# PhD Thesis

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By

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# Smart City: Implementation and development of platforms for the management of SunRise Smart Campus

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# Abstract

This PhD work concerns the implementation and development of platforms for the management of Smart Cities. It is a part of SunRise project, which aims at turning the Scientific Campus of Lille University into a large-scale demonstrator site of the "Smart and Sustainable City". The campus is representative of a small town of 25000 inhabitants and 100 km of urban infrastructure.

This thesis is composed of five parts.

The first part includes a literature review concerning the Smart Cities with its definitions and components.

The second part presents the role of data in Smart Cities, as well as the latest technologies that are used for Smart City management. It presents also the different existing architectures and platforms for management a Smart City.

The Third part presents the SunRise Smart City demonstrator, which is used as a basis for this thesis. The part details the instrumentation installed in the demo site as well as the GIS model of the demonstrator.

The fourth part concerns the architecture of the two professional platforms PI System and OpenDataSoft as well as their implementation and use for the analysis of water consumption.

The last part describes the architecture of the platform SunRise and details its layers. It presents also the stages of the platform development and implementation.

**Keywords**: Smart Cities, data management, IoT, PI system, OpenDataSoft, platform, ICT, WebGIS, GIS, SunRise, Campus.

# RESUMÉ

Ce travail concerne la mise en place et le développement de plateformes informatiques pour la gestion des villes intelligentes. Il s'inscrit dans le cadre du projet SunRise qui vise à transformer le campus de la Cité Scientifique de l'Université de Lille en une «ville intelligente et durable». Le campus est représentatif d'une petite ville de 25 000 habitants et de 100 km de réseaux urbains.

Cette thèse est composée de cinq parties.

La première partie comprend un état de l'art concernant les villes intelligentes, notamment les composantes de ces villes.

La deuxième partie présente le rôle des données dans les villes intelligentes, ainsi que les dernières technologies utilisées pour la gestion des villes intelligentes. Elle présente également les architectures et plateformes existantes pour la gestion de la ville intelligente.

La troisième partie présente le démonstrateur SunRise Smart City, sur lequel s'appuie cette thèse. Elle décrit l'instrumentation du site de démonstration ainsi que son modèle SIG.

La quatrième partie concerne l'architecture des deux plateformes professionnelles PI System et OpenDataSoft ainsi que leur installation e utilisation pour l'analyse de la consommation d'eau.

La dernière partie décrit l'architecture de la plateforme SunRise développée dans ce travail de thèse. Elle présente les étapes du développement et l'implémentation de cette plateforme.

**Mots-clés** : Ville intelligente, gestion des données, IoT, PI system, OpenDataSoft, plateforme, ICT, WebSIG, SIG, SunRise, Campus.

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# List of Abbreviations

| | |
|---|---|
| AWS | Amazon Web Services |
| API | Application Programming Interface |
| AF | Asset Framework |
| AMR | Automatic Meter Reader |
| BCN | Barcelona |
| BRS | Bus Rapid System |
| BRT | Bus Rapid Transit |
| CSS | Cascading Style Sheets |
| EPC | Electronic Police Center |
| EPIC | European Platform for Intelligent Cities |
| GIS | Geographic Information System |
| GBM | Global Balance Method |
| GPS | Global Positioning System |
| GCE | Google Compute Engine |
| HMVC | Hierarchical Model-View-Controller |
| HTML | Hypertext Markup Language |
| PHP | Hypertext Preprocessor |
| HTTP | Hypertext Transfer Protocol |
| ICT | Information and Communication Technologies |
| IT | Information Technologies |
| IaaS | Infrastructure as a Service |
| CICC | Integrated Command and Control Center |
| IES | Intelligent Energy System |
| ITS | Intelligent Transportation System |
| IADB | Inter-American Development Bank |
| ISMP | Integrated Service Management Platform |
| ICU | Interface Configuration Utility |
| ITU | International Telecommunication Union |
| IT | Internet of Things |
| LTA | Land Transport Authority |
| LTE | Long-Term Evolution |
| MEL | Metropole Europenne de Lille |
| MVC | Model-View-Controller |
| MIMO | Multiple Input Multiple Output |
| NEA | National Environment Agency |
| ODS | Open Data Soft |
| OGC | Open Geospatial Consortium |
| OSM | OpenStreetMap |
| OFDM | Orthogonal Frequency Division Multiplex |
| PSE | PI System Explorer |
| PaaS | Platform as a Service |
| PUB | Public Utilities Board |
| RFID | Radio Frequency Identification |

| | |
|---|---|
| RTDM | Real Time Data Monitoring |
| REST | Representational State Transfer |
| ORC | Rio Operations Center |
| SCDF | Singapore Civil Defense Force |
| SPF | Singapore Police Force |
| SBS | Smart Bus System |
| SaaS | Software as a Service |
| SQL | Structured Query Language |
| TWCP | Threshold Water Consumption Profile |
| TMB | Transports Metropolitans de Barcelona |
| USN | Ubiquitous Sensor Network |
| UN | United Nations |
| UFL | Universal File and Stream Loading |
| WCS | Web Coverage Service |
| WFS | Web Feature Service |
| WMS | Web Map Service |
| WSNs | Wireless Sensor Networks |



# General introduction

Cities around the world already host around 50% of the world population – and by 2050 this proportion is expected to increase to 75%. The population is shifting from rural areas to cities in search of better life conditions. Due to rapid growth of the world's population, cities are facing big challenges such as lack of natural resources, increase in energy and water consumption, increase in demand for social services and healthcare, and an increase in greenhouse gas emission, which is responsible for global warming and climate change. All of these challenges impact the quality of life in the City, which is a determinant factor in building a Happy City. Happiness in the city requires a high environmental quality (green space, public space, fresh air…), excellent urban services (mobility, education, health, culture, entertainment…) and involvement of citizens in the city governance.

These challenges pushed cities to search for intelligent solutions to ensure a good quality of life for citizens. Fortunately, the Information and Communication technologies (ICT) could help cities to develop smart solutions, such as the Smart City solution, which uses both ICT and social innovations to achieve sustainability goals at optimal cost. Since this concept is new, cities need to learn more about it through large scale experimentations and pilot projects covering the various sides of the smart city such as (i) construction of urban information system including both assets and operating information of urban systems, (ii) smart monitoring of urban infrastructures, (iii) analysis of large amounts of data, including both historical and real-time data, (iv) optimal and secure management of urban infrastructures and (v) involvement of the city stakeholders in city governance.

The management of urban infrastructures is crucial for the city development. It should ensure an optimal use of these urban and their interoperability. Infrastructures' management requires a good knowledge of the infrastructures asset and operating performances. The concept of Smart City helps us to get this knowledge by attaching new technologies to the different networks in the infrastructure then building a comprehensive platform to manage both infrastructures asset and exploitation. This platform should meet functional requirements such as data management (collect, store, and analyze data) and real-time monitoring as well as non-functional requirements such as flexibility, scalability, security and privacy. The integration of the Geographic Information System (GIS) with the platform constitutes an excellent tool for an efficient management of the infrastructures.

The construction of smart cities' demonstrators and pilots is seen as a major element in the strategy of Smart Cities development around the world. In 2014, Singapore's government established Smart Nation Vision that invented Singapore Smart City. The idea was to integrate ICT with the urban networks for better resource use and provide better life quality. The city developed then an integrated data sharing platform by finding rules and agreements for data integrating among different governmental agencies, which can access commonly shared information, collected from smart sensor networks.

Other cities have lunched Smart City projects and platforms in the last few years such as SmartSantader project in Sanatander in Spain. The platform collects and processes data form 20,000 sensors including data about traffic conditions, CO2 emissions, etc. It helped to reduce the traffic jam and the gas emissions in the city.

This research work aims firstly to implement professional management platforms for the management of SunRise Smart City project, which concerns the construction of a large scale demonstrator of the Smart City at the Scientific Campus of Lille University. The professional platforms PI system an OpenDataSoft were implemented and used. We will describe the implementation of these platforms and give a feedback about their use in this report.

We have also developed a specific platform for the management of SunRise Smart City project. This platform meets the specific requirements of SunRise project, mainly simplicity and flexibility.

This report presents the work conducted within my thesis. It includes five chapters.

The first chapter includes a literature review. The review describes the city challenges and the concept of smart cities with its definitions and components. The final part of the chapter gives some examples of existing smart cities around the world and describes the services of each city.

The second chapter describes the role of data in smart cities and the latest technologies used in data management. It describes also the existing architectures of smart cities. The final part of this chapter explains the existing smart city platforms and extracts the essential requirements for buildings a Smart City platform.

The third chapter presents SunRise Smart City demonstrator. It describes the layers of the GIS model, which is created by the team of SunRise project.

Chapter 4 presents the architecture of the two professional platforms PI System and OpenDataSoft as well as their implementation and use for the analysis of water consumption.

Chapter 5 describes the architecture of the platform SunRise and details its layers. It presents also the stages of the platform development and implementation.



# Chapter 1

# Smart Cities: literature review



# Chapter 1 – Smart Cities state of the art

This chapter presents the state-of-the-art concerning the Smart City. Big cities are facing challenges due to the rapid growth of population. There is lack of natural resources, increase in water consumption and air pollution. People need more services. Traditional solutions cannot handle these demands. Consequently, new intelligent solutions are needed to solve these problems. The first section presents the common challenges that facing cities. The second section presents the importance of finding smart solutions that raise the concept of smart cities. The third section presents case studies of smart cities.

## 1.1 City Challenges

The world's population is increasing and it is estimated to be 8.6 billion by 2030 and will increase to 9.8 billion by 2050 and 11.2 billion by 2100 (Khatoun & Zeadally, 2016) Figure 1.1. In the 1950s, only 30% of the world's population lived in cities; by 2014, the urbanization level had reached 54%. The United Nations predicts that by 2050, it will reach 66% Figure 1.2. People are shifting from rural areas to cities in search of better life. They want a high quality of life and optimal conditions for business creativity and professional development. They want efficient, sustainable transportation and energy systems that feed durable economic development. Since cities are not only hubs of human activity, but also the place where economic, environmental and societal demands are magnified. (United Nations & Department of Economic and Social Affairs, 2014).

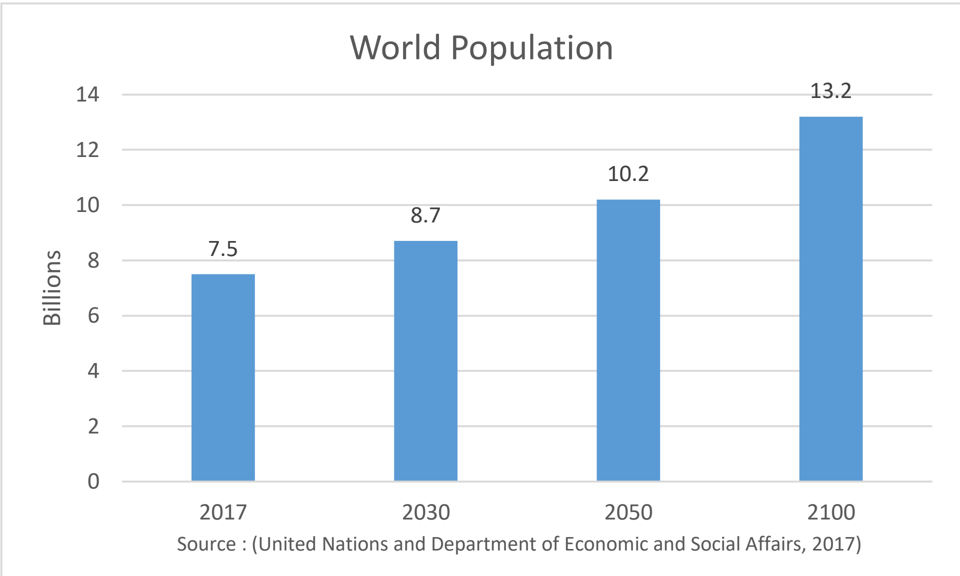



Figure 1.1: World's population estimation

The urbanization causes important economic, social and demographic transformations. The urbanization has greatly improved people's standard of living, providing water supplies and sewerage systems, residential and office buildings, education and health services and convenient transportation networks (United Nations & Department of Economic and Social Affairs, 2014).



But the rapid urban growth leads to complex challenges. Indeed, cities' services and infrastructures are stretched to their limits in terms of scalability as they adapt to support the rapid population growth Figure 1.2. Traffic congestion, waste management, scarcity of resources, water and energy consumption, air pollution, human health concerns, and social problems are increasingly complex and intertwined (Khatoun & Zeadally, 2016).

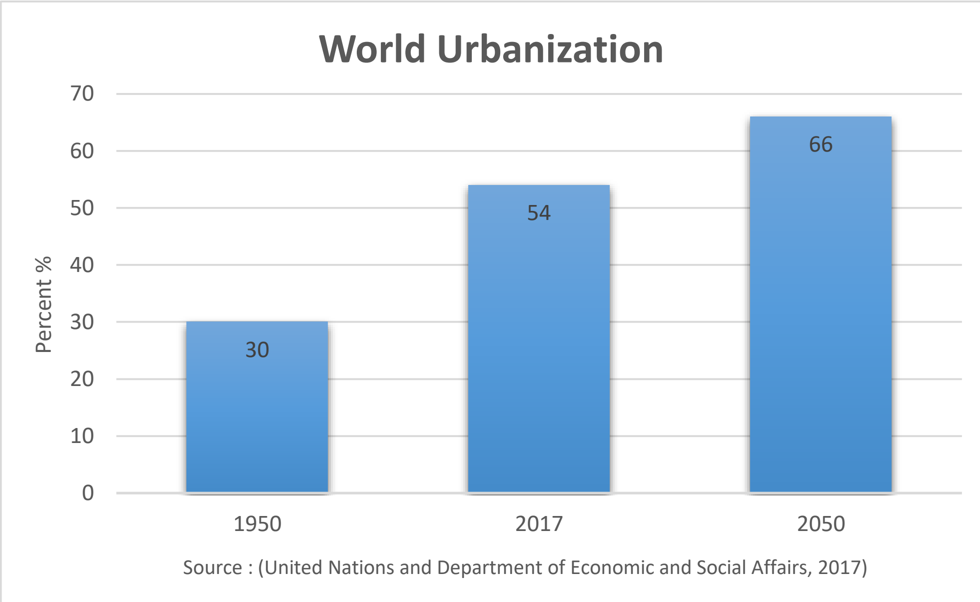



Figure 1.2 : World's Urbanisation Estimation

### 1.1.1 Transportation

The rapid urban growth over the last 50 years have placed a heavy load on cities transportation systems. Increasing population is leading to increase the number of vehicles, which increases traffic congestion and traditional roads construction is restricted by the land and cannot hold all these loads. Increasing traffic congestion not only delays the movement of people and delivery of goods but also contributes in exhaust emissions, and the deterioration of the air quality. In 2017, U.S. drivers wasted 46 hours in traffic, to be compared with 14 hours in 1982. The total amount of fuel wasted reached 3.9 billion gallons, which is equal to 130 days of flow in the Alaska Pipeline (IBM smarter city). In China, the average vehicle speed has been reduced to 20 km/h, even down to 7.5 km/h in some road sections (Xiong, Sheng, Rong, & Cooper, 2012).

### 1.1.2 Waste Management

Solid waste management is one of the key challenges of the 21st century. It is one of the key responsibilities of a city government (United Nations Human Settlements Programme 2010). The rapid urban growth leads to large waste management problems for cities all over the world. Cities become centers of garbage production; the amount of created garbage is increasing faster than their population, according to a recent report from the World Bank. The management of waste is going through a critical phase, due to the unavailability of suitable facilities to treat and dispose of the larger amount of waste generated daily in metropolitan cities (Sharholy, Ahmad, Mahmood, & Trivedi, 2008). This is rapidly becoming an environmental and economic catastrophe for cities in many developing countries. Over the time, the waste generated by urban residents has nearly doubled, from 680 million tons per year to more than 1.3 billion tons per year and it's expected to reach to 2.2 billion tons per year by 2025. This leads to high increase in the cost of waste management (Hoornweg & Bhada-Tata, 2012).

### 1.1.3 Water and Energy Management

Water is fundamental for sustaining human life. Municipalities and local governments are facing serious crisis in the management of water: the consumption of water is increasing and the availability of fresh water is limited. Global water demand is projected to increase by 55%, due to growing demand from manufacturing (+400%), thermal electricity generation (+140%) and domestic use (+130%) (OECD 2012). As a result, city inhabitants and industries are increasingly competing with other water users for access to water resources. If not properly managed, this competition can have undesirable social, environmental and economic consequences. Cities are increasingly at risk of floods and droughts, especially because of increasing climate variability. Cities need to ensure the availability and quality of water for residents while also working to balance the needs of industry and agriculture. They need to address failing water infrastructure and manage overall complexity of water delivery and treatment.

Water and energy are related to each other. In short, energy is needed to provide much of water people need, and water is needed to provide most of the energy we need and use (Cosgrove & Loucks, 2015). Limitations of either can constrain future economic and social development as well as negatively affect human and environmental health. Increasing the population leads to expansion increase in water and energy consumption. Buildings are among the biggest consumers of energy resources. They consume 42 percent of all electricity up to 50 percent of which is wasted. The U.S. Environmental Protection Agency (EPA) estimates the energy costs to 30% of the total operation costs. At the same time, buildings are the top contributors to global $CO_2$ emissions.

### 1.1.4 Human Services

One more big challenge for cities concerns the increase in demand for social services and healthcare, due to the significant growth of population. Citizens expect to find healthier environment for their families to live, access to the best healthcare services, more comfortable jobs, and more security. Cities are finding troubles to provide citizens with required environment and services. The demand of education, learning, and knowledge are increasing, schools and higher education systems have strained by the budget cuts. Cities need to provide citizens with comfortable jobs, while many jobs require updating of worker skills continually. Social services organizations are under more pressure than ever (Dirks, Gurdgiev, & Keeling, 2010). They need ways to integrate a huge amount of heterogeneous information, improve uniformity of services and reduce forgery, all while accommodating shrinking budgets.

## 1.2 Need for Smart Solutions

The current scenario requires cities to find ways to manage these challenges. Cities worldwide need new ways to sustain high service levels for citizens and businesses while improving efficiencies. They need to drive economic growth and create new opportunities while facilitating coordinated responses to crises, providing new transportation options, ensuring reliable delivery of energy and water, protecting residents from crime and improving the efficiency of buildings. At the same time, cities must educate residents for tomorrow's challenges, help to sustain the health of citizens and achieve better outcomes for social services.

Fortunately, city leaders today have capabilities that yesterday's leaders could not have imagined. With the revolution of ICT, cities have the ability to collect, store and analyze data to improve the management and safety of their complex. They can understand the interaction between transportation, water and energy systems, and optimize their operations, individually or collectively. They can predict the impact of changes on the public safety system on adjacent systems, such as education, healthcare and social services. In doing so, they can make confident, informed decisions that will reduce costs and improve living conditions citywide. Many of the smart solutions related to urban services have been based on harnessing technologies, including ICT, helping to create what some call "Smart Cities" (Albino et al., 2015).

### 1.2.1 Why Smart Cities?

Ensuring livable conditions within the context of such rapid urban population growth worldwide requires a deeper understanding of the Smart City concept. The urgency around these challenges that mentioned above are triggering many cities around the world to establish ingenious solutions to manage them using the Smart City concept (Chourabi et al. 2012).

The concept of a Smart City is based on the use of technology to enhance performances, efficiency, and competitiveness by providing new ways of creating sustainable development and higher levels of life quality and better manage natural resources. Technology implemented in a Smart City can improve sustainability. It can provide an environmentally friendly transportation system in a city to reduce gas emissions; it can reduce energy consumption and increase its efficiency. While building, it leveraged Big Data, or 'smart' data, to reduce vibrations and noise, monitor cultural effects and resource consumption, reduce fuel costs and consumption, and distinguish the impact on air and water quality in nearby areas. A smart city could also do things such as measure water levels, average consumption and weather patterns — like a drought — to help its citizens better manage their supply. It could even track waste patterns to help citizens to optimize recycling and cut back on the amount of waste they use as a society. Both of these scenarios would require the Smart City to monitor activities and collect data.

### 1.2.2 What is a Smart City?

Since several years, the concept of the “Smart City” has attracted world interest, including governments, companies, universities and institutes. Each organization has tried to understand and explain the Smart City concept from different viewpoints. The term “Smart City” appeared for the first time in the early 1990s (Albino, Berardi, & Dangelico, 2015). The concept of a ‘Smart City’ can seem elusive and vague. First of all because of the fact that there are many ways to be smart. Secondly, because there is a tendency to use the concept as a tool for self-promotion, rather than a strategy for actually becoming smarter. Indeed, it might prove easier to describe what the Smart City is not than coming up with an accurate definition of the concept.

First, a city is not smart when there is too much of everything in it. An excess of cars, food, water, energy consumption etc. is the sign of an unsustainable city defined by inefficiency. Instead, the waste streams and the surplus of the city should be used as a valuable input in new production or as a source of energy. The waste of the city must be converted and used in sustainable ways. A Smart City turns its surplus into resources.

Secondly, a city is not smart when the different networks are not able to communicate and function together. When the power grid, for instance, is not able to communicate with the electrical devices of the city, how can they know when it would be smartest to use electricity? Likewise, when the parking spaces of the city are not equipped with smart parking meters, how can car owners know where to go in order to find a parking space? Such a city has developed separate solutions to common problems.

Thirdly, a city is not smart when the systems and networks, which it contains, are static and immobile. Having to wait in long lines of cars during rush hour is not smart. Instead, the mantra should be ‘fewer cars and more mobility’. Furthermore, a stagnant city is not just an inefficient city; its lack of flow impedes innovation and creativity among its many stakeholders. A Smart City is characterized by a high level of mobility allowing people, information, capital, and energy to flow together easily.

Lastly, a city is not smart when it does not include all its stakeholders in the decision and planning process. Public authorities, private companies, knowledge institutions and the city’s inhabitants all possess valuable knowledge and information about the city. A city which does not make use of the vast amount of valuable data is made up of a number of disconnected ‘silos of knowledge’, which do not learn from and inspire one another.



Instead, the Smart City is based on knowledge sharing and collaboration across all levels of society. It is an open source community, where the ideas of one actor can be borrowed, improved, and ultimately returned to the community by others. In the following section, we are going to present what is the difference between digital, intelligent, and smart city, then we are going through smart city definitions and components.

### 1.2.3 Digital City, Intelligent City and Smart City

All different terms that have been invented refer to use of ICT to improve the performance of a city and its capabilities. Digital city, intelligent city and smart city are all slightly different concepts used to describe ICT-driven city. These differences reflects the evolution of strategy to improve the quality of city life (Yin et al. 2015).

A digital city refers to the digitization of a city, involving networks, visualization and information technologies (IT) to access population, resource, environment, economic and social data (Li, Yao, Shao, & Wang, 2014). It combines communication and computing infrastructure to meet the needs of city services (Yovanof & Hazapis, 2009). The aim of a digital city is the sharing of information and networks (Ishida & Isbister, 2000). Chicago is a prime example of existing digital cities, which built its digital metropolis with large networks (Widmayer 1999).

An intelligent city is defined as a city equipped with the infrastructure of ICTs. It can be considered to be a cross between a digital city and knowledge society (Moser 2001). An intelligent city is a city in which the systems are enhanced by digital collaboration spaces, interactive tools and embedded systems, the aim of an intelligent city is to transform the life of a city in significant and fundamental manners (Komninos 2012).

From a technical perspective, a digital city describes the city's characteristics; but from more complex viewpoint, a smart city includes the technology, human and governmental aspects, it can make intelligent response to different kinds of needs, including daily livelihood, public safety and city services, environmental protection, industrial and commercial activities. Therefore, a digital city is not necessarily smart, but a smart city must be digital first of all. A digital city is more focused on the technological basis and has clearer boundaries, whereas a smart city relates to both technology and sustainability (Yin et al. 2015).

To summarize, the differences between the terms. A digital city is one whose procedures, communication and information have all been digitalized. An intelligent city is a digital city that has a layer of intelligence that can make high-level decisions based on a level of artificial intelligence. A smart city is an intelligent city where application is focused on practical use and user experience.



### 1.2.4 Definitions of a Smart City

Various definitions have been given to the Smart City:

“A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rails, subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens”. (Hall et al. 2000)

“A city well performing in a forward-looking way in economy, people, governance, mobility, environment, and living, built on the smart combination of endowments and activities of self-decisive, independent and aware citizens. Smart city generally refers to the search and identification of intelligent solutions which allow modern cities to enhance the quality of the services provided to citizens”. (Giffinger et al. 2007)

“The Smart city is the use of Smart Computing technologies to make the critical infrastructure components and services of a city—which include city administration, education, healthcare, public safety, real estate, transportation, and utilities—more intelligent, interconnected, and efficient”. (Washburn et al. 2009)

Smart city is defined by IBM as the use of information and communication technology to sense, analyze and integrate the key information of core systems in running cities. IBM 2010

“Smart cities will take advantage of communications and sensor capabilities sewn into the cities’ infrastructures to optimize electrical, transportation, and other logistical operations supporting daily life, thereby improving the quality of life for everyone”. (Chen 2010)

“A city to be smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance”. (Caragliu, Del Bo, and Nijkamp 2011)

“[Smart Cities are about] leveraging interoperability within and across policy domains of the city (e.g. transportation, public safety, energy, education, healthcare and development). Smart City strategies require innovative ways of interacting with stakeholders, managing resources and providing services”. (Nam and Pardo 2011)

“Smart city as a high-tech intensive and advanced city that connects people, information and city elements using new technologies in order to create a sustainable, greener city, competitive and innovative commerce, and an increased life quality". (Bakıcı, Almirall, and Wareham 2013)

"A city which has certain smart ability to deal with a city's problems and provides citizens with a better living environment through intelligent accumulation and analysis of different kinds of data from the city's routine operation based on advanced information technologies". (Wenge et al. 2014)

"A smart City is a city where social and technological infrastructures and solutions facilitate and accelerate sustainable economic growth. This improves the quality of life in the city for everyone" ("Amsterdam Smart City").

### 1.2.5 Smart City Components

Smart infrastructure provides the foundation for all of the key themes related to a smart city, including smart people, smart mobility, smart economy, smart living, smart governance and smart environment. The core characteristic that underlies most of these components is that they are connected and that they generate data, which may be used intelligently to ensure the optimal use of resources and improve performance. This section introduces some key components of smart city infrastructure and concludes by highlighting the need for an integrated approach in dealing with such infrastructure Figure 1.3.

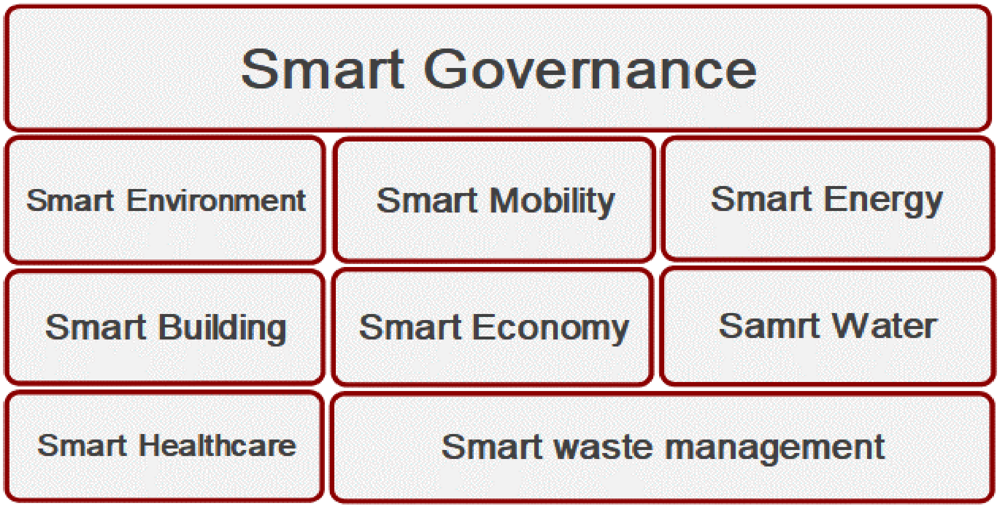



Figure 1.3 : Smart City components

#### 1.2.5.1 Smart Mobility

The best phrase, which describes methodologies that reduce traffic congestion, provide healthier and cheaper transportation options, and help to achieve sustainable mobility for society, is the Smart Mobility system. This smart system depends on ICT to collect data from various sources about transportation system in a city, in order to support the optimization of traffic stabilities (Benevolo, Dameri, and D'Auria 2016). Intelligent transport systems integrate the entire huge transit public and private mobility systems, that works together in order to improve the efficiency, effectiveness and environmental sustainability of cities. The Smart Mobility system includes all the initiatives carried out by companies or organizations supplying the local public transport service in the city. These initiatives normally involve a network of sensors, global positioning system-tracked public transportation, dynamic traffic lights, passenger information panels, automatic vehicle registration plate readers, closed-circuit television systems, navigation facilities, signaling systems, and most importantly, the capability of integrating live data from most of these sources. This can lead to improvements in safety, network management, traffic congestion, environmental performance, accessibility, convenience and public perception (UN 2016). They provide smart solutions such as the adoption of electric vehicles, which reduce gas emission, ridesharing (i.e., carpooling), which taps into an abundant yet underutilized resource: empty car seats. This option does not add any new vehicles to the system, and that is why it could help to reduce traffic congestion, that plagues most cities today. Bicycle commuting, which has been on the upswing in recent years, particularly in Europe and in cities with relatively flat terrain, miles of bike lanes, and other cycling infrastructure. For commutes of a few miles or less, biking is often the fastest way to get to work. Recently in Lille city, a new smart system of bike sharing is implemented, it is called "Gobee.bike", the geo-location that allows each user to no longer be dependent on the "famous" terminals and thus have more flexibility to place the bicycle on a simple bicycle parking. Finish the usual twists and turns to find a terminal with available places. Gobee.bikes are available through a mobile app, allowing users to locate bikes nearby. Users will be able, once the choice made to unlock them via a unique QR Code. Once the journey has been made, the bicycles can be placed in a dedicated car park for this purpose and to officially terminate the lease the user will only have to manually lower a lock located on the rear wheel (Hamladji 2017).

Car sharing, enabled by new technology that allows companies and individuals to rent cars by the minute or hour. On-demand ride services companies such as Uber and Lyft, which allow ordinary motorists to use their personal cars to offer planned transportation services. These services, enabled by mobile and GPS technologies, are making the taxi market more competitive (Viechnicki et al. 2015).

### 1.2.5.2 Smart Environment

One of the core concepts of smart cities is sustainability. Citizens will enjoy a quality of life, clean, green living environment. Smart environment can be achieved by implementing technologies in order to control natural resources, reduce waste and ensure an optimum usage of water, measure the consumption of energy, detect leakages, and increasing air quality (UN 2016). With embedded sensors, displays, and computing devices the awareness and habits of citizens can be changed. The European Parliament introduces two branches within Smart Environment. The first is related to urban utility networks "street lighting, waste management, drainage systems, and water resource systems that are monitored to evaluate the system, reduce pollution and improve water quality. The second is related to "renewables energy", ICT enabled energy grids, metering, pollution control and monitoring, renovation of buildings and amenities, green buildings, green urban planning, resource use efficiency, reuse and resource substitution". Smart Environment uses data from the utility networks, users and other city resources, in order to establish main areas of action in urban planning and city infrastructure planning as well as to inform urban services managers to achieve a more efficient and sustainable urban environment while improving the citizens' quality of life (Monzon 2015).

#### 1.2.5.3 Smart Buildings

People spend 80 to 90 percent of their lives in buildings, be it in homes, offices, recreation, retail, transport, or public service facilities (Honeywell 2015). A smart building integrates the different physical systems present in an intelligent way to ensure that all the systems act together in an optimized and efficient manner. It uses automated processes to automatically control the building's operations including heating, ventilation, air conditioning, lighting, security and other systems. Smart building management systems can improve building energy efficiency, reduce waste and ensure an optimum usage of water, with operational effectiveness and occupant satisfaction. It is estimated that implementing smart building solutions could save as much as 30% of water usage and 40% of energy usage and reduce overall building maintenance costs by 10 to 30 percent.

#### 1.2.5.4 Smart Energy

Smart energy management systems use sensors, advanced meters, renewable energy sources, digital controls and analytic tools to automate, monitor and optimize energy distribution and usage. Such systems optimize grid operation and usage by balancing the needs of the different stockholders involved (consumers, producers and providers). There are a number of innovations in smart energy infrastructure, such as distributed renewable generation, micro grids, smart grid technologies, energy storage, automated demands response, virtual power plants and demand-side innovations such as electric vehicles and smart appliances. Such innovations provide extended network of intelligent energy devices across a city, with a detailed view of patterns of energy consumption, enabling community-based energy monitoring programs and improving the energy efficiency of buildings. A key component of smart energy infrastructure is smart grids. A smart gird may be defined as "electricity delivery system from point of generation to point of consumption integrated with ICT for enhanced grid operations, customer services and environmental benefits" (Mohanty, Choppali, and Kougianos 2016).



#### 1.2.5.5 Smart Water

A smart water management system uses digital technologies to save water, reduce costs and increase the reliability and transparency of water distribution. Physical pipe networks are overlaid the data and information networks. The system typically analyses available flow and pressure data to determine anomalies such as leakage in real time to better manage water flow. Customers may be provided real-time information on the water situation and relevant information to help conserve water, leading to lower water bills. For example, Mumbai, India, as part of improvements to the water supply system, has installed water meters that may be controlled remotely, leading to a 50 percent reduction in water leakage.(IBM 2011)

#### 1.2.5.6 Smart Waste Management

Smart waste management includes monitoring, collection, transport, processing, recycling and disposal of waste. It reduces waste and categorizes type of waste at the source, and develop methods for the proper handling of waste. Such systems may be used to convert waste into a resource and create closed loop economies. Their primary benefits are in improvement efficiency of waste collection, pick up, separation, reuse and recycling. One of the primary inefficiencies of waste management is the inability to predict when waste is to be picked up; trucks are often sent to collect waste when bins are not full. Sensors, connectivity and the internet of things offer ways to mitigate additional costs arising from such inefficiency. Smart waste management enable movement of different kinds of waste to be monitored, and technology may be leveraged to better understand and manage the flow of waste from source to disposal (Hoornweg and Bhada-Tata 2012).

#### 1.2.5.7 Smart HealthCare

The health and well-being of urban residents are a particular concern with regards to the sustainability of urban areas and their supporting ecosystems. Smart cities can develop capacity to use technology such as Big Data to develop predictions or identify hotspots of population health. Smart healthcare management converts health-related data into clinical and business insights, which include digital health records, home health services and remote diagnoses, treatment and patient monitoring systems. It also facilitates the provision of healthcare using intelligent and networked technologies that help monitor the health conditions of citizens. It is enabling a shift in focus to prevention instead of cures, with a wider view of overall care, healthy living and wellness management. Smart health-care systems have a great potential in ageing societies, and may lessen inequality in healthcare between high and low-income groups. Examples of smart health approach include crowdsourcing to collect data on epidemics and predict epidemic outbreaks and take the necessary precautions, remotely collecting patient health vitals and data for diagnostic purposes and establishing automated alerts for patients with regards to medications and health check-ups. Telemedicine is a specific example of smart health care. Telemedicine can also be a subset of smart health care. Tele-medicine uses ICTs for providing clinical health care at a long distance or in remote locations. This approach is particularly useful for remote places in which health-care services are not easily accessible; telemedicine eliminates the distance barriers and improves access to medical care. Telemedicine is envisioned to provide critical care in emergency situations and can save lives in such critical situations. (Mohanty, Choppali, and Kougianos 2016).

#### 1.2.5.8 Smart Governance

Smart governance is about using technology to facilitate and support better planning and decision-making. The governance for smart cities must improve democratic processes, transparency in governance, citizen-centric development and political strategies for the cities. To achieve this, the government needs to gather information about citizens' perceptions, demands, development priorities, grievances, and feedbacks about policies that are being developed or implemented. To involve the citizens in governance, governments should facilitate multiple ways to citizens to communicate. Social media platform empowers the citizens to use technology oriented common platform to communicate among themselves as well as with government.

Smart cities call for new governance models. Effective smart city management needs to balance top-down and bottom-up governance approaches. On one hand, collating the information generated by smart sensors deployed in different smart infrastructures and taking policy actions, especially during emergencies, may require strong top-level leadership and top-down execution processes. On the other hand, bottom-up governance approaches, including citizen-driven innovations and co-creation, have been the defining the characteristic of much smart city infrastructure. Managing a good balance between these two approaches is therefore important. Achieving such a balance helps city governments harness the synergy between various participants such as universities, the private sector, civil society and local governments. Further, an efficient governance model for smart cities requires breaking down silos across different government departments. Information islands act as the greatest barrier to resource integration in the course of development, at both the technical and management level s of smart cities. Governance models need to be reformed in order that the data from smart infrastructure may be made available and used effectively in decision-making processes. City government administrators thus face the challenge of devising new forms of governance processes that adequately place citizen needs at the core of the governance process by adequately balancing top-down and bottom-up governance approaches (Nam and Pardo 2011).

#### 1.2.5.9 Smart Economy

In the European Parliament's document "Mapping Smart Cities in the EU", Smart Economy is understood as a mixture of "e-business and e-commerce, increased productivity, ICT-enabled and advanced manufacturing and delivery of services. ICT-enabled innovation, as well as new products, new services, and business models" and it involves "local and global inter-connectedness and international embeddedness with physical and virtual flows of goods, services and knowledge".

Economy is the major driver of smart city initiatives, and a city with a high degree of economic competitiveness is thought to have one of properties of a smart city. As well, one of the key indicators to measure growing city competition is the capacity of the city as an economic engine (Giffinger et al. 2007). The Smart Economy concept includes factors concerning economic competitiveness as innovation, entrepreneurship, trademarks, productivity and flexibility of the labor market as well as the integration in the national and global market. A series of studies (IBM, How smart is your city) released by the IBM Institute for Business Value identify business as one of core systems of smarter cities, which comprise city services system, citizens system, business system, transport system, communication system, water system, and energy system. Capacities for smart business systems include ICT use by firms, new smart business processes, and smart technology sectors. The smart city initiatives are designed to develop information technology capacities and establish an agenda for change by industry actions and business development. Creating an environment for industrial development is pivotal to a smart city. The economic outcomes of the smart city initiatives are business creation, job creation, workforce development, and improvement in the productivity (Chourabi et al. 2012).

An urban economy is considered to be a Smart Economy, when the sector combines innovation and productivity to adapt to the market and workers' needs to enhance new business models and a resilient global model for competing both locally and globally (Monzon 2015).

## 1.3 Examples of Smart Cities

Many countries and cities have launched their own smart city projects to resolve urbanization issues and challenges. The Korea Research Institute for Human Settlements (KRIHS), in association with the Inter-American Development Bank (IDB) have published a report concerning ten smart cities, this section presents some case studies inspired from this report. (Bouskela et al. 2016)

### 1.3.1 Singapore

Singapore's government established Smart Nation vision in 2014 that invented Singapore smart city, which look for integrating ICT for better resource use, networks and data to provide better life quality, provide stronger social relations, strengthening businesses, and to create more job opportunities, as a response to growing urban challenges of aging population, urban density and energy sustainability (S. K. Lee et al. 2016). Singapore's smart services are expected to be extremely innovative with its technical advancement, legendary infrastructure and the quality of human resources. So far, the most developed smart services in Singapore is e-government, which has been adopted since the early 80s, as well as the Intelligent Transportation System (ITS) with history of more than 10 years. Smart Nation Vision includes a wide range including smart transport, energy, building, security, health education, and many more, and some services has been lunched as trials while others are on their planning stage.

Singapore's Smart Nation idea is to avoid physically integrated platform and instead, to find rules and agreements for data integration among different governmental agencies, which is one of the most interesting characteristics of Smart Nation vision. Singaporean Government sees that there is only need to develop an integrated data sharing platform, where all agencies can access commonly shared information , collected from shared smart sensor network. Gathering very senior level of each governmental agency at times of large-scale emergencies is observed to be more safe, efficient, and effective way of managing the city. In the following section, we are going to have an overview of the smart services and high level functions

## I. Smart Transportation

The most developed services in Singapore is the urban mobility and transportation system. Singapore has implemented a sophisticated ITS to keep road traffic running safety and to enhance traffic flow. The strength of the ITS in Singapore comes from its holistic manner towards traffic management; ITS work together with other transport initiatives, to enhance overall transport system in the city. Utilizing ITS components, Singapore provides a number of smart transport services for citizens.

The Land Transport Authority (LTA) uses surveillance cameras to look out for road accidents. When an accident is detected, LTA activates the vehicle recovery crew that aims to reach at site in about 15 minutes to pull vehicle to the nearest designated car park outside the expressway. LTA has lunched as well the Parking Guidance System since 2008 and this provides drivers with real-time information on parking availability. This reduces the amount of circulating traffic searching for available spaces and promotes a more efficient use of existing parking facilities. Information is displayed on electronic sign board or online on one motoring portal, or mobile application such as MyTransport.SG ("Land Transport Authority, 2015. Singapore Government.").

MyTransport.SG smartphone application provides real-time information for commuters. It updates its features regularly to improve commuters' travelling experience ("Land Transport Authority, 2015 MyTrnasport.Sg.").

Over the past year, LTA has been working with SBS Transit and SMRT to install and test a new centralized system, which determines real-time bus location, and hence provide more accurate bus arrival information for more than 4.700 public buses over 360 routes.



Bus loading information is also available for selected bus services. Commuters are able to see color-coded space availability information to help them decide whether to board the arriving bus or choose to get on the next bus. The color green indicates available seats, yellow indicates available standing spaces, and red indicates limited standing.

ONE.MOTORING is the comprehensive portal serving all drivers and vehicle owners in Singapore. On this web portal, citizens can access traffic information collected from surveillance cameras installed on roads and taxi vehicles with GPS. Through Traffic Smart, drivers are able to see snapshots of roadways that is taken at every 5-minute interval. Due to security reasons, real-time moving video or close-up shots are not provided online ("Land Transport Authority, 2015. One Motoring.").

'Your Speed Sign' is a smart, live electronic device, which displays the real-time speed of vehicles and alerts drivers if they are violating the speed limit. It encourages drivers to stay under the limit and thus improve safety on the roads.

## II. Smart Environment

Singapore collect and store rainwater in a small land with the increasing of demand therefor, Singapore innovated and developed capabilities in the area. Under the Ministry of environment Water Resources, there are two lawful boards, the Public Utilities Board (PUB), which deals with all matters regarding water in Singapore, and National Environment Agency (NEA), which controls air and water pollution, promote energy efficiency, handle waste management, etc.

The national water utility sends water efficiency messages to the public, to involve citizens in increasing water-use efficiency. The Singapore Power also allow citizens to view their outstanding bills and payment status by providing them with mobile applications, that let them gain better understanding of the utility usage and submit meter readings. This leads citizens to manage their water consumption and to audit their home usage.

In 2015, smart waste management program introduced smart waste bins as a part of the program. Information about bins location and contents are collected by attaching smart sensors on them, this information is stored in central server, which can send notification to a garbage team to help them to optimize their route planning and at the same time, constantly keep the public spaces clean.

## III. Smart Energy

To achieve eco-friendly and energy-efficient energy system a smart Singapore embedded smart and motion detection sensors inside household appliances such as lights can be automatically turned on when someone enters home. These smart lighting systems is installed in office buildings as well to detect motion and automatically adjust the lightning. Singapore's Intelligent Energy System (IES) attempts to facilitate active participation among consumers and improve network operations for more efficient energy use. Smart meters that are embedded in the energy system play a substantial role in saving energy, they have communication capabilities, which allowing the system to be two–way channel. They provide both the grid operator and consumers with information on how much electricity they are using("Singapore Government, Energy Market Authority.") .

## IV. Smart citizen security

One of the most famous and widely known feature about the Singapore is that crime is very rare. Singapore has one of the lowest crime rates not only in the Southeast Asian region, but worldwide. According to the report by the Economist Intelligence Unit Singapore is the world's second safest city. The Police Force of Singapore established a web-based electronic police center (ePC) for citizens to let them conveniently gather information, file police report online, and handle administrative affaires such as applying for certified copy of police report, criminal records, etc. For example, CrimeStopper on ePC provides an alternative online way to citizens to make less urgent reports, or submit information to help Police in combating crime.

Singapore Police Force SPF also provide services and committing to operate efficiently. They provide two separate police hotline as well as traffic hotline. There is a SMS service called the Emergency Short Messaging Service Helpline, which is prepared to help citizens with handicaps, members of deaf, speech-impaired and hard-of-hearing community different approach of communication ("Singapore Police Force (SPF), 2015.").

## V. Smart Emergency

Ministry of Home affairs of Singapore Government oversees the Singapore Civil Defense Force (SCDF) that provide fire-fighting, emergency medical and rescue services. SCDF recently in April 2015 has launched a mobile application called myResponders, which has been designed to increase survival rate from accidents. It alerts users and guide them how to response when there are nearby cases of suspected cardiac arrest before the SCDF arrives.

Tele-medicine is another major aspect of Smart Nation initiative. Singapore aim to encourage the widespread use of wearable technologies such as smart watches, fitness pursuer and even smart clothing, which repetitively record vital signs for patients such as body temperature, blood pressure, and health rate, it can monitor the well-being of a patient and transmit the data via internet to family members or designated healthcare professionals.("Singapore Civil Defense Force, 2015. Singapore Government SCDF.").

## VI. Smart Governance

Singapore has asserted the importance of connectivity between the Government, industries and its citizens. Singapore has started its journey to build e-government platform in 1980s with the goal of altering the government into an excellent user of information technology. Most of Singapore Government's official websites became more sociable by adding more citizen-central contents and enable transmitting more information to citizens through social media and mobile applications. E-government programmes are divided into three categories; Government, citizen, and business programme. These allow better communication between the government and its citizens ("Singapore Government, Singapore EGov.").

For conclusion, Singapore's case study provides an interesting example of a nation's approach towards being a Smart Nation. Since there are no other cases where the entire country is being transformed under careful plan of the central Government, Singapore is believed to be unique in comparison to other smart cities initiatives around the world.

### 1.3.2 Barcelona, Spain

Barcelona in one of the most important city in Spain, Barcelona smart city aims to provide better life quality and efficient services to its citizens by attaching ICT to its infrastructure through Barcelona smart city model implementation. Barcelona Smart City is represented by twelve different sectors of initiatives: "mobility, environmental, water, energy, waste, ICT, nature, built domain, public spaces, openness of the government, information flows, and services" (Cisco 2014).

Barcelona's Smart City Strategy covers six main components charactering Smart Cites: 1) smart governance, 2) smart environment, 3) smart mobility, 4) smart economy, 5) smart living and 6) smart people (Giffinger et al. 2007). The following section presents briefly what has been done in each one of these components. Barcelona Smart City Services:

#### I. Smart Governance

Barcelona is very active in the field of Smart Governance. Different initiatives and projects have been lunched by the city council with the aim to simplify the communication between government, industries, and citizens by improving and facilitating administrative procedures. Barcelona developed an electronic administration service, which allow citizens accomplish operations and achieve information in a flexible manner. The main actions are Transparency, Open Government, Participation and Open government data.

- Transparency: make public services more transparent in order to facilitate information sharing for everyone. The goal is to simplify citizens' lives using technologies.
- Open government: in order to reinvigorate political life using technology, which will result in a shift from a policy of "governing for the people" to a policy of "governing with the people".



- Participation: Barcelona is encouraging channels through which ideas and solutions for improving the city's quality can be proposed (Bluestone et al. 2014).
- Open government data: Open government data allow the private sector, citizens, companies and other institutions to exploit public data and create services, free or not, that integrate those offers by the municipality. To facilitate integration in other platforms, the data are provided in a standard, comprehensive, open, and digital format with a clear structure and information support (Capdevila and Zarlenga 2015).

## II. Smart Living

Barcelona smart living initiatives are active in various sectors, such as health, education, technology facilities, and communications. Several initiatives have been implemented in the field of health and social services, such as Telecare and Vincles BCN. Their main aim is to improve the life quality of aged citizens and/or people who have difficulties living alone. Telecare is a service that uses alarms, sensors and other supplies to support and assist elderly, disabled or dependent people by means of remote control. The service uses continuous monitoring: if an activity changes and/or if something is different, there will be an emergency call (Davies and Newman 2011). In Barcelona, more than 70,000 citizens use Telecare services. Its main objective is to enhance quality of life and autonomy for people who spend most of their time home alone. Telecare services are active 24/7. Telecare's two main purposes are to answer user demands for assistance and to adopt precautionary actions by keeping recurrent contact with citizens in order to avoid unsafe circumstances and solitude.

Vincles BCN is an initiative that aims to help elderly people who live alone and/or people who have physical and/or mental constraints to avoid a sense of isolation. This service relies on a social support network through tablets and/or smartphones. Thanks to these devices, they can reach their family members and friends, as well as people working in health management and social services. In 2014, this project competed in and won the Bloomberg Philanthropy's 2014 mayors challenge. This competition grants prizes to the most innovative initiatives whose aim is to enhance citizens' quality of life.

## III. Smart Environment

Since the beginning of the 1980s, Barcelona has launched different initiatives to reach its environmental goals. The main goal of Barcelona city is to become a self–sufficient city with no emissions. To reach its objective, the city needs to focus on three aspects (Barcelona Smart City, 2014, p.10): 1) smart waste management, 2) smart water management, and 3) energy conservation & self-sufficiency.

The Barcelona government proposes a Smart system of collecting waste by smart garbage cans equipped with monitoring sensors and a wireless device that sends an alert when it is full of waste. The quantity of waste in the trashcans can be monitored in real time, but when they are more than 80% full, a mobile communications network alarm is sent to a web-based software application controlled by the waste management company.

The City Council applies different initiatives in the field of smart water management in order to manage the hydrological resources of the city in terms of rational groundwater and public services consumption. Tele-managed irrigation is a measure initiated by the City Council that consists in six irrigating the city's green spaces. This initiative uses latest-generation technology for optimizing water use through sensors positioned in the soil to monitor humidity, salinity, temperature, wind and various other factors that determine the quantity and the timing of water use. It uses a program that can be controlled with computers, smartphones and tablets. According to the deputy mayor of Barcelona, this new irrigation system will permit water savings of 25%, which correspond s to monetary savings of approximately USD 555,000/year (Logitek, 2014).

Barcelona is committed to reducing energy consumption and increasing local renewable energy generation in order to reduce dependence on fossil energy. Barcelona provides hot water in buildings based on solar collectors and/or solar panels that capture solar energy. Since 2004, Barcelona has exploited a giant photovoltaic plant whose sea-facing panel is 10,500 square meters and that produces 550,000 kWh/year, which is equivalent to the annual electric consumption of 140 Barcelonan families.

## IV. The 22@Barcelona district

The 22@Barcelona district is an innovative area "offering modern spaces for the strategic concentration of intensive knowledge-based activities" (22Barcelona, 2016). Several smart initiatives are located in this district. The project relies on a 2000 government initiative that aimed to transform the old industrial area of Poble Nou, located in the center of the city, into a high-tech and knowledge-driven economic leader. The new district has created new green spaces and has attracted more than 7,000 companies, businesses and shops (ECPA Urban Planning). Various high-tech and innovative companies collaborate and cooperate in research and training in order to enhance productivity in the district. Moreover, the district has seen a 25% increase in the number of residents, thus generating new houses. The district is home to ten universities, twelve R&D centers, and several training centers, start-ups and innovative companies. Furthermore, this location has generated more than 130,000 new jobs (Scott 2013).

## V. Smart Mobility

Barcelona aims to reduce environmental impact while simultaneously ensuring a more fluid, easy, effective, and sustainable electric mobility with no emissions (BCN Smart City, 2016s). Barcelona's initiatives to make the city's mobility more efficient and environmentally friendly mainly rely on the "Biking project", which comprises smart traffic light management, smart parking organization, and smart bus network design and management.



Bike sharing program consists of a new transportation system, recommended for short distances, that allows users to borrow a bike for a specified period at any self-service station and return it to any other city bike station. It was launched in May 2007 with 750 bikes and 50 stations. By the end of 2008, the initiative had grown considerably. In fact, Barcelona offered 6,000 bikes and 400 stations (Midgley 2009). In 2012, there were 420 stations located approximately 300 to 400 meters from each other, making this transportation system very accessible and practical. Barcelona has added 22 km of new bike lanes to the already existing 128 km network.

The smart traffic light initiative in Barcelona consists of devices emitting a particular sound for blind people and supplying green corridors for fire brigades. The system works with a small remote control that emits a sound when a blind person approaches the traffic light so that it turns green; when the sound stops, the light turns red again. In this way, the noise pollution is limited to the time it takes the blind pedestrian to cross the street. There is also a service that manages traffic lights so that firefighters 7 can reach accident sites more quickly. The system controls all traffic lights and switches them to green until the fire fighters have passed; it then returns the lights to their normal setting.

Barcelona has an intelligent parking system that helps drivers find a car park faster and more easily and allows the government to enhance the planning and management of Barcelona's mobility. The service is available only in certain districts, but the goal is to expand it. The project leads to less time searching for parking lots and, thus, less pollution, noise and traffic congestion.

Barcelona's new bus network is organized on vertical, horizontal and diagonal lines in accordance with the composition of the city's street. The new routes are based on an orthogonal grid scheme designed for maximum efficiency in an urban system. Bus drivers pass through the most direct route possible and always turn at right angles (Transports Metropolitans de Barcelona, 2016). This new system allows for the reduction of pollution and traffic congestion. It also reduces economic costs, making bus transportation in Barcelona more attractive, since numerous places can be reached in a single bus journey. In addition to this orthogonal bus network, the Transports Metropolitans de Barcelona (TMB) improved environmental quality by using hybrid buses. Electric propulsion motors power these busses or diesel motors, allowing for a 30% reduction in consumption and emissions.

## VI. Smart Economy

In 2014, the city won the iCapital award thanks to its innovation competency. "Barcelona Growth" is a collective initiative created in 2011 by the Barcelona City Council that aims to create a meeting point where local authorities, companies and civic bodies can discuss and propose solutions to stimulate the economic development of Barcelona, setting the conditions for economic growth and for creating new jobs. A new Smart City Campus is currently in development. This campus will be located in an old factory in the 22@



technological district. The aim is to transform the factory into an innovative center focusing on Smart Cities. This building is only the first step towards the establishment of the Smart City Campus. The objectives of the Smart City Campus are to offer a meeting point for business, technology, innovation centers, universities, and other actors related to technology, innovation, ICT, ecology and urban planning.

The City has also developed "Shared Innovation Centers" and a "City Operating System". The Shared Innovation Centers are multidisciplinary and multifunctional work teams and/or collaborations among different research units established to offer innovative suggestions in the ICT sector. The City Operating System (City OS) is a technological platform of services and solutions for Barcelona. Practically, it collects and handles all information quickly and efficiently on how the city functions. Information is of various natures: "water and air quality, mobility management, waste recycling, energy efficiency, population management, local meteorology, etc." (City OS). City OS allows local authorities to make decisions in real time in order to enhance citizens' quality of life and to make it easier to govern Barcelona.

#### VII. Smart people

The Smart Citizens Project is a platform based on social participation in urban areas. The project aims to connect data, people and knowledge, creating open indicators using sensors in the possession of the city's residents. The low-cost sensor tracks information on various physical measurements across the city, such as real levels of air pollution in a given zone, the level of noise pollution, the level of humidity, light levels, and temperature. The project works thanks to a geo-location system, the Internet and hardware and software for data collection and sharing. This open platform includes a website and a mobile app, where all the real time data are collected and shared.

Other platforms and apps have been developed to enhance collaboration and the sharing of information among citizens (i.e., the Sustainable Barcelona Map). Barcelona set up Fabrication Laboratories that are essentially open high-technology spaces where people can develop and build personalized items, which would be unavailable using traditional industrial-scale technologies.

### 1.3.3 Rio de Janeiro, Brazil

Over the last few years, Rio de Janeiro has been heavily using the information and communication technology to bring the government closer to the citizens. It has adopted solutions that are helping the city to become more equal, more inclusive, and provide better quality of life.

The basis for the development of the smart city plan for Rio de Janeiro was the expansion of the local government's telecommunications network, which has intensified the presence of the government throughout the city, and a Digital Inclusion Program, an important indicator that tracks the population's access to new technologies, particularly in disadvantaged communities and segments. This plan includes the implementation of various initiatives and projects that demonstrate how technology has a positive impact on the life of the city.

One of the main innovation management initiatives of the local government is the **Rio Operations Center**, known as **COR**. The local government continuously monitors the city from this center so that the agencies can act more quickly in different situations, such as unforeseen events in traffic or environmental disasters.

Many projects are proposed by the initiatives. Some of them are finished and others are being designed and discussed together with the population. These projects involve issues that are important to the city, such as:

## I. Smart mobility

A series of structural interventions in the transport and mobility area is in progress in Rio de Janeiro. They include for example, the construction of exclusive Bus Rapid Transit (BRT) and Bus Rapid System (BRS) corridors and the integration of various means of transportation with the launch of Unified Ticket of Rio de Janeiro.

In view of such interventions, the technology projects that are in progress include modernization of the infrastructure of the traffic equipment network such as traffic lights, variable message signs, cameras, and other sensors, in addition to the real-time monitoring of the bus fleet.

This whole network is integrated into COR, which also receives information from urban mobility operations centers such as BRT, MetrôRio utilities, and Supervia Urban Trains. Other initiatives are also bring deployed, such as "Digital Traffic", which monitors and repots in real time the path of the main routes and alternative routes in the city.

## II. Smart Safety and Emergencies

Public spaces are monitored, and technology is used to maximize resources and reposition teams in events in the city. The Municipal Guard has radios, smartphones, and GPS in cars, plus an occurrence system, elements integrated into COR, through the Geoportal. COR also shares this information with the Integrated Command and Control Center (CICC).

COR has a strong and successful partnership with the CICC, bound the Department of Public Security of the State of Rio de Janeiro. This partnership allows a job aligned with the emergency services of military police, ambulances, fire emergency and state civil defense. These agencies operate from CICC.

The CICC and COR are composed of fiber channel and have a cooperation agreement for sharing data and information. The municipal civil defense also has several prevention initiatives with actions for disaster reduction in the city. The focus of this agency is on community protection, especially for residents in areas of high geological risk. The community alert and alarm system is a positive and successful example of the Community Protection Program, based on three pillars: neighborhood empowerment, community alert and alarm system, and performance in schools.

### III. Smart Environment

In recent years, the government of Rio de Janeiro has implemented a series of actions that contributed to the restoration and preservation of the environment. To improve air quality, the MonitorArRio Program, in charge of monitoring the city's air quality, has been expanded. The program currently has eight fixed stations that analyze particles and gases. There is also a mobile unit, which verifies each part of the city over a period of three months. Data on air quality from all regions are on the website of the Municipal Department of the Environment and in daily newsletters published by COR. Based on the data, emergency situations can be identified and the population warned.

### IV. Smart Energy

The local government has been working on initiatives on energy efficiency, with the challenge of identifying impact solutions for the city of Rio. The Program for Modernization of the Street Lighting Network, for example, includes geo-referenced mapping of the street lighting network of the city, cataloging points of light and equipment. The program also provides for the development of a Master Plan for Street Lighting and the replacement of technology with LED and solar energy.

### V. Citizen Participation

The local government has used LAB.RIO to encourage citizen participation with the government. This is a laboratory that encourages, engagement, collective, and collaborative construction of the city, through digital and on-site experiments, to test, create, and discover new forms and formulas, achieving results expected by society.

LAB.RIO's main project is a social network that allows citizens to propose and debate public policy with municipal departments and agencies. It works in thematic cycles on the web page. Started in September 2014, the first issue was the legacy of the Olympic Games. The theme of the second issue, in January 2015, was mobility, which included the participation of the mayor through a video conference tool.

For conclusion, COR is the backbone of this developing smart city. Having more and more information in real time, technology is a major partner in managing the routine of Rio. COR presented as a differential a team of meteorologists dedicated full time to monitor the weather conditions of the municipality as well as the communication plans for the dissemination of procedures, messages, and alerts to the population.

### 1.3.4 Amsterdam, Netherlands

Amsterdam's transition to becoming a Smart City began in 2009 when the independent organization, Amsterdam Innovation Motor, and the grid operator, Liander, launched the Amsterdam Smart City project in close collaboration with the Municipality of Amsterdam. The project has as its explicit aim the reduction of carbon emissions and energy use, thus creating a more sustainable and efficient city. This is done through unique collaboration between governmental agencies, private companies, knowledge institutions and the citizens of Amsterdam. Together, all these different actors develop and implement innovative new technologies in the city fabric, which will not only help to directly reduce the use of energy and CO2 emissions, but also stimulate behavioral change amongst the city's inhabitants. Currently the program comprises 32 projects that present innovative ideas and new business models across Amsterdam's neighborhoods. These projects fall within seven "areas of interest": **Smart Mobility, Smart Living, Smart Society, Smart Areas, Smart Economy, Big & Open Data and Infrastructure (water, roads, energy, ICT)**. Initially, they are to be tested on a small scale and the ones that prove to be effective will be extended to larger areas. All projects are built around informing citizens, entrepreneurs and the public sector about their energy consumption and educating them about how to manage it more prudently. To achieve this, smart devices and wireless meters transmit information over broadband networks helping the citizens and organizations of the city to behave more "intelligently" by reducing their energy consumption.

All new initiatives are tested in local, small-scale projects. The initiatives which prove to be the most efficient and smart are implemented on a large scale. So far this has led to a vast amount of new projects ranging from smart school education with a focus on sustainability, to smart transport, to larger smart grid, smart metering and smart electrical vehicle charging projects. To support the innovation process taking place in the city, the Municipality of Amsterdam is constantly opening up and sharing their data. This has resulted in an "Apps for Amsterdam" concept, where data about life in the city is shared, ranging from crime rates to refuse collection routes. This access facilitates open innovation, as citizens/developers are able to create applications based on city data. The result is not only economic growth, but also more importantly new solutions, which make life in the city smarter.

## 1.4 Conclusion

World's population is increasing and the urbanization reached to high levels, which causes many cities to face increasingly lot of complex challenges. Cities' services and infrastructures are being stretched to their limits in terms of scalability as they adapt to support this population growth, traffic congestion, waste management, scarcity of resources, water and energy consumption, air pollution, human health concerns, and social problems. These challenges are triggering many cities around the world to establish ingenious solutions to manage them, which arises the concept of smart city, the core concept of smart cities is to use the technology and (ICT) to enhance performance, efficiency, live quality for citizens, and improve sustainability by providing eco-friendly transportation system to reduce gas emissions in the city and reducing energy consumptions and so on. Different stockholders have given many definitions for smart cities. The majority have divided the smart city to major components: smart mobility, smart people, smart environment, smart economy, smart governance, and smart living. Many cities have started there smart city projects by implementing new technologies and smart meters in their infrastructure and many platforms and mobile applications have been created to manage the different services in the city and to provide the citizens the ability to reach the information about the city services easily.

The Smart City projects are complex projects, because combine the complexity of the city and its transformation using an edge-cutting concept concerning the use of the digital technology as well as social innovation. The implementation of the Smart City concept requires innovative management system as well as powerful platforms that can collect, store, share, analyze and take-decision. The following chapters will discuss these crucial issues and their implementation.



# Chapter 2

# Smart City Management



# Chapter 2 – Smart City Management

The implementation of the Smart City is complex. It raises major questions such as the role of data, data management, the architecture of the Smart City solutions, and the construction of platforms for the Smart City management. This chapter presents a discussion of these issues.

## 2.1 The Role of Data in Smart Cities

Data is considered as the "oil" of the future (DeRen Li, Cao, and Yao 2015). Data will soon become one of the most precious treasures we have ever had (Ahmed, Bouhorma, and Ahmed 2014). If we can collect data from every detail and service in the city, we can analyze it using most recent technologies to convert the collected data to useful information. This information enables services to be smarter and we will be living in a world of smart services, which helps to raise the quality of life and make it easier for citizens. This information can be provided online in real-time; therefor cities can optimize the use of resources for various operations such as traffic management, water consumption, street lightning, all with the aim of improving efficiencies and reducing costs. Data can have direct effect on citizens live. By collecting data from citizens homes, analyze it, and allow citizens' access to home data such as temperature, electricity consumption, humidity and air quality, this allow them to control their consumption and improve their life quality.

During the past ten years, many cities have embedded new technologies in their infrastructure such as water network, electrical network, transportation network etc. That allowed them to solve many urbanization issues by analyzing the data collected from the installed sensors. Recording, storing, and analyzing data enable service to get smarter which lead us to construct a smart city.

## 2.2 Smart City Data Management

The key concept of the smart city is to obtain the right information at the right place and on the right device to make a city-related decision with ease and to aid citizens more quickly (Rathore et al. 2016). In the context of smart cities, an enormous volume of heterogeneous and real-time data will be created by millions of various devices periodically sending observations about certain monitored phenomena or reporting the occurrence of certain or abnormal events of interest (Abu-Elkheir, Hayajneh, and Ali 2013). Collecting and managing these data is a big challenge for city managers. All these data need to be transported to data repositories. Either organizations or public owns, these data repositories, they can be located at specialized servers or on the cloud. Then, they must be processed and analyzed in both offline and real-time to link data together and turn them into valuable information.

Traditional data management systems cannot handle and process these amounts of data. Thus, a flexible, efficient, and comprehensive management platform is needed. This platform will be responsible for fetching data from IoT devices and uniform the different structures of these data, store them in one structure. They should include data mining algorithms, big data tools to extract meaningful information that can be used by authorized stakeholders in the city.

This platform should provide citizens with the needed information about services in the city. It should include interactive and user-friendly interfaces to facilitate querying data and visualize the analyzed data in an understandable manner, such as interactive maps, graphs, and statistical charts. Data management in smart cities pass through a life cycle, which contains four stages: **data collection, data storage, data analysis, and data visualization**. Each stage uses different technologies.

### 2.2.1 Internet of things (IoT)

The Internet is one of the most important and powerful creations in human history (Zeinab and Elmustafa, 2017). In 1995, just 1% of the world population used internet. The number of internet users increased to one billion for the first time in 2005. The second billion was reached in 2010. The third billion in 2014. Around 46% of the world population has an internet connection nowadays according to statistics from International Telecommunication Union (ITU) ("Internet Live Stats - Internet Usage & Social Media Statistics,"). The internet has an impact on education, communication, business, science, government and humanity.

Now the internet is not just for humans it can also be accessed by other items such as vehicles, sensors, actuators, embedded with electronics and every physical device Figure 2.1. In recent years, there has been a proliferation of devices capable of collecting and transmitting information to the Internet and to databases, and exchanging data with other devices. These devices make up the so-called "Internet of Things" or the "Internet of Everything". Anything will be able to communicate to the internet from everywhere at any time to provide different services from any network to everyone. This concept allows new types of services to be created such as smart homes, smart transportation, smart healthcare and so on (Zeinab

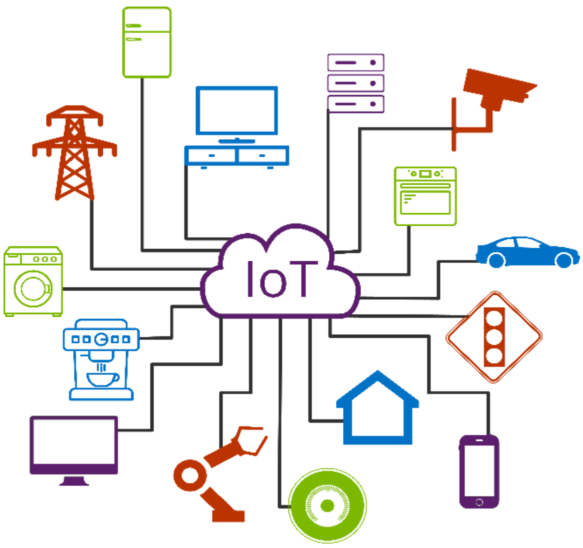


Figure 2.1: Internet of Things (IoT DawnBIT.com))

and Elmustafa 2017). IoT becomes an important technology that promises a smart human being life, since it is the main source of data in smart cities.

By 2020, it is estimated that around 50 to 100 billion objects will be connected to the internet. Massive amounts of data are collected from seemingly everywhere from infrastructure, transportation, environment, and our daily activities. These data are meticulously collected, stored, sold, manipulated, repurposed and reused. There are great varieties of devices – mostly sensors – that exist today and generate enormous amount of data. And, "once filtered through big data analytics, these data are the grist for drawing revealing and often unexpected inferences about habits, predilections and personalities." (Peppet 2014).

The very large number of devices used to collect data from cities forces platforms for Smart Cities to use IoT technologies. The data collected from these devices must be transmitted via interconnected networks so that they can be grouped and processed to provide advanced Smart City services. (Zanella et al. 2014) presents multiple potential uses of the Internet of Things for Smart Cities, e.g., monitoring the health of historical buildings, detecting the load level of waste containers, sensing noise in central areas of the city, observing the conditions of traffic lights, and analyzing the usage of energy in Smart Homes and so on.

To date, a number of technologies are involved in IoT, such as Radio Frequency Identification RFID, Wireless Sensor Networks WSNs, Wi-Fi, ZigBee, Bluetooth, 4G LTE, LTE-A, and 5G. Hashem et al 2016 (Hashem et al. 2016) summarized these technologies as following:

- **Radio Frequency Identification (RFID)** (Kaur et al. 2011)

RFID operates based on electromagnetic fields to automatically identify and track tags attached to objects. The tags contain electronically stored information and can be active, passive, or battery-assisted passive types Figure 2.2. The RFID technology represents a breakthrough in embedded communication and can be used to identify virtually any object, including animals, clothes, and even human beings. This robust application of RFID has made the technology suitable for smart cities; RFID can be applied in hospitals, libraries, and for monitoring cargo. Unlike a barcode, an RFID tag can be put inside any object and the reader can still read the signal even when the tag is invisible. This capability has placed RFID at the forefront of building embedded devices with full tracking functionality. For instance, RFID tags can be embedded in a meter, thereby making it a smart

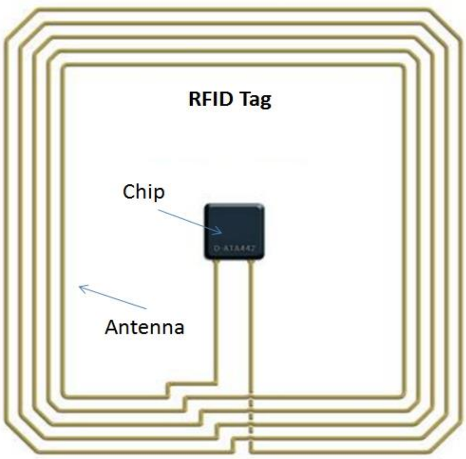


Figure 2.2 : Radio Frequency Identification

reading device. RFID tags are used in many organizations. For example, an RFID tag attached to an automobile during production can be used to track its progress through the assembly line. The RFID microchips embedded in livestock and pets allow the positive identification of animals. Such an identification method enables the realization of smart city intelligent devices through the RFID embedded technology (Kaur et al. 2011).

- **Wireless Sensor Networks (WSNs)** (Dargie and Poellabauer 2010)

WSN is a network of distributed autonomous sensing nodes that use low-power integrated circuits and wireless communication technology to distribute data among the connected sensor devices. This network supports hundreds to thousands of low-cost and low-power miniature devices that are connected to one or more sensors Figure 2.3. The sensor has a radio transceiver to send and receive signals, as well as a microcontroller, which is an electronic circuit to interface with the sensors and an energy source, usually a battery or an embedded form of energy harvesting (Dargie and Poellabauer 2010). The ability of the WSN to connect devices with low cost and sizes has improved the possibility of using a sensor network with numerous intelligent sensors. This network enables the seamless connection and sharing of valuable information from different environments, which can be processed and analyzed efficiently (Al Nuaimi et al. 2015). This characteristic of WSN enables it to be useful in many areas, such as industrial process monitoring and control, machine health monitoring, natural disaster prevention, as well as water quality monitoring. The WSN can cope with large-scale deployment in any environment, and it is therefore applicable for smart city integration. The network provides a simple economic approach for deploying distributed monitor and control devices, thereby avoiding the overhead cost that may be incurred in wired systems. The WSN can monitor physical and environmental conditions in real time, such as temperature, pressure, light, and humidity. The devices, such as switches, motors or actuators, control these environmental conditions via an efficient wireless communication. These characteristics enable WSN to be applicable for smart homes, smart buildings, and for smart health. Although WSN faces the challenges of energy consumption most especially at the application level, a number of protocols have been studied to improve WSN in this area (Patil and Biradar 2012). The wide adoption of WSN can improve communication and businesses in a smart environment.

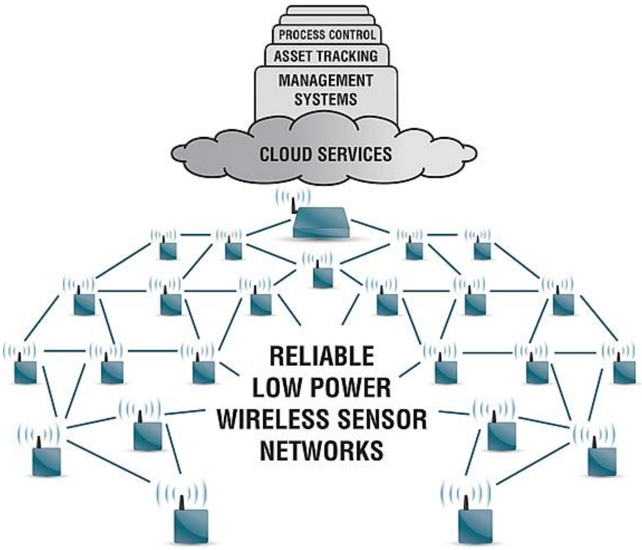


Figure 2.3: Example of Wireless Sensor Network



- **Wi-Fi, ZigBee, and Bluetooth** (Hashem et al. 2016)

Wireless communication is a fast-growing technology that provides increasing flexibility and mobility. Wireless technology offers dynamic network formation, low cost, and easy deployment. Wi-Fi is a wireless protocol that serves as a replacement for the standard cable networks and allows users to access the Internet at broadband speeds when connected to an access point or when in ad-hoc mode. ZigBee is also designed for short-range wireless communication with provision for long lifetime battery usage capability (Hancke, Silva, and Hancke, Jr. 2012). Bluetooth is a standard based on a wireless radio system designed for short-range and cheap devices to replace cables for computer peripherals, such as mice, keyboards, joysticks, and printers(J. S. Lee, Su, and Shen 2007). These short-range wireless technologies have played a key role in wireless data transmission, providing low-power consumption network.

- **4G LTE, LTE-A, and 5G** (Cox 2012)

The LTE technology is used to describe 4G wireless network, which is an extension of the existing 3G wireless standards. As such an extension, 4G shifts the paradigm from hybrid data and voice networks to a data-only IP network. Furthermore, 4G uses multiple-input multiple-output (MIMO) and orthogonal frequency division multiplex (OFDM) to acquire more data throughput than 3G. OFDM is a transmission technique that uses many closely spaced carriers modulated with low data rates. This technique is a spectral efficiency scheme that enables high data rates and permits multiple users to share a common channel. To further improve data throughput and spectral efficiency, MIMO uses multiple antennas at the transmitter and receiver. The 4G wireless networks are expected to be used for the majority of the machine for machine communication traffic (Abdalla and Venkatesan 2012). LTE-Advanced (LTE-A) bridges the gap between 4G and 5G by introducing high band-widths, and it promises nearly three times greater speed than does the basic LTE network and comprises carrier aggregation, increased MIMO, coordinated multipoint, relay station, and heterogeneous network. In addition, 5G is an improved technology that provides a platform for collecting more than one hundred billion devices and supports bandwidth of up to 10 Gbit/sec with a relatively low latency. The introduction of 5G networks will result in fast and resilient access to the Internet and support for smart city realization.

### 2.2.2 Big Data (DeRen Li, Cao, and Yao 2015)

The term of “Big Data” is mainly used to describe enormous datasets. Conventional technologies, such as relational databases and sequential processing tools, cannot deal with such a vast volume of data. The amount of collected data is increasing with the significant increasing of connected objects. The scale of data will gradually increase from



Gigabyte and terabyte to Petabyte or even Exabyte. According to Machesney Global Institute 43 trillion Gigabytes of data will be created in 2020, it is estimated that 2.3 trillion Gigabytes of data are created each day and most companies in US have 100,000 Gigabytes of data stored. Each engine generates 20 TB of data per flight hour. A flight from London to New York City will generate 640 TB of data. In Beijing, the public transportation card system receives approximately 40 million uses on a daily basis; and the subway system receives 1 million uses. At all times, people sharing and exchanging their data, ideas, and information on the Web (DeRen Li, Cao, and Yao 2015). Within one second, 2,631,065 emails sent, 49,314 GB of internet traffic, Facebook has 11,333 new posts, 7,786 Tweets sent, 2,801 Skype calls, 71,106 YouTube videos viewed (Ahmed, Bouhorma, and Ahmed 2014). Currently, the total number of websites is more than 1 trillion. All these data have complex structure and large size. If we can thoroughly analyze these data using the most recent technologies, we will be able to rapidly convert the data to valuable information, which can have a direct effect on the behavior of the city.

There are four major characteristics of Big Data Figure 2.4:

**Volume:** refers to the amount of all types of data generated from many sources distributed across the city and continue to expand.

**Varity:** refers to the data collected from different sources and have structured, semi structured or unstructured formats, such as video records, relational databases, and raw texts. This is important for smart cities, since city data is collected from multiple sources, such as surveillance cameras, sensors, and citizen devices.

**Velocity:** refers to the speed of data processing and, in some cases, real time. City infrastructure, operators, and managers need to respond to urban problems, such as traffic jams, accidents, and floods, in short time.

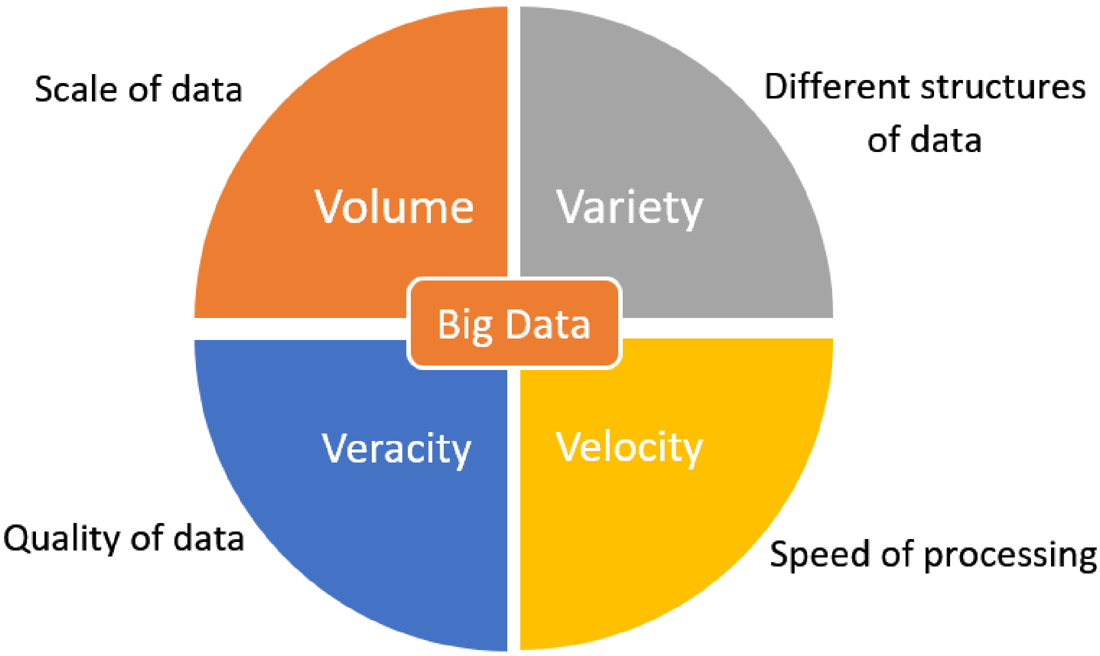



Figure 2.4: Big Data characteristics

**Veracity:** because of the large amount of data collected, and the use of multiple sources, it is important to ensure data quality, because errors in the data or usage of unreliable sources can compromise its analysis. In cities, incorrect GPS readings, malfunctioning sensors, and malicious users can be sources of poor data.

Big Data systems are stored, processed, and mined in smart cities efficiently to produce information to enhance different smart city services. In addition, Big Data can help decision makers plan for any expansion in smart city services, resources, or areas. The various characteristics of big data demonstrate its considerable potential for gains and advancements. The possibilities are endless; however, they are bounded by the availability of advanced technologies and tools. Big data can achieve its goals and can advance the services in smart cities using the right tools and methods for efficient and effective data analysis. Such effectiveness will encourage collaboration and communication between entities and can facilitate the creation of additional services and applications that can further enhance the smart city. The big data applications can serve many sectors in a smart city, thereby providing better customer experiences and services, which help businesses achieve improved performance (e.g., higher profits or increased market shares). Healthcare can be enhanced by improving preventive care services, diagnosis and treatment tools, healthcare records management, and patient care. Transportation systems can greatly benefit from big data to optimize routes and schedules, accommodate varying demands, and increase environmental friendliness.

Smart cities already use Big Data tools to support the amount of data generated from city devices. Sensor networks regularly transmit data about city conditions, such as temperature, air quality, and pluviometery. Citizens generate data using smartphones and social networks, and vehicles continuously send their positions.

## 2.2.3 Cloud computing (Hashem et al., 2015, 2016)

Cloud computing is a fast-growing technology that has established itself in the next generation of IT industry and business. Cloud computing promises reliable software, hardware, and IaaS delivered over the Internet and remote data centers (Armbrust et al. 2010). Cloud services have become a powerful architecture to perform complex large-scale computing tasks and span a range of IT functions from storage and computation to database and application services Figure 2.5. The need to store, process, and analyze large amounts of datasets has driven many organizations and individuals to adopt cloud computing (Liu 2013). A large number of scientific applications for extensive experiments are currently deployed in the cloud and may continue to increase

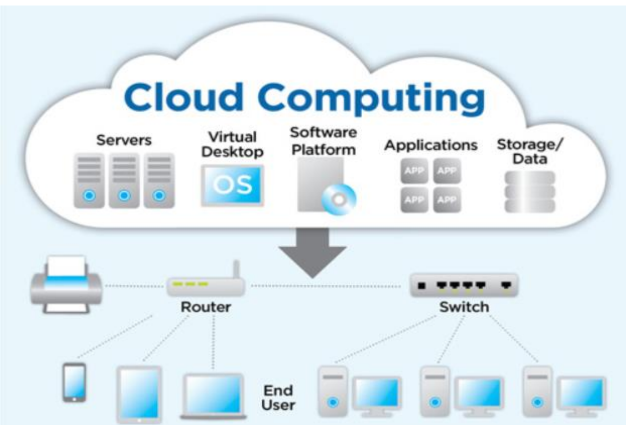


Figure 2.5: Cloud Computing (source: datamation.com)



because of the lack of available computing facilities in local servers, reduced capital costs, and increasing volume of data produced and consumed by the experiments (Pandey and Nepal 2013). In addition, cloud service providers have begun to integrate frameworks for parallel data processing in their services to help users to access cloud resources and deploy their programs.

Cloud computing is used to describe a variety of different types of computing models that involve many computers or clusters connected through a real-time communication network. Cloud computing provides services to perform complex large-scale computing tasks such as mining big social network data generated through smartphone applications (Chang et al. 2010). Cloud computing models typically consist of; i) Infrastructure as a service (IaaS), such as Amazon Web Services (AWS), Microsoft Azure, and Google Compute Engine (GCE), refers to hardware equipment operating on a cloud provided by service providers and used end users upon demand. ii) Platform as a service (PaaS) such as Google's Apps Engine, Heroku, and Microsoft Azure, refers to different resources operating on a cloud to provide platform computing for end users. iii) Software as a service (SaaS), such as Google Docs, Gmail, and Online Payroll, refers to applications operating on a remote cloud infrastructure offered by the cloud provider as services that can be accessed through the internet Figure 2.6. All these services can be combined with IoT. Such an incorporation can transform every business; with the introduction of big data technology, a large amount of data can be processed easily. Moreover, cloud computing can provide the virtual infrastructure for utility computing that integrates monitoring devices, storage devices, analytics tools, visualization platforms, and client delivery (Armbrust et al. 2010). The cost-based model that uses a business framework that cloud computing can offer will enable end-to-end service provisioning for businesses and users to access applications on demand from anywhere (Chang et al. 2010). Cloud computing also provides the underlying engine via the big data technology such as Hadoop framework (Hashem et al., 2015, 2016). Hadoop was introduced to provide an enabling platform and programming models for the distributed processing of large datasets across different clusters. Hadoop comprises two primary components: Hadoop Distributed File System and MapReduce, which are closely related to each other. Although the real-time requirements of data storage and processing in the smart city are considered, the adoption of streaming architecture will guarantee the efficient and seamless communication between sensing devices within the smart city network. Such technology has been adopted recently with the introduction of many stream processing platforms, such as Apache S4, Storm, and Spark streaming, which can enable data storage and processing across various interconnected nodes.



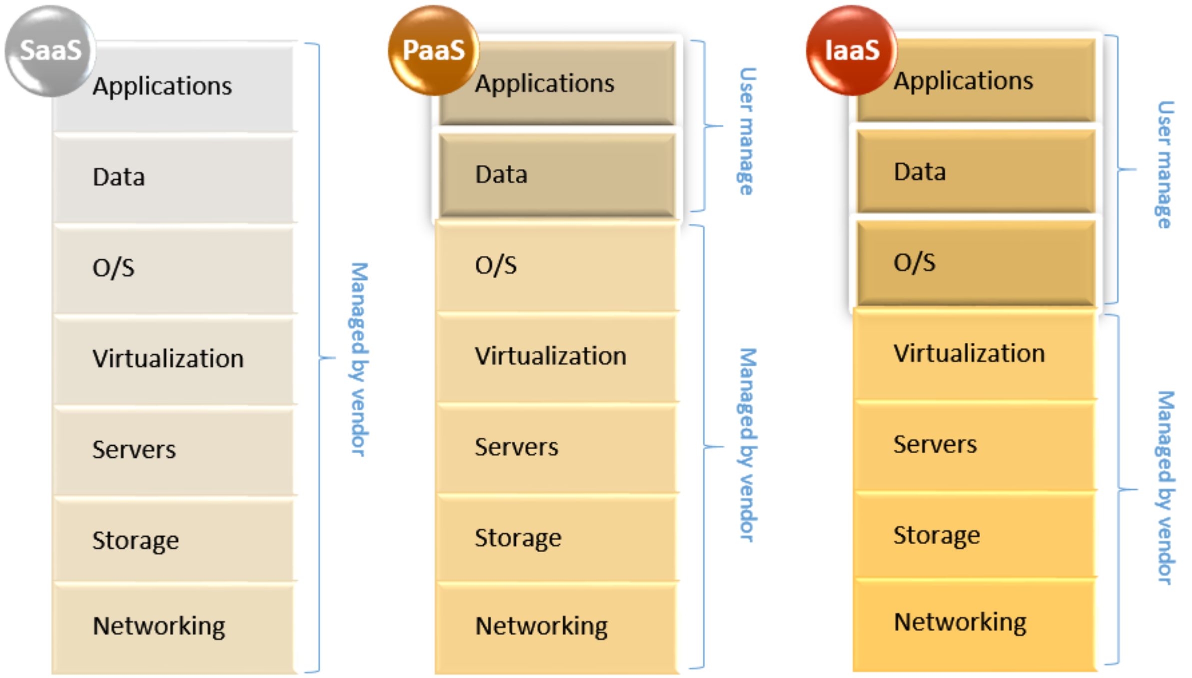



Figure 2.6: The difference between IaaS, PaaS, and SaaS

## 2.3 Smart City Architectures

Because of the vague definition of the Smart City. As a result, a large number of smart city architectures are proposed with focus on different areas of scientific knowledges, such as, technology, human-system interaction and logic. This section presents the main proposed architectures.

Al-Hader and Rodzi proposed two big parts for the Smart City (Al-Hader and Rodzi 2009). Table 2.1 summarizes this architecture. The first concern the monitoring layer that provides surveying and data communication updates. The second layer is the development layer, which contains geospatial applications and the network data model. Geospatial applications include the network analysis model, facility-sitting model and the maintenance and operational model. Network data models for electricity, communication, water, gas, sewers, and storm provisions are included.

Table 2.1 : Architecture proposed by City (Al-Hader and Rodzi 2009).

| Layer | Services |
|---|---|
| Monitoring layer | Surveying and data communication updates |
| Development layer | Geospatial applications and network data model |

From a logical and physical view, Anthopoulos and Fitsilis proposed a five-layer generic smart city architecture (Anthopoulos and Fitsilis 2010). Table 2.2 summarizes this architecture. The stakeholder layer describes the potential users, including citizens, user groups and servants. The service layer contains releasing information to the public as well as providing information to citizens and businesses through application software. The business layer provides the definition of the rules and policies to allow the smart city to understand how to operate. The infrastructure layer includes the basic network and other access points. The information layer is designed to produce and store data properly.

Table 2.2 : Architecture proposed by (Anthopoulos and Fitsilis 2010).

| Layer | Services |
|---|---|
| Stakeholder layer | Describes the potential users |
| Service layer | Releases and provides information through application software |
| Business layer | Provides the operation policies |
| Infrastructure layer | Includes the basic network an access points |
| Information layer | Produces and stores data |

Hernandez et al. proposed an architecture called Ubiquitous Sensor Network (USN) (Hernández-Muñoz et al. 2011). The goal was to provide an infrastructure that enabled the integration of heterogeneous and geographically dispersed sensors in a centralized technological base, in which services could be developed at minimal cost. To this end, the project based itself on the integration of Internet of Things and Internet of Services.

The architecture consists of three layers Application layer, Control layer, and Access layer. Figure 2.7 shows this architecture layers. Additionally, the architecture included a module known as USN-Gateway that enabled interoperability between sensor networks and the IP network.

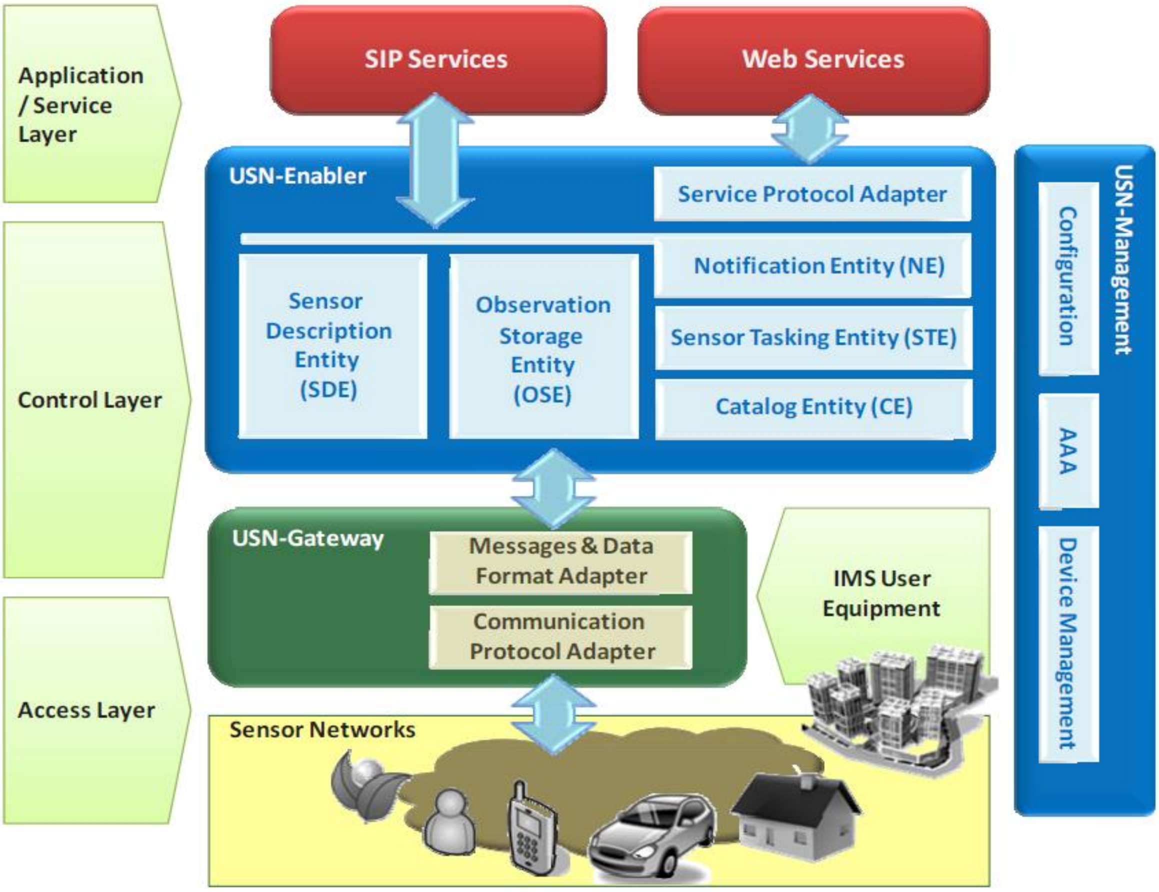



Figure 2.7: The architecture of USN platform

One important concern that arises with the need to build cities that provide high quality of life for its citizens is the sustainable issue, where the premise is the adoption of environmentally friendly, economically viable, and socially fair measures. Based on this concept, Lee et al. (J. Lee, Baik, and Lee 2011) describes the proposal of an ubiquitous city, or u-city, in which urban infrastructure is composed of people and objects connected through ICT, providing an array of services to an effective and integrated urban management, coupled with environmentally friendly technologies, providing a harmonious coexistence between people, environment and technological advancement. The work proposes an architecture called U-eco City Integrated Service Management Platform (ISMP-UC). It consists of three layers shown in Table 2.3.

Table 2.3: Architecture proposed by (Lee et al., 2011).

| Layer | Services |
|---|---|
| Bottom layer | Sensors, actuators, and other devices distributed about the city |
| Middleware | Data collection and processing |
| Top layer | Provides a range of services |

The sustainable aspect is explored in the architecture proposed by Zygiaris (Zygiaris 2013). The main goal is to propose a model that can be used on any smart urban planning, including all sustainable concepts, specifically in the second layer, known as Green City. This layer is supported by the infrastructure layer and contains all environmental policies (for example, the level allowed by $CO_2$ of residences). The other layers correspond, respectively, to innovation, implementation, integration, synchronization and interconnection between different networks Table 2.4. As validation, this model was used in the following cities: Barcelona, Amsterdam and Edinburgh.

Table 2.4: Architecture proposed by (Zygriaris, 2013).

| Layer | Services |
|---|---|
| City layer | Conveys the traditional components present in every city |
| Green City layer | Contains all environmental policies |
| Interconnection layer | Interconnect people, smart nodes, and other embedded devices |
| Instrumentation layer | Provides the connection between real-time devices and the city |
| Open Integration layer | Provides integration and access of other applications to data |
| Application layer | Provides intelligence through several forms of ICT applications |
| Innovation layer | Provides fertile innovation environment for new business opportunities |

(Asimakopoulou and Bessis 2011) proposed an architecture to disaster management, based on information collected from various entities including people, homes, and vehicles immersed in an environment completely connected, that monitor the environment around them. In the process of generating responses to emergencies is necessary to have historical and real-time knowledge of the entities and the domain they concern. They used the approach crowd sourcing, in which citizens themselves, enabled by some kind of application and/or device, contribute to the provision of accurate and updated data on critical scenarios, helping the stakeholders in the decision-making process.

Attwood et al. (Attwood et al. 2011) proposed an architecture for critical infrastructure, which highlights the need to collect real-time data from various services within the urban environment, properly related, serving as base for decision-making in critical situations. The basic operation of the architecture consisted of a mechanism for annotation and aggregation, in which a sensor network distributed throughout the city would be connected and whose data would be mapped to a specific service (e.g., failure in the electricity distribution system). When any fault is detected, the collected data is provided to a reasoning instance, responsible for suggesting measures to be taken to normalize the situation. In case of failure in any sensor, another overlay network would be created from nodes still in operation, allowing data preservation and distribution. The high-level requirements of their framework:

- Smart City Internet of things Integration
- Maintenance and extraction of failing sensor actuator network state
- Semantic Decision Making
- Critical Infrastructure Visualization

Chourabi et al. proposed a framework from the perspective of systems to provide a comprehensive understanding of the smart city (Chourabi et al. 2012). They divided influencing factors into two groups. Outer factors include the governance, people and communities, the natural environment, infrastructure, and economy. Inner factors are technology, organization, and related policies Figure 2.8.

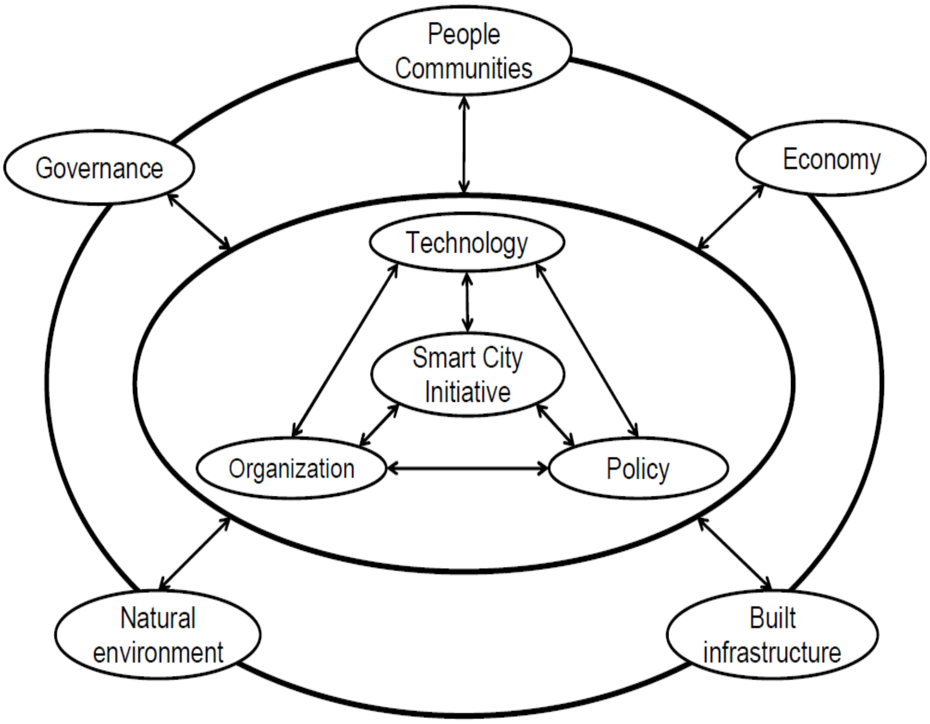



Figure 2.8 : Smart city initiative Framework

Komninos summarized the architecture for smart cities from the perspective of technology, in which a smart city is divided into three different layers (Komninos 2006) Table 2.5 summarize the layers. First, the information storage layer stores all kinds of digital content. The second layer is the interface layer, which exposes this functionality through a variety of web applications by using maps, 3D images, text, charts, and other interface tools. The third layer is the interaction layer, where people can exchange information and communicate. There is another administration layer, which is responsible for providing proper access right for users to digital contents.



Table 2.5: Architecture proposed by (Komninos, 2006)

| Layer | Services |
|---|---|
| Information layer | Stores all kinds of digital content |
| Interface layer | Provides users will objects that visualize the city |
| Interaction layer | Provides an environment for users to exchange information |

Santander smart city architecture includes five layers. Table 2.6 summarize the layers. The first layer is for integration and interoperability, which permits the capture, compilation, and real-time analysis of data from devices with interconnection capacity. The second layer is for treatment, management and exploitation of data, it provides an integrated management system that makes it possible to work with a large number of variables and data from diverse data in real-time conditions. Business support is the third layer for generating reports and needed visualizations for the information to managers and users. Application and access layer make it easy to entrepreneurs and developers to interact with the existing information. Management layer is the last one, which provide tools for configuration existing services (Gutiérrez Bayo 2016).

Table 2.6: Architecture proposed by Santander Smart City.

| Layer | Services |
|---|---|
| Integration layer | Integrates the various sources of data coming from the urban services information systems |
| Treatment layer | Treats all coming heterogeneous information |
| Business layer | Visualize all needed information |
| Application layer | Facilitate the interaction with exiting information |
| Management layer | Provides configuration tools for existing services |

Wenge et al proposed a multi-layered smart city architecture from data perspective (Wenge et al. 2014). Table 2.7 summarize the layers. The bottom layer concerns data acquisition, which composes all sensor system and data sources in the city. It has the ability to capture any kind of information including images, video, sound, and others and stores it logically. The second layer concerns data transmission, which is the platform for data resource integration. The third layer concerns data cleaning, association, and maintenance. Support service is the fourth layer, which facilitate computing intensive data for the application that will sit above. Finally, the fifth and sixth layers are domain service and event driven smart applications, they are important since they have direct interaction with citizen, these layers integrate abilities from multiple different systems and provide services based on people needs.

Table 2.7: Architecture proposed by (Wenge et al., 2014).

| Layer | Services |
|---|---|
| Data acquisition | Composes all sensor system and data sources in the city |
| Data transmission | Integrates data resources and sent it to data storage |
| Data storage & visualization | Provides data cleaning, association, and maintenance |
| Support service | Facilitate computing intensive data |
| Domain service & Event driven | Provide direct interaction with citizens |

Rathore et al. proposed a combined IoT-based system for smart city development and urban planning using Big Data analytics. Their complete system consists in various types of sensor deployment, including smart home sensors, weather and water sensors, vehicular networks, and surveillance objects. They proposed a four-tier architecture. Table 2.8 summarize the tiers of the architecture that includes Bottom Tier, which is responsible for IoT sources and data generation and collection. Intermediate Tier-I, which is responsible for all types of communication between sensors, relays, base station and the Internet. Intermediate Tier-II, which is responsible for data management and processing using a Hadoop framework, and Top-tier, which is responsible for application and usage of the data analysis and the results generated (Rathore et al. 2016).

Table 2.8: Architecture proposed by (Rathore et al., 2016)

| Layer | Services |
|---|---|
| Bottom Tier | Data generation and collection |
| Intermediate Tier-I | Responsible for all hardware communications |
| Intermediate Tier-II | Data management and processing |
| Top-Tier | Data interpretation |

Most of the proposed architectures in the literature are still in the conceptual phase with few practical validations. Considering this scenario, the Smart Santander project (Sanchez et al. 2014) aims to be a laboratory for prototyping and developing technologies in a real environment. The city contains 20,000 experimental sensors, capturing information from different services. During the project idealization, some requirements were categorized as highest priority. Among them, it highlights the authentication and authorization mechanisms, test management subsystems, experiments subsystem and applications module support. A solution was initially developed to optimize the vehicles flow in parking lots.



## 2.4 Smart City Platforms

The environment, which is able to manage different technologies and devices, and enable different applications and services for different systems of the city, is called a "Smart city platform". It can be defined as a framework for sensing, communication, integration and intelligent decision-making.

The main goal of a platform for smart cities is to provide citizens with useful information about the service they want to use and to facilitate the development of smart city applications. Considering that cities usually have different characteristics, it is natural to imagine that the same architecture does not apply to all of them, mainly because one cannot generalize local, financial, social and environmental restrictions. To establish a sustainable urban environment and enhance the quality of life of its citizens, different approaches were used. The most analyzed platforms implemented requirements for collecting data from the city, managing and sharing data with real cases or not. Despite the common goals of these initiatives, there is no consensus on what requirements an architecture must meet to be considered effective, regardless of how it was implemented. The most common enabling technologies employed in smart city platforms are grouped into three main categories:

- **Internet of Things (IoT)** applied to control sensors and actuators responsible for retrieving information from the city.
- **Big Data** to support storage and processing of the data collected from the city.
- **Cloud computing** to provide elasticity to the services and data storage.

The following section presents a number of existing platforms provided by different stakeholders.



### 2.4.1 Presentation of existing Smart Cities platforms

The Smart City platforms can be divided into four categories, according to the enabling technologies that each platform uses. Figure 2.7 presents an overview of the platforms for Smart Cities that has been analyzed. The majority of platforms use Cloud Computing. Almost all of them use at least one more enabling technology, more commonly IoT and Big Data.

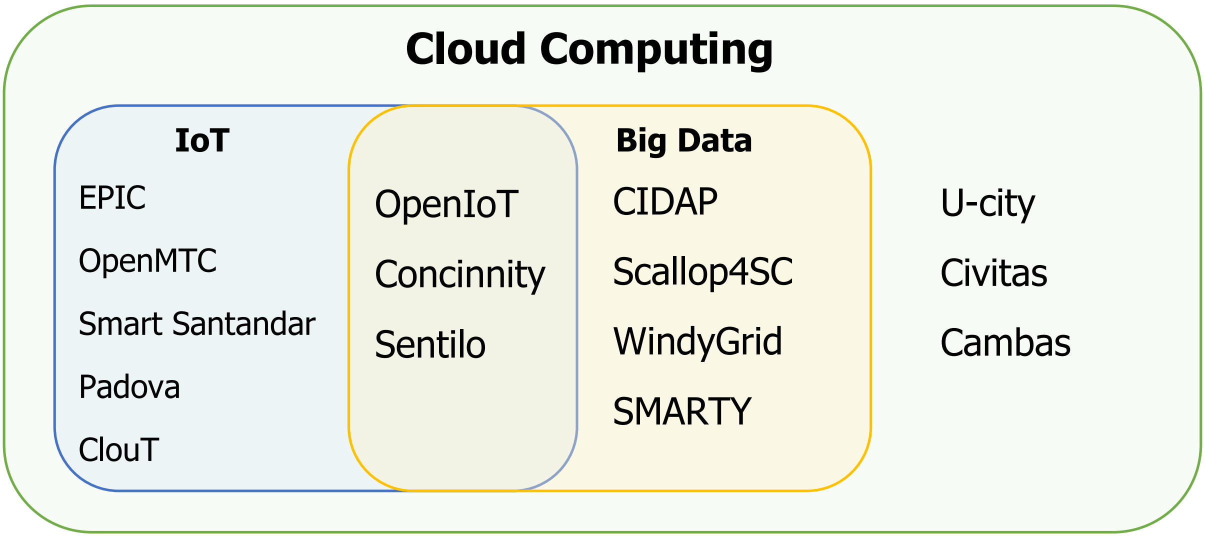



Figure 2.9: Platforms based on enabling technologies (Santana et al., 2016)

#### 2.4.1.1 Internet of Things and Cloud Computing

The European Platform for Intelligent Cities (EPIC) project proposes a complete IoT Middleware to facilitate the use and management of the Wireless Sensor Network (WSN). This middleware aims to deal with the heterogeneity, interoperability, scalability, extensibility, and configurability problems in a WSN (BALLON, Cunningham, and Cunningham 2011).

OpenMTC (Open Machine Type Communications) is a Machine-To-Machine (M2M) based communication platform for Smart Cities. Its goal is to enable efficient communication among a large number of devices, associating them with multiple services. To achieve this, the platform supports standard interfaces to various types of devices, data/event processing methods to achieve real-time performance, and easy application development, providing a software development kit (Elmangoush et al. 2013).

SmartSantander is an experimental infrastructure to support the development and deployment of Smart City applications and services. The project is centered on Santander, with smaller facilities in other European cities. The platform processes a large variety of information, including data about traffic conditions, temperature, $CO_2$ emissions, humidity, and luminosity. Currently, the project has implanted more than 20,000 sensors in the city (Sanchez et al. 2014).



Padova Smart City uses IoT to create a sensor network in the city of Padova, Italy. Using more than three hundred sensors, the platform collects environmental data, such as CO2 emissions and air temperature, and monitors streetlights. A feature highlighted in this platform is the use of common protocols and data formats to allow interoperability among multiple city systems (Zanella et al. 2014).

ClouT proposes a two-layer architecture to collect data from the WSN and manage the sensors and actuators in the city network. The first layer is the Sensors and Actuators Layer, which handles data from the WSN. The second layer, the IoT Kernel Layer, manages and monitors the sensors and actuators network (Tei and Gurgen 2014) .

Analysis of above-mentioned allows the identification of four major functional requirements:

- Management of a WSN,
- Management of the data collected from the city,
- Management of services and applications,
- Infrastructure to make the data from the platform available to city applications.

This analysis also led to the identification of five nonfunctional requirements: adaptation, interoperability, scalability, extensibility, and configurability.

There are two weak points of these platforms:

- Lack of pre-processing components to verify the integrity of the data collected from the city and make small transformations of the data, such as aggregations,
- Most of the platforms do not include a discussion about security concerns.

#### 2.4.1.2 Internet of Things, Cloud Computing and Big Data:

OpenIoT is an open source middleware for the development of IoT-based applications. It has an API to manage the WSN, and a directory service to dynamically discover the sensors deployed in the city; it also has a layer for service definition and access. Big Data tools are used to store and analyze the data from the platform. A Smart City project called Vital builds on this platform and uses the term ”Cloud of Things” to refer to the use of Cloud Computing and IoT (Petrolo, Loscri, and Mitton 2014).

The Concinnity project provides a platform for managing data and applications following the PaaS model, with which the authors built Big Sensor Data Applications. However, this platform focuses on multiple data sources such as the WSN, social networks, and data from platform users. It also includes a service directory where developers can find and publish services facilitating its reuse (Wu et al. 2014).



OpenIoT and Concinnity, offer developers tools to implement applications directly on the platform. OpenIoT allows the mash-up of the services defined in the platform and automatically creates a visual interface for end-users. Concinnity provides a set of development tools, such as a Workflow Editor and Engine, a Service Publisher, and an Application Editor.

Sentilo is a platform that deals with the management of sensors and actuators, designed for Smart Cities that looks for openness and interoperability. Sentilo uses IoT concepts to control the WSN, and Cloud Computing to share data with the applications. Big Data tools are mainly used to collect and store data from sensors, ensuring platform scalability. The Sentilo project was originally designed to be deployed in the city of Barcelona; after its deployment, the City released the code under the LGPL and EUPL open source licenses (Bain 2014).

The main functional requirements identified for this group of platforms were:

- Management of a WSN,
- Management of data life cycle (collect, store, and process),
- Making the data from the platform publicly available,
- A service directory for application developers,
- Tools for application development.

As non-functional requirements, interoperability and scalability can be identified.

Weak points of these platforms are:

- Lack of streams processing tools to analyze real-time data from the city, an important requirement for many Smart City applications.
- Most of the platforms do not support the customization of services with citizen data; in spite of privacy issue, offering context-aware, customized services to the citizens is highly desirable.

#### 2.4.1.3 Cloud Computing and Big Data

CiDAP is a big data analytics platform deployed into the SmartSantander testbed. The platform uses data collected from SmartSantