lighting worldwide, deployed in urban, suburban and rural environments and around the main roads. The global trends define increasing needs for energy including the requests and needs for installation more public lighting units because of the global urbanization process which becomes more intensive in the last few years. The global population migrates to the main urban centers because of a better quality of life, better chances for a career, more information, better education opportunities, better healthcare system and many other reasons.

The main motivation for modernization of conventional public lighting system is energy and costs savings and optimization of existing resources managed by the cities. There are two paths for this approach, first one related to changing conventional and old units with new LED units, and the second one related to adding “smart” component into city services including a public lighting system and “smart” means manageable, monitorable and dynamic system. The term “smart” hides behind the sensor network, actuators systems, data collecting and storing into data centers for the future analysis manually or preferably automatically using advanced algorithms for data mining, machine learning and artificial intelligence as a support for decision making and optimal management.

The area of East Ilidza becomes an urban area and there is a constant process of urbanization, what is the challenge for the local government to keep existing and eventually improve the quality of city services and quality of life for the citizens.

The municipality of East Ilidza is one of six municipalities in the East Sarajevo City. East Sarajevo (or former Serbian Sarajevo) is in the east part of Sarajevo and after the war, it becomes independent administrative area from the existing Sarajevo City. From the official source, East Ilidza has 14.763 permanent residents and a population density of 530 inhabitants/km^2 in the total area of 27.9 km^2 which is mostly suburban and rural area. A small part of the East Ilidza has a description of the urban area, which needs specific public services as a public lighting system.

The existing public lighting system is implemented in the urban part of the municipality and the part of main roads.

City Development Agency East Sarajevo aims to create an experimental area in the town square in East Ilidza municipality to deploy and test smart digital solutions that will contribute to reducing the energy consumption of the city due to smart public lighting. Public lighting installations are important sources of energy consumption that are affected by certain factors, such as regulation and maintenance. This energy consumption can be reduced considerably by applying new communication and control technologies.

The strategic aims of the City of East Sarajevo are:

- Providing an appropriate level of city lighting in public spaces
- To use smarter streetlights to improve and optimize:
- Public Lights system („conventional“ -> „smart“)
- Energy Consumption (dimmable, manageable)
- Public Safety
- Simplify and Optimize Maintenance of Public Services
- Monitoring, Data Collection, Automatization and Management

Two-thirds of the public lighting systems currently in use are still based on obsolete and inefficient technologies, with higher energy consumption than needed. Therefore, there is great technological potential to renovate public lighting and reduce energy consumption. According to estimates, around 5% of the used energy is consumed by public lighting, what means that the public lighting is the most important component of a city's energy consumption.

City Development Agency East Sarajevo defines the following goals from the project:

- Test a system based on digital and energy saving technologies in the field to verify the overall functionality under variable real-life conditions.
- Contribute to providing policymakers, PA and energy managers with decision support tools to optimize environmental impacts of their decisions and operations.

Benefits for City of East Sarajevo from the project are following:

- Electricity and Maintenance Cost Savings
- Resource Savings and Optimal Usage
- Time Savings
- Earning Money for the Community
- Reducing Light, Noise and Air Pollution
- Improving General Well-Being and Quality of Life
- Promoting and planning additional smart city applications for the Future

Implementation of the LED-based public lighting system, which is energy-efficient and environment-friendly with additional smart functionalities as dimmable and manageable lights depending on the part of the day and year, real sunlight cycle, traffic and other factors, is critical for energy and costs savings for the city. Energy costs are immediately reduced by up to 35% through intelligent ON/OFF switching, targeted progressive dimming and efficient management of the consumption, while overall operational costs come down by up to 42% through detailed maintenance and preventive grid interventions based on system generated reports. It is also important to underline the fact that, in the last years worldwide in average, the energy price increased steadily at a rate of 20% and there are no indications that this growth will slow down any time soon. In Bosnia and Herzegovina, more than 90% energy comes from non-environment-friendly sources and more than 50% from non-renewables (existing hydropower plants are counted as renewable but they are considered as a non-environment-friendly energy source in the same time). There are many positive side effects for the implementation of smart public lighting system related to energy savings, as reducing CO_2 emission, decreasing light pollution (what impacts migrating birds and wildlife in general, e.g.) and many other effects.

4.2.1.2 Site Description

The pilot will be deployed on the territory of the Municipality of East Ilidza, in a town square Veljine. There are two measuring points at this square, but for the testing, it is important Measuring point Dobrinja 1 (promenade).

Existing public street lighting system in the location for testing is with the following characteristics:

- Number of the street lamps: 36
    - 16 street light poles with two lamps
    - 1 pole with four lamps
- Length of the street light system: 272 m
- Metal poles in good shape, 7 m high
- Automatic mode
- Power of the street lamps: 70 W, Na
- Cable: PP00 – A4 x 16 mm^2

Figure 21: Veljine

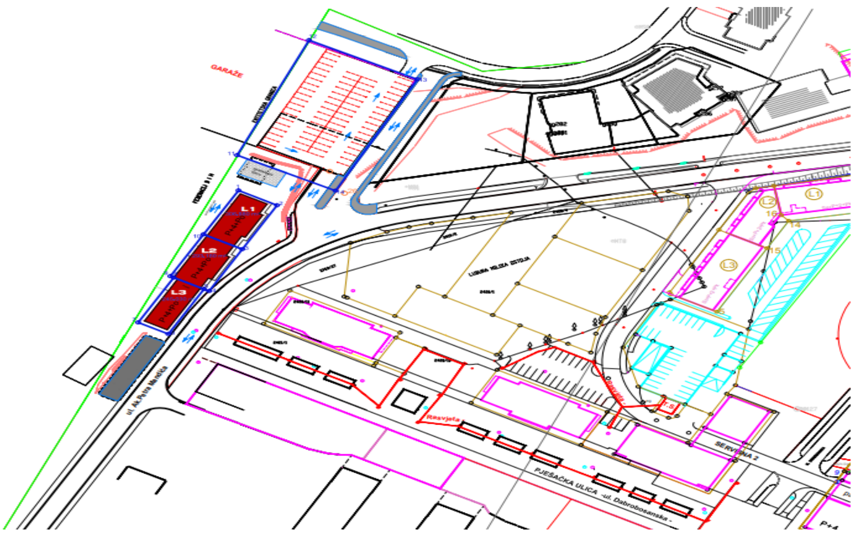


Figure 22. Town square Veljine

4.2.1.3 Pilot Deployment Description

It is envisaged one type of pilot smart street light what means precisely:

- Supply, Setting Up, Configuration and Installation in the appropriate street's light poles of a system based on digital and energy-saving technologies;
- The system will manage 20 Energy Meters and be composed by Energy Metering Controllers, Energy Meters and Sensors.

The specific goals are:

- To design and execute the advanced development in an embedded system for energy saving of street lights.
- Taking advantage of the Internet of Things (IoT) infrastructure and services to collect data from city street public lights system in order to monitor and optimize the street lighting efficiency.
- To adopt a suitable distributed embedded infrastructure.

The proposed system should monitor and analyze in real-time:

- Air Quality
    - Temperature
    - Pressure
    - Humidity
    - CO
    - CO_2
    - NO_2
    - SO_2
- Motion (Counters)
- Ambient Light and UVA/UVB
- Public Lighting System parameters and statistics (for future profiling)

The system should be modular and expandable, in both hardware and software, so that in the future it can be converted into an integrated control system for Smart City of East Sarajevo and all other services within the jurisdiction of the City.

Telecommunications Infrastructure will be composed of:

- Free ISM band: Radio-communications technology that will be used is LoRaWAN (in combination with Wi-Fi, particularly if necessary); LoRaWAN system is connected to the mobile network for the interconnection between the sensors system and Data Center.
- Future Compatibility and Modularity: LoRaWAN is a long-range, low power radio frequency communication technology that allows unprecedented fast and cost-efficient street light control system deployment and it is compatible and applicable to all future Smart City & IoT applications.
- Environmental-Friendly Approach: LoRaWAN technology enables real-time connectivity, energy-efficient bidirectional communication between sensors network and central access point, which is connected to the Internet.

Smart City system is very depended on various telecommunications (mostly, radio-communications, but sometimes cable communications as a fiber-optic and copper-coax or power-line communications). 5G is a future key enabler for smart services including the Smart Cities applications. Smart City is based on local subsystems which are interconnected by LPWAN (Low-Power Wide Area Network) systems.

There are 3 key technologies in LPWAN family:

- LoRaWAN
- NB-IoT (Narrowband Internet of Things)
- SigFox (most cost-efficient, but uplink only -> no management!)
- LTE-M (coming)

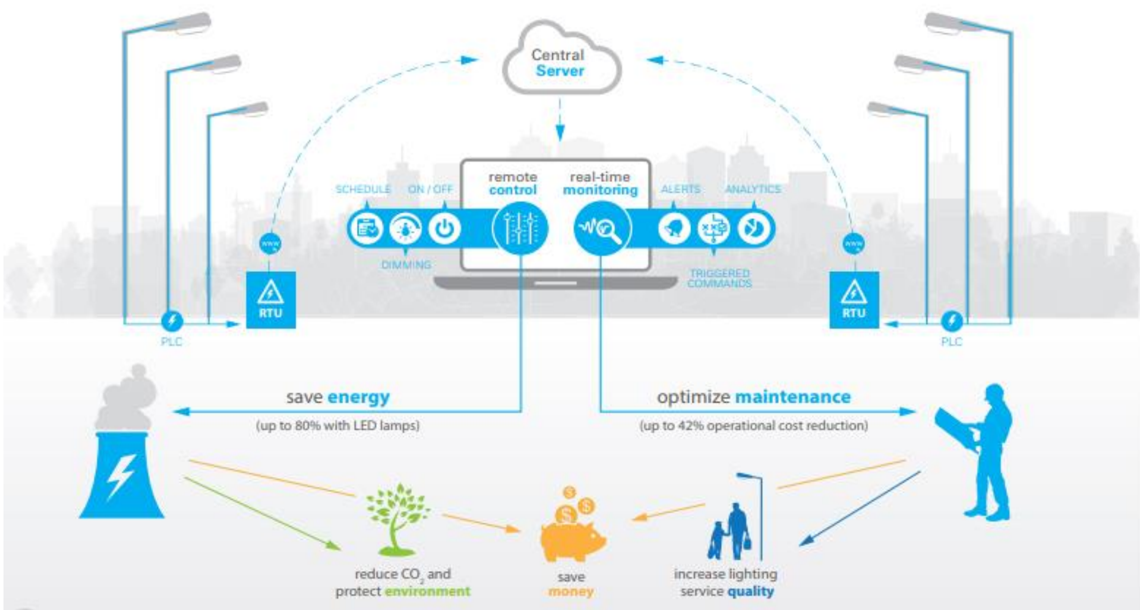


Figure 23. Telecommunications Infrastructure as Enabler for Smart Applications/Services

LoRa is a non-cellular modulation technology for LoRaWAN.It is a proprietary modulation technique. Those two terms, LoRa and LoRaWAN, are *not* interchangeable. LoRaWAN is the standard protocol for WAN communications and LoRa is used as a wide area network technology LoRaWAN RF bands in Europe: 433 MHz or 868 MHz.

LoRaWAN advantages:

- It is perfect for single-building applications.
- Easy set up and manage your own network.
- it is a good option if you need bi-directionality, for example, command-and-control functionality, because of the symmetric link.
- Its devices work well when they are in motion, which makes them useful for tracking assets on the move, such as shipments.
- Its devices have longer battery life than NB-IoT devices.

LoRaWAN disadvantages:

- It has lower data rates than NB-IoT.
- It has a longer latency time than NB-IoT.
- It requires a gateway to work

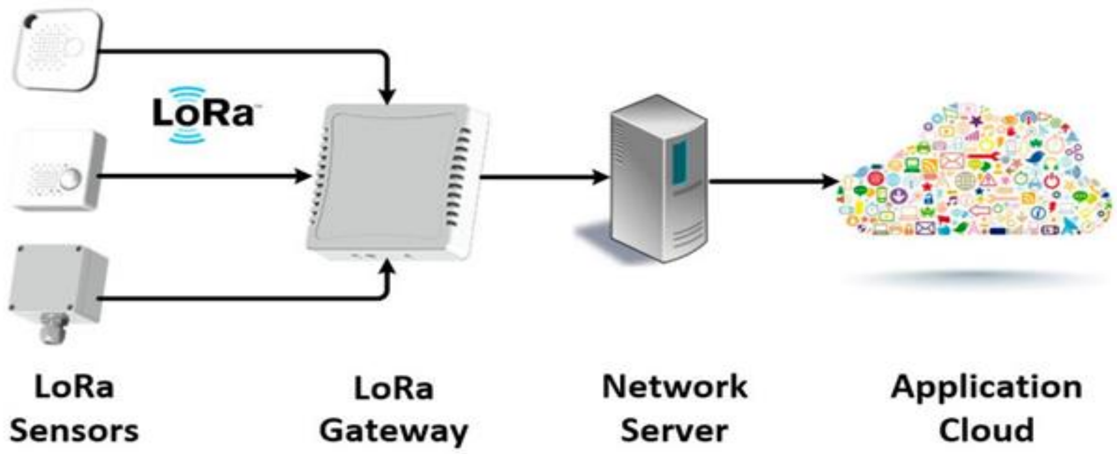


Figure 24. LoRaWAN, SystemArchitecture

The pilot project is focused on Sensors and Transport Subsystem. City Data Center would be implemented in the future; in this stage of the project, the City deploys a standalone server for the pilot project.

Implementation Cost for the project Smart Public Lights is divided into three segments:

- Core System (City Data Center), as a central point for collecting data, data storage and data analytics, but also for monitoring the system in real-time and to manage the system
- Sensors (Peripheral) System, to measure different parameters depends on applications
- Telecommunications System, to transport data from the point of collection (sensors) to the City Data Center as a central point of the Smart City system.

There are two possible models for the implementation:

- Model 1: to use existing solutions from many vendors
- Model 2: to develop own solutions in the local community

Model 1 is faster and it could be a good approach for the pilot project to prove the concept; the disadvantage of this approach is a bad business model, depending on foreign vendors.

Model 2 is slower but long-term better as a strategic approach. This model allows to "wake up" local hardware-based start-up community, to build open data community to engage software-based start-ups and to engage the whole local community to entrepreneurship solution approach.

Depending on the project limitations and future plan and strategies of the City, RAIS will choose one of these models.

4.2.1.4 User Requirements specification

The main goal of the pilot deployed by RAIS is to create an experimental framework that will allow users to test some smart city applications in the real-time and real environment under different parameter settings and environmental factors. To achieve this, the service has to meet the following User Requirements:

- <u>Sensors (Sensor Network):</u> Various sensors will be used to make the system more robust and provide various kinds of information. For this pilot project, deployed sensor network has to support primary monitoring and management of the public lighting system and secondary to provide additional co-located applications as an Air Quality monitoring, which are perfectly matched for co-location and installation at the once.
- <u>Data Collection Point:</u> The City has a plan to develop the Data Center as a central point of the data collection, storage and data analytics. This center is going to be enhanced by Machine Learning, Data Mining and Artificial Intelligence algorithms to be able to reach a deeper knowledge. In this pilot project, as an early-stage of developing smart city ecosystem, the focus will be on data logging and user-friendly presentation. With the future growth of the sensor network and with the implementation of new smart applications with different sensors, the data collection is going to reach higher volume,

relevance and diversity which enables deep knowledge collection and makes sense to implement full data center. The system is designed with the following goals:

   - Gather the public lighting system parameters values as key data for monitoring and management of the system;
   - Gather the environmental data from the predefined locations of the interest (Air Quality, Noise and Light pollution, statistic focused on the behavior of the citizens as a counter of people passing the locations in the real-time, e.g, what is useful for the future profiling and planning)

- Open Data Policy: The City has a plan to support the start-up community and make many of collected data public. Wider availability of the collected data is a key enabler to motivate the local engineering community to develop a different type of software applications based on them.

4.2.2 Smart Sportive Facility Lighting in Huetor Tajar and Smart Public Lighting in Agron, Andalusia, Spain

4.2.2.1 Introduction

The combined main strategic aims of both Agron pilot and Huetor Tajar pilot are:

- Converting conventional public lighting facilities and conventional sportive facilities to innovative, more sustainable, and with better management services.
- A first aim is to convert regular lighting facilities of Agron municipality in Granada, to LED lighting facilities with near zero light emissions to the sky (night protection standards important for rural areas), and with ease of management to improve energy efficiency, giving environmental information to the municipal technicians, as well as possible options to improve it.
- Provide a complete standardized open/scalable product for public and multi-sportive lighting facilities/services easy to replicate in medium and small sized municipalities.
- It is preferred to combine multi-sportive facilities of HUETOR TAJAR municipality in coordination with already existing smart city technology in some of the public buildings.
- Test in real context and under real operating conditions, concepts, and possible replication of the experience in small and medium municipalities (as well as bigger municipalities of course).
- Actively participate to provide policy-makers, PA and energy managers with decision support tools to optimize environmental impacts of their decisions and operations.
- Enhance the state-of-the-art know-how and to boost technology transfer activities.

4.2.2.2 Site Description

HUETOR TAJAR: Two main sportive lighting facilities are, at the moment, evisaged:

“Campo de Futbol Miguel Moranto de Huetor Tajar”: 24 lighting points in the field with MH technology and 2000W, already changed to LED technology and 900W each (MASLIGHTING Spanish national company).

“Pista polideportiva del ayuntamiento de Huetor Tajar”: 16x2 lighting points already with LED technology (SALVI Spanish national company)

The municipality of Huetor Tajar already has a telemanagement system implemented in its public lighting facilities, as well as LED technology in almost all those facilities, so the aim within the project would be to interconnect the new experience with the previous existing one.

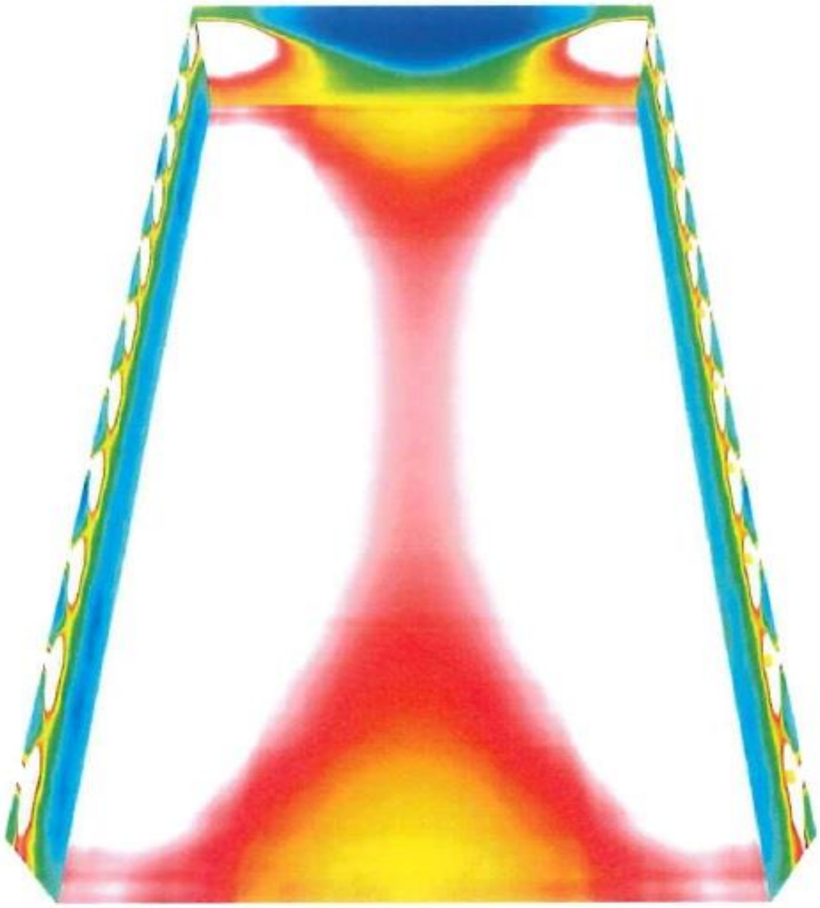
As well the municipality has a small District Heating Facility based on Olive Pit Biomass, that distributes heat to 5 public buildings and is as well tele managed. And possible interactions could be studied.

For this issue, it is needed to implement a new horizontal solution based on standards, such as FIWARE European standard, that could communicate with already existing systems. As well a new vertical solution in the sportive fields would be implemented.

The facilities of the pilot project are situated in the main sports center of the Municipality, it contains two sportive fields that have to be lightened as with regular Public Lighting, sharing some similar problems, it has different other facilities in the neighboring public buildings, and the facilities are open all days of the week to the general public, and thus a smart communications and management platform would be desirable.

The aim will be to model, monitor and control at least one of the sportive fields, depending on the final budget.

Local / Rendering (procesado) de colores falsos



AGRON: Two main different facilities are, at the moment, evisaged to be included in the pilot:

The 4 high power (400W) MH public lighting points in the municipality center to be changed to LED technology with powers per lighting point of 150 W with indications of nearly zero light emissions to the sky, low impact environment colors, and top-down illumination.

Other 36 CF lamps with low consumption but as well low light performance, and classified in the municipal energy audit as light deficient, are envisaged to be changed to LED technology and achieve both, better energy consumption (40 to 30-27 W) and better light conditions. All respecting the same principles of nearly zero light emissions to the sky, low impact environment colors.

To do so, the aim will be to take advantage of the fact that Agron is one of the first 5 municipalities in our province with a municipal policy/ordinance on night sky protection, and from those 5 is the smallest one. Thus, if the promotion of a success story in this municipality is achieved, the implementation of this kind of solution in mostly any other municipality will be encouraged.

As well, the municipality of Agron has no telemanagment system, no metering system, neither any energy savings automatic system to lower down energy consumption in late night hours, better policy of turning on and off public lighting, etc. Thus, the aim within the project would be to include a communications device and sensors and meters in the new lighting points in order to promote a Smart public lighting able to save even more energy.

The facilities of the pilot project are situated in the municipal streets, in those with MH technology as well as in the streets identified to have or bad upper hemisphere flow of lighting points and/or deficient light conditions (always trying to promote a homogeneous installation).

4.2.2.3 Pilot Deployment Description

The specific goals of both Agron pilot and Huetor Tajar pilot are:

- To develop a complete experience that would be replicable in almost all other municipalities of the province (as this is a very common facility), as well as in most of the European municipalities, related to energy management, night sky protection, and communications with users.
- To take advantage of high-performance affordable technology to monitor and analyze the use and energy consumption of the fields.
- To finalize and deliver a specific methodology to include communications with citizens and if possible, night sky protection, at the same time as important energy savings are achieved together with a maintained light quality in the fields.
- The solution should be scalable and replicable to other municipalities as stated before.

4.2.2.4 User Requirements specification

The user requirements of both pilots can be summarized as follows:

- The proposed system should perform a smart management of lighting
- The proposed system should act actively on the overall energy consumption.
- In the case of Huetor Tajar, the information on energy savings and other possible measures should be dealt to the citizens.
- In the case of Agron, the information on energy savings and other possible measures should be dealt to the municipal technicians.
- The system should be modular and expandable, in both hardware and software.

4.2.3 Smart Lighting in Lyon, France

4.2.3.1 Introduction

INSA Lyon aims to create an experimental urban area on the Lyon Tech - La Doua campus for deploying and testing smart digital solutions that will help improve the life of citizens, and that will contribute to reducing the energy consumption of the city due to smart public lighting. The strategic aims of INSA Lyon are:

- Test in a real context and under real operating conditions, concepts, algorithms, and technologies for smart cities. The specific setup of the deployment site (described below) gives us the perfect environment for testing new solutions based on different parameters and conditions, in order to choose the best one for our scenario.
- Replicate the experience in different urban scenarios. It is well know that wireless technologies are highly depended on the environment where they are deployed. Hence, in order for a pilot deployment to be successful, pre-deployment tests have to be conducted on site. However, even these tests are not enough, since environment conditions are still going to change throughout the year. Our goal is to replicate the tests of the chosen solution under different environmental conditions, so that there are no unwanted surprises on the final pilot deployment.
- Enhance the state-of-the-art know-how.

4.2.3.2 Site Description

The pilot will be deployed on the Lyon Tech La Doua campus, where INSA Lyon is located. La Doua campus is situated on the edge of the Lyon-Villeurbanne conurbation (Figure 1), occupying an area of 100ha. Built in 1957 on the site of a former military camp and a hippodrome, the campus is currently under heavy rehabilitation on 1/3 of its surface. The project incorporates a strong experimental eco-campus dimension aimed at making the campus a real support for research on the sustainable city, facilitating the development of alternative and innovative solutions for urban planning and space management.

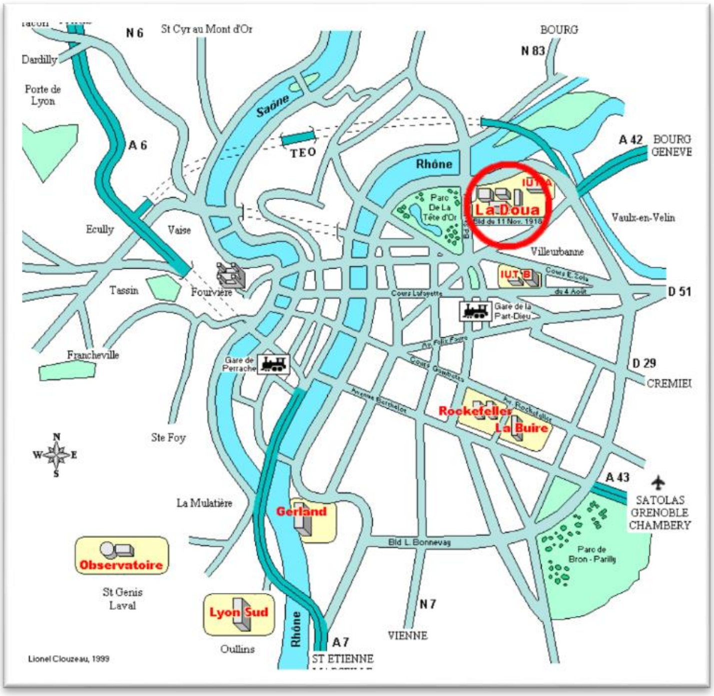


Figure 25. Lyon and La Doua campus

La Doua campus hosts 700 company employees, 25 000 students, 1 500 researchers, 1 300 PhD students, and 2 500 administrative staff. The buildings situated on the campus have several uses: 80 research laboratories, 70 companies, 6 higher education establishments, technical and industrial centers, several restaurants, student residences, and sport facilities (Figure 2).

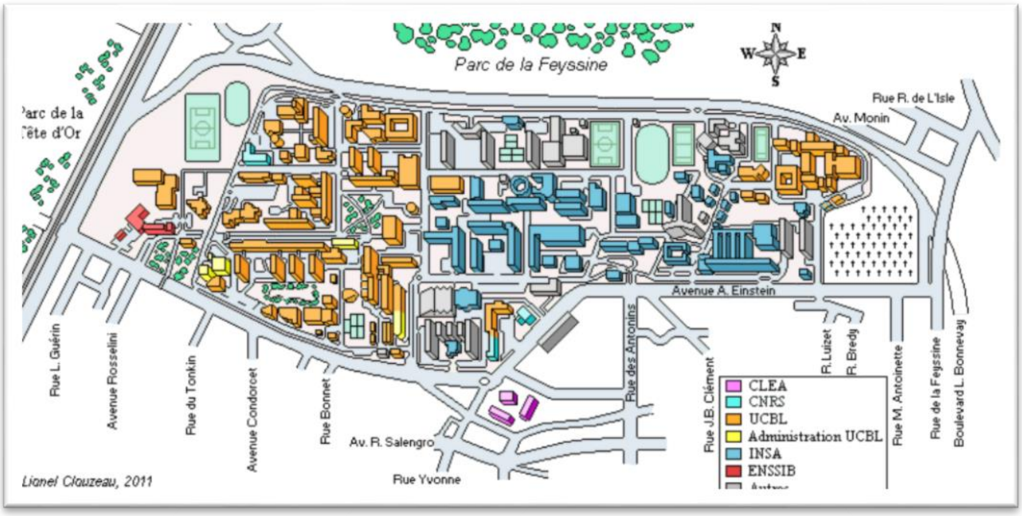


Figure 26. Lyon Tech La Doua campus

4.2.3.3 Pilot Deployment Description

In order to achieve the strategic aims presented in Section 4.2.3.1, the pilot deployed by INSA Lyon consists of two modular testbeds (from a logic point of view):

1. *A sensor network* composed of several sensors (e.g., motion, light, temperature) that will have the role of monitoring and recording the environmental conditions of the site where this network will be deployed. The sensor network will be autonomous and easily deployable, which will allow us to record the environmental conditions from different sites on the campus.
2. *A wireless network* composed of wireless devices that will replay different predefined scenarios (e.g., scenarios created with data obtained from the sensors network, or from the pilots deployed by the other partners). The wireless network will be able to test several parameterizations of the pilots tested, and to do a stress test of the network under different traffic loads, in particular typical future smart cities scenarios with thousands of competing applications.

From a hardware perspective, these two testbeds could be physically one single testbed, considering the deployment costs (Figure 3).

The specific goals of the INSA Lyon pilot are:

1. Create an experimental setting where pilots can be tested under real operating conditions, before the final deployment in an urban environment.
2. Collect sensor data from intelligent objects deployed on the campus and use this data as an input to evaluate pilot deployments under different environmental conditions.
3. Make a stress test of pilot deployments under harsh conditions (increased network load, high density of deployment, etc.).

Figure 27. Pilot deployment on Lyon Tech La Doua campus

4.2.3.4 User Requirements specification

The main goal of the pilot deployed by INSA Lyon is to create an experimental platform that will allow users to test their smart city solutions under different parameter settings and environmental factors. In order to achieve this, the following user requirements are specified:

- Gather environment information (e.g., temperature, humidity);
- Gather information about people passing by;
- Store gathered information locally;
- Send commands to the wireless network;
- Ease of deployment.

4.2.4 Smart Street Lighting in Pescara, Abruzzo, Italy

4.2.4.1 Introduction

The complexities of transportation infrastructure mean varying types of illumination are needed to ensure people feel safe, and cities save on costs.

Street lighting systems have to be smart and versatile,:

ABRUZZO REGION aims to create an experimental urban area on the Municipality of Pescara for deploying and testing smart and versatile digital Street lighting systems that will contribute to:

- reduce energy use
- manage, maintain, and monitor the entire system simply and efficiently
- reduce CO2 emissions for a greener, more sustainable city

The strategic aims of ABRUZZO REGION are:

- Test a innovative system of point-point remote control that meets all managerial needs, aimed at a more rational use of economic resources and the improvement of the quality of the service offered to citizenship
- Contribute to providing policy makers, PA and energy managers with decision support tools to optimize environmental impacts of their decisions and operations.

4.2.4.2 Site Description

The pilot will be deployed on the Municipality of Pescara.

Pescara is an Italian municipality of 120 151 inhabitants [5], capital of the homonymous province in Abruzzo. It is the most populous municipality in the region and is the heart of a metropolitan area of more than 250,000 inhabitants with adjoining municipalities and up to 420,000 including the entire area of influence.

There are several parallel road axes that cross almost entirely the city in a north-south direction, including the SS 16 (via Nazionale Adriatica Nord, viale Bovio, Corso Vittorio Emanuele II, viale Marconi, via della Bonifica) and the seafront promenade (lungomare Matteotti e viale Primo Vere). The pilot project will be developed along a stretch of about 400 meters of Viale Primo Vere Road.

Figure 28. Pescara, Viale Primo Vere

The pilot project intends to create an integrated system of Smart lighting along one of the main roads of Pescara, replacing the old lighting system with a new intelligent system effective and efficient, in order to evaluate the actual Saving of electricity through a combination of the brightness adjustment of the lamps to the conditions of environmental visibility and lighting management.

Figure 29. Old lighting system

4.2.4.3 Pilot Deployment Description

In order to achieve the strategic aims presented in Section 1.1.1.1, the pilot deployed by ABRUZZO REGION consists of:

- *Control device and cabinet command :* It is made up of components to be placed in the Electrical Control Panel that feeds the lighting lines. It is able to dialogue using the existing power line, with conveyed waves, with the devices of control/Command lamp placed on the lamps supplied by the line itself;

- *controller and lamp control device :* It is an electronic device to be installed in Series after the lamp protection fuse. It is able to diagnose the malfunction of the lamp and converse with the device Control/Command cabinet, on the lamp power line, to receive instructions from the control device/Cabinet control to command Turning the lamp on or off, reducing or adjusting the luminous flux of the Lamp itself and to filter the noise generated by the lamp;

- *supervision unit :* It consists of a server machine operating on a Linux platform that Allows access via web browser to the management and control software of the systems Public lighting and associated sensors.

The benefits of the system are as follows:

- Increase the efficiency and functionality of street lighting
- Expand the street lighting system by adding additional functions
- Provide a platform for future smart city applications.
- To design and execute the advanced development in embedded system for energy saving of street lights.
- Collect data from city street lights in order to monitor and optimize the street lighting efficiency.
- To adopt a suitable distributed embedded infrastructure

4.2.4.4 User Requirements specification

The main goal of the pilot deployed by ABRUZZO REGION is to test a innovative system of point-point remote control that meets all managerial needs, aimed at a more rational use of economic resources and the improvement of the quality of the service offered to citizenship.

To achieve this, the service should meet the following User Requirements:

- Enhance energy monitoring and management and to ensure control of environmental factors in smart street lighting
- Propose a vertical solution
- Inform the citizens of the improvements achieved through technology
- Replicability and scalability of the project

4.3 User Requirements analysis and codification

The user requirements presented by the different deployment use cases have been classified according to a unique User Requirement Codification. This codification aims at clarifying the specific focus of each pilot usecase deployment, highlighting the similarities and complementarities among them.

The project pilot testing utilizes both themes of “Building Energy Efficiency” and “Smart Public Lighting”. A number of user requirements pertains to both themes and these requirements are applicable to most of the pilot deployments. Such requirements are denoted as Common User Requirements – “CURnn” nn being an incremental index.

- CUR01 – Replicability: this user requirement is necessary to validate the possible future spread of the solution proposed by each pilot deployment.
- CUR02 – Promotion of innovative technologies: together with the replicability condition, the project will be able to prove the cutting-edge technology ease of use and its advantages.
- CUR03 – Utilization of smart devices: the project will rely on and utilize smart devices, i.e. sensors, actuators and embedded devices that enable different data acquisition and control scenarios.
- CUR04 – Experimentation at the edge level: the project will promote experimentation at the edge level utilizing intelligence and computational resources of devices at the edge.
- CUR05 – Open source platforms: the project will promote utilization of open source non-proprietary platforms wherever possible and with reference to the data acquisition.
- CUR06 – Cloud based services: the project will utilize services at the cloud level with reference to data storage and analytics.
- CUR07 – Quick and simple installation procedures: the project will focus on devices and systems that present quick and simple installation procedures.
- CUR08 – Durability of devices and systems vs inspection and maintenance: the project will make utilization of devices and systems that are easy to inspect and maintain.
- CUR09 – Privacy and other legal framework issues: the project will make utilization of devices and systems that do not raise privacy or other legal framework concerns.
- CUR10 – Low intrusion and aesthetics issues: Emphasis will be placed on such commercial issues as no intrusion and aesthetics wherever possible.
- CUR11 – Quality of captured information: Emphasis will be placed on the quality of the captured information in a time and spatial context.
- CUR12 – Cost of the different devices / systems: Overall cost of acquisition, installation and maintenance is an aspect of the overall system.

Considering the existing differences between the two themes “Building Energy Efficiency” and “Smart Public Lighting”, the functional specifications will be analyzed in the two separate following sections.

4.3.1 Building Energy Efficiency User Requirements

The user requirements related to the Building Energy Efficiency theme have been classified according to the following codification – signed “BURnn” nn being an incremental index:

- BUR01 – Testing different heating/cooling structures and control strategies
- BUR02 – Storing data on a server for big data analysis
- BUR03 – Provide a GUI for real-time, historical data and other specific features
- BUR04 – Monitoring people occupancy
- BUR05 – Monitoring environmental and structural characteristics of the building
- BUR06 – Testing the effect of complex thermal network on the building consumption
- BUR07 – Deploy a highly heterogeneous devices network and manage its interconnection
- BUR08 – Collecting the electrical consumption of different buildings
- BUR09 – Study/implement complex renewable energy systems
- BUR10 – Providing an intervention planning analysis tool

The table below considers the use cases related to the Building Energy Efficiency theme and links each pilot deployment with the presented User Requirement Codification.

Building User Requirement	RWG	ISI	MCM	PoliMi	ENA
CUR01 – Replicability	X	X	X	X	X
CUR02 – Innovative technologies	X	X	X	X	X
CUR03 – Utilization of smart devices	X	X	X	X	X
CUR04 – Experimentation at the edge level	X	X	X	X	X
CUR05 – Open source platforms	X	X	X	X	X
CUR06 – Cloud based services	X	X	X		X
CUR07 – Quick and simple installation procedures	X	X	X	X	X
CUR08 – Durability of devices and systems	X	X	X	X	X
CUR09 – Privacy and other legal framework issues	X	X	X	X	X
CUR10 – Low intrusion and aesthetics issues	X	X	X	X	X
CUR11 – Quality of captured information	X	X	X	X	X

CUR12 – Cost of the different devices / systems	X	X	X	X	X
BUR01 – Control studies		X	X	X	
BUR02 – Big data analysis	X	X	X		X
BUR03 – GUI		X			X
BUR04 – People occupancy		X	X		
BUR05 – Environmental and Structural monitoring			X		
BUR06 – Thermal network studies				X	
BUR07 – Network heterogeneity		X		X	
BUR08 – Building electrical consumption	X				X
BUR09 – Renewable energy studies				X	
BUR10 – Intervention planning tool					X

"Building Energy Efficiency" User Requirements Codification

It is possible to analyze the whole ensemble of the presented user requirements as the image of a single pilot deployed through different use cases. In fact, beside the straightforward relevance of the common user requirements CUR01 and CUR02 in this project, it is possible to see different sides of the whole picture by logically grouping the building user requirements BURxx into three categories:

- **Control studies**:
  User requirements BUR01, BUR06 and BUR09 studies the effect of different factors on the building energy efficiency theme. These studies are conducted by exploiting a real testing environment or by manipulating real systems involved in the pilot deployments. This category thus envisages a more active-investigative approach on the issue.

- **Data infrastructure, collection and analysis**:
  Many of the presented user requirements (BUR02, BUR04, BUR05, BUR7 and BUR08) are concerned with the acquisition and analysis of data, together with all the necessary measures to fulfill this general task – like the developing of a dedicated devices network BUR08. This category, unlike the "Control studies" category, is focused on the observation and data collection performed on the use cases systems. In this way, it is possible to draw conclusions on the current functioning of the buildings, highlighting eventual strengths or flaws to work on.

- **User tools**:
  A third category of user requirements is represented by the ones focused on the development of user tools, i.e. BUR03 and BUR10. These tools are meant to share in the

easiest way possible the results obtained by the studies and analyses related to other user requirements.

4.3.2 Smart Public Lighting User Requirements

Similarly to the Building Energy Efficiency case, the User Requirements related to the Smart Public Lighting have been classified according to the following User Requirement Codification – signed "LURnn" nn being an incremental index:

- LUR01 – Street light energy saving embedded system development based on a suitable embedded infrastructure
- LUR02 – Utilization of Internet of Things (IoT) infrastructure for street lighting
- LUR03 – Monitoring environmental characteristics
- LUR04 – Monitoring street motion
- LUR05 – Enabling public street light profiling
- LUR06 – Rely on wireless networking solutions
- LUR07 – Smart energy management of lighting
- LUR08 – Perform stress tests of different scenarios under harsh conditions

The table below considers the use cases related to the Smart Public Lighting theme and links each pilot deployment with the presented User Requirement Codification.

Lighting User Requirement	RAIS	APEGR	INSA	ABRREG
CUR01 – Replicability	X	X	X	X
CUR02 – Innovative technologies	X	X	X	X
CUR03 – Utilization of smart devices	X	X	X	X
CUR04 – Experimentation at the edge level	X	X	X	X
CUR05 – Open source platforms	X	X	X	X
CUR06 – Cloud based services	X	X	X	X
CUR07 – Quick and simple installation procedures	X	X	X	X
CUR08 – Durability of devices and systems	X	X	X	X
CUR09 – Privacy and other legal framework issues	X	X	X	X
CUR10 – Low intrusion and aesthetics issues	X	X	X	X
CUR11 – Quality of captured information	X	X	X	X
CUR12 – Cost of the different devices / systems	X	X	X	X
LUR01 – Street light energy saving	X			X

embedded system				
LUR02 – IoT Utilization for street lighting	X		X	X
LUR03 – Environmental monitoring	X	X	X	X
LUR04 – Motion monitoring	X	X	X	X
LUR05 – Light profiling	X			
LUR06 – Wireless Networking solutions	X		X	
LUR07 – Smart energy management			X	X
LUR08 – Stress tests under harsh conditions			X	

"Smart Public Lighting" User Requirements Codification

5 Functional Specifications

This chapter builds on top of the aforementioned user requirements in order to derive the pilot deployment functional specifications. The main envisaged functionalities denoted as Fxx, where xx is a functionality incremental index, are presented below:

- F01 – Planning
- F02 – Device Installation and maintenance
- F03 – Central platform deployment and management
- F04 – Edge Tier
- F05 – Communication
- F06 – Services
- F07 – Operational Issues
- F08 – Public Perception Issues
- F09 – Commercial Issues
- F10 – Institutional Issues

The above generic functionalities are further broken down into more detailed functional specifications denoted as Fxx.yy where Fxx is the corresponding functionality and yy is an incremental index. Resulting functional specifications are detailed as follows:

5.1 Planning

The overall system must be designed so that it is easily customizable and deployed. Following the generic Smart City paradigm modularity is a key parameter for the system wide adaption and replication in other usecases. In this context F01 is analyzed into the following Functional Specifications

- F01.01 – Ensure easy customization and deployment: the system should be easily customizable to cover the differences in settings of the pilot deployments as well as potential future usecases. Easiness in deployment is a critical element as well. Combination of commercial off the shelf devices, components and systems is envisaged integrated with developments undertaken in the framework of the project and adequate parameterizations. F01.01 addresses primarily user requirements CUR01, CUR07, CUR08.
- F01.02 – Ensure system modularity: Modularity is the ability of the system components to be regarded as separate elements, so as to be recombined and produce a different system characterized by flexibility and variety. Modularity is a required functionality for Esmartcity

and in general in the context of the Smart City paradigm that is characterized by increased complexity, hiding the complexity of the different parts and enabling overall efficiency. F01.02 addresses primarily user requirements CUR01, CUR02, and CUR04.

5.2 Device Installation and Maintenance

The Esmartcity system will utilize devices of great variety ranging from simple sensing and actuating devices to controller devices with embedded intelligence that can perform part of the anticipated control algorithms at the edge of the system to gateways that offer a communication to the cloud and to smart devices that can combine some or all of the aforementioned capabilities.

Following the Internet of Things (IoT) principles all these devices may be regarded as interconnected “things” that are expected to function with a level or autonomy under different scenarios scaling from absence of any central management and monitoring to being part of a hierarchical scheme. Ideally and from the point of view of maintenance the devices should be “forgotten” after installation, and should either incorporate self-diagnostics or in the absence of such capacity the system should employ diagnostics to periodically check for their health.

Functional specifications associated with functionality F02 are the following:

- F02.01 – Coverage of the need for measurements of the specific space. Both with reference to the themes of “Smart Public Lighting” and “Building Energy Efficiency” the need for measurements is profound. The major categories of measurements include environmental monitoring, building structural monitoring, building occupancy, motion monitoring, energy consumption. It is of critical importance that the measurements cover the anticipated spaces in their entirety. F02.01 addresses primarily user requirements CUR11, BUR01, BUR04, BUR05, BUR06, BUR08, BUR09, LUR03, LUR04, LUR07.
- F02.02 – Ensure installation procedures, including calibration, so that captured information is adequate. Ascertaining adequate measurements is quite critical for the overall system. Especially for environmental monitoring and especially gas concentration level sensors adequate calibration procedure is quite important. F02.02 addresses primarily user requirements CUR11, BUR01, BUR04, BUR05, BUR06, BUR08, BUR09, LUR03, LUR04, LUR07.
- F02.03 – Installation in places that ascertain communication. Sensing devices make possible the digitization of the physical quantities that have to be communicated to the overall system in order to be adequately used. For each device installed communication has to be ascertained either wired or wireless. In this context installation should cater for

adequate places with network connectivity. F02.03 addresses primarily user requirements BUR07, LUR02, LUR06.

- F02.04 – Installation in places that minimize their destruction / malfunction possibilities. Appropriate installation needs to take into account the need to avoid malfunction or destruction of the installed devices. This could be the result of not complying with specific operating conditions, e.g. installing an indoors device outdoors without proper casing, or of an accident or vandalism. Minimization of these possibility should be sought. F02.04 addresses primarily user requirements CUR08, CUR10, CUR11.
- F02.05 – Installation places and procedures permitting easy diagnostics, replacement and maintenance. Maintaining easy procedures for diagnostics, replacement and maintenance contributes to the overall system simplicity and replicability. F02.05 addresses primarily user requirements CUR01, CUR07, CUR08.
- F02.06 – Long maintenance-free life expectancy in the order of 10 years. It is envisaged that all devices utilized in the framework of the pilot testing will have power connection both in the "Building Energy Efficiency" and the "Smart Public Lighting" themes. In the case that some devices or equipment will operate with battery, functionality F02.06 may be reconciled. F02.06 addresses primarily user requirements CUR01, CUR08.
- F02.07 – Diagnostics. Ability of the overall system to diagnose potential malfunctions either as a result of device self-diagnostics or as an overall system diagnostic functionality. The system should employ diagnostics functionalities in order to be possible to address the measurement health. This could be either accomplished in the form of self-diagnostics at device level or as part of a system level capacity. F02.07 addresses primarily user requirements CUR07, CUR08.

5.3 Central platform deployment and management

A centralized platform is envisaged for the retrieval of information by the different devices and components of the system, the processing of this information and its utilization for the provision of services or reasoning. It is envisaged that the different pilot deployments will not utilize a single platform due also to the data part associated with them, but rather use separate platforms under the same centralized scheme. In fact the level of centralization might be different for the different deployments including or not cloud connectivity and data storage.

Functional specifications associated with functionality F03 are the following:

- F03.01 – Contained cost of purchase. In order to enhance system replicability central platform costs have to be maintained low. To this end the project proposes utilization of open source platform solutions that are also reviewed in the state-of-the-art presented in this deliverable. In this context the overall cost could be associated with the necessary infrastructure costs. F03.01 addresses primarily user requirements CUR01, CUR05, CUR12.

- F03.02 – Low maintenance needs. The central platform maintenance needs should be as low as possible. Focus of the project on open source platforms reduces such costs. Furthermore, overall infrastructure costs associated with the central platform are in general contained. F03.02 addresses primarily user requirements CUR01, CUR05, CUR07, CUR08, CUR12.
- F03.03 – Data Storage. The central platform is envisaged to be involved in the real time data storage associated with the pilot deployments. This might be done either on local infrastructure or on the cloud. Furthermore, the project will investigate different combinations to this end also with reference to functionalities F04 and F06 that deal with infrastructure at the edge and the cloud / services tier respectively. F03.03 addresses primarily user requirements CUR02, CUR04, CUR06.

5.4 Edge Tier

The edge tier represents the lower tier with reference to the system hierarchy, the tier that is close to the devices installed. A number of diverse devices is envisaged comprising sensing and actuating devices, control devices and gateways with different computational resources. Based on such resources they may be classified as smart or not. The utilization of smart devices leads to different scenarios that make use of the potential for increased autonomy and lead to a distribution of functionalities down to the smart devices. Further to the classic distribution of control functionalities to the edge devices, current innovative architectures also introduce analytics functionalities in order to deal with the data generated at the edge tier rather than transferring them to a cloud or an upper hierarchical layer.

Functional specifications associated with functionality F04 are the following:

- F04.01 – Smartness. The project has a firm orientation towards smart devices wherever possible. This actually means both smart sensors and actuators with advanced computational resources that in addition to measurement and digitization may also perform some part of the control and data analytics, and embedded systems increasing overall autonomy. F04.01 addresses primarily user requirements CUR03, CUR04, LUR01, LUR02.
- F04.02 – Control code distribution. The existing intelligence at the edge tier both in smart and embedded devices makes possible the distribution of part of the control code to the edge. F04.02 addresses primarily user requirements CUR03, CUR04, LUR01.

- F04.03 – Remotely controlled actuation devices. The system should offer the possibility for remote actuation based on specific scenarios. F04.03 addresses primarily user requirements CUR03, CUR04.
- F04.04 – Edge computing. The project will experiment at the edge tier with edge computing functionalities moving some part of the application, data and services from the higher layers to the edge. F04.04 addresses primarily user requirements CUR02, CUR03, CUR04, LUR02.

5.5 Communication

Networking and communications represent a significant part of the system and an enabler for its other functionalities. Communications cover the whole range from the devices and the edge tier to the upper layers, the central platform and the cloud. Different types of network interconnections are envisaged in the context of wired, wireless, IoT and internet technologies.

Functional specifications associated with functionality F05 are the following:

- F05.01 – Real timeliness. The communication network should support real timeliness in the acquisition and storage of data. End to end real timeliness should be ascertained. F05.01 addresses primarily user requirements BUR01, BUR04, BUR05, BUR06, BUR08, BUR09, BUR10, LUR01, LUR02, LUR03, LUR04, LUR05, LUR07, LUR08.
- F05.02 – Heterogeneous interconnection. Different types of networking could be supported ranging from IoT networking technologies to wired and wireless networking solutions. The different pilot deployments could utilize one or more out of them and the system should be seamlessly interoperable. F05.02 addresses primarily user requirements BUR07, LUR01, LUR02, LUR06.

5.6 Services

Different services are envisaged to be employed at the higher layer. Depending on the different pilot deployment the higher layer could be the Cloud or not. In any case the overall structure presents similarities. Services like big data analysis could for instance be done on the Cloud or on local computing infrastructure. Different application level tools and platforms could take advantage of such services and data in order to provide useful impact to the partner areas.

Functional specifications associated with functionality F06 are the following:

- F06.01 – Big data analysis. The central platform is responsible for data storage according to F03.03. This data may be stored in local infrastructure or on the Cloud. Big Data Analysis is a useful tool for discovering useful information, coming to conclusions with reference to data, and supporting decision making. F06.01 addresses primarily user requirements CUR06, BUR02.
- F06.02 – Real simulation environment. With reference to the Building Energy Efficiency theme and some pilot deployment a real simulation environment, endowed with different building material, heating/cooling systems and advanced renewable-resources power generation management systems, will utilize real time measured and stored data so that it elaborates different scenarios. F06.02 addresses primarily user requirements BUR05, BUR06, BUR08, BUR09.
- F06.03 – Air purification system to ensure high-level environmental conditions. With reference to the Building Energy Efficiency theme and some pilot deployment an air purification system ensuring high-level environmental conditions will make use of real time and stored data. F06.03 addresses primarily user requirements BUR05, BUR08.
- F06.04 – Graphical User Interface for user friendliness. With reference to the Building Energy Efficiency theme and some pilot deployments GUIs will be needed in order to ease user interaction with the system and enable different interventions. F06.04 addresses primarily user requirements BUR03.
- F06.05 – Web monitoring platform. With reference to the Building Energy Efficiency theme and some pilot deployments Web monitoring will enable event reporting and intervention planning. F06.05 addresses primarily user requirements BUR08, BUR10.
- F06.06 – Light profiling and energy management. With reference to the Smart Public Lighting theme and some pilot deployments light profiling and public lighting energy management will be enabled. F06.06 addresses primarily user requirements LUR05, LUR07.
- F06.07 – Lighting stress testing. With reference to the Smart Public Lighting theme and some pilot deployments lighting stress testing under harsh conditions will be undertaken utilizing real time and stored data. F06.07 addresses primarily user requirement LUR08.

5.7 Operational Issues

The issue of operational sustainability is critical for the project. It is in fact a point that has to be addressed so that the pilot deployment results maintain a permanent effect in the partner areas. Different problems are associated with this context including costs after the pilot testing phase, as well system integration and usability issues.

Functional specifications associated with functionality F07 are the following:

- F07.01 – Ease of deployment, management and maintenance of the overall system. In combination with functional specifications associated with functionalities F01, F02 and F03 the overall system deployment, management and maintenance should be as easy as possible, so that no operational barriers are raised due to these aspects. F07.01 addresses primarily user requirements CUR01, CUR05, CUR07, CUR08, CUR10.
- F07.02 – Integration of the system with related existing and future systems. It is critical that the system is integrated in the everyday operation of the institutions that are involved in its pilot testing. This mandates a seamless integration at least at the information / data layer with existing systems as well as taking into account this system for future improvements. F07.02 addresses primarily user requirements CUR01, CUR05, CUR07, CUR08, CUR10.
- F07.03 – System usability. The system usefulness has to be ascertained at operational level and its resulting information should be integrated in the operation of the institutions that it is pilot tested in. F07.03 addresses primarily user requirements CUR01, CUR06, BUR02, BUR10, CUR05, CUR08.

5.8 Public Perception Issues

Public perception of any system dealing with measurements in buildings or public spaces is important. Especially when these measurements are associated with the occupancy patterns or positional tracking of persons or the motion of people of vehicles as is the case for Esmartcity.

Functional specifications associated with functionality F08 are the following:

- F08.01 – Overall system must be as less invasive as possible; relevant device installation must be appropriate to this end. F09.01 addresses primarily user requirements CUR09, CUR10.

5.9 Commercial Issues

In order to address sustainability and replicability of the system the market / commercial aspect has to be taken into account.

Functional specifications associated with functionality F09 are the following:

- F09.01 – Low overall cost. F09.01 addresses primarily user requirements CUR01, CUR05, CUR12.

- F09.02 – Simple installation of the system preferably not requiring specialized personnel and being a fraction of the overall cost. F09.02 addresses primarily user requirements CUR01, CUR07, CUR08, CUR12.
- F09.03 – Maintenance-free system or as an alternative low-cost maintenance / replacement procedures. F09.02 addresses primarily user requirements CUR01, CUR08, CUR12.

5.10 Institutional Issues

Esmartcity deals with measurement data that depending on the theme are relevant to building energy behavior and other influential parameters or lighting in public spaces. This data might be regarded as sensitive at an institutional level and have to be treated as such by the project.

Functional specifications associated with functionality F10 are the following:

- F10.01 – Access to system data is limited at institutional level. The project develops a strategy around this context by enabling different central platforms for real time data acquisition and storage per pilot deployment. This strategy enables a common testing without compromising institutional issues and contributes to the wider sustainability of the system. F10.01 addresses primarily user requirements CUR01, CUR05, CUR09.

6 Conclusions

D.3.2.1 presents a Feasibility Study for the Pilot Testing Activities of the project. The project deals with the Smart City paradigm and more specifically the “Building Energy Efficiency” and “Smart Public Lighting” themes. To this end the pilot testing will comprise a number of deployments in the different partner areas.

The methodological approach behind D.3.2.1 starts from a certain idea that is related to improving modern cities making them smarter and enabling smarter services and applications. This idea is mapped on the user requirements of the partner areas, as well as a technology state of the art survey applicable for the idea implementation. The combination of the user requirements and the state of the art leads to the project functional specification and determines the technical feasibility of the project.

The state of the art survey covers on the first hand the general area of Smart Cities and the Internet of Things paradigm with some wider applicable reference architectures. Furthermore, it focuses on the two themes dealt with by the project, more specifically Building Energy Efficiency and Smart Public Lighting, and details state of the art aspects.

The following table comprises the overall user requirements of the project.

Common User Requirement	Building Energy Efficiency User Requirements
CUR01 – Replicability	BUR01 – Control studies
	BUR02 – Big data analysis
CUR02 – Innovative technologies	BUR03 – GUI
	BUR04 – People occupancy
CUR03 – Utilization of smart devices	BUR05 – Environmental and Structural monitoring
CUR04 – Experimentation at the edge level	BUR06 – Material studies
	BUR07 – Network heterogeneity
CUR05 – Open source platforms	BUR08 – Building electrical consumption
	BUR09 – Renewable energy studies
CUR06 – Cloud based services	BUR10 – Intervention planning tool
	Smart Public Lighting User Requirements
CUR07 – Quick and simple installation procedures	LUR01 – Street light energy saving embedded system
CUR08 – Durability of devices and systems	LUR02 – IoT Utilization for street lighting
CUR09 – Privacy and other legal framework issues	LUR03 – Environmental monitoring

	LUR04 – Motion monitoring
CUR10 – Low intrusion and aesthetics issues	LUR05 – Light profiling
	LUR06 – Wireless Networking solutions
CUR11 – Quality of captured information	LUR07 – Smart energy management
	LUR08 – Stress tests under harsh conditions

The following table comprises the overall functional specifications of the project.

Functionality	**Functional Specification**
Planning	F01.01 – Ensure easy customization and deployment
	F01.02 – Ensure system modularity
Device Installation and Maintenance	F02.01 – Coverage of the need for measurements of the specific space
	F02.02 – Ensure installation procedures, including calibration, so that captured information is adequate
	F02.03 – Installation in places that ascertain communication
	F02.04 – Installation in places that minimize their destruction / malfunction possibilities
	F02.05 – Installation places and procedures permitting easy diagnostics, replacement and maintenance
	F02.06 – Long maintenance-free life expectancy in the order of 10 years
	F02.07 – Diagnostics
Central Platform Deployment and Management	F03.01 – Contained cost of purchase
	F03.02 – Low maintenance needs
	F03.03 – Data Storage
Edge Tier	F04.01 – Smartness
	F04.02 – Control code distribution
	F04.03 – Remotely controlled actuation devices
	F04.04 – Edge computing
Communication	F05.01 – Real timeliness
	F05.02 – Heterogeneous interconnection
Services	F06.01 – Big data analysis
	F06.02 – Real simulation environment
	F06.03 – Air purification system to ensure high-level environmental conditions
	F06.04 – Graphical User Interface for user friendliness
	F06.05 – Web monitoring platform
	F06.06 – Light profiling and energy management
	F06.07 – Lighting stress testing
Operational Issues	F07.01 – Ease of deployment, management and maintenance of the

	overall system
	F07.02 – Integration of the system with related existing and future systems
	F07.03 – System usability
Public Perception Issues	F08.01 – Overall system must be as less invasive as possible
Commercial Issues	F09.01 – Low overall cost
	F09.02 – Simple installation of the system preferably not requiring specialized personnel and being a fraction of the overall cost
	F09.03 – Maintenance-free system or as an alternative low-cost maintenance / replacement procedures
Institutional Issues	F10.01 – Access to system data is limited at institutional level

Deliverable D.3.2.1 provides the necessary information for the finalization of the pilot project preparatory activities and the elaboration of deliverables D.3.2.2 and D.3.2.3.

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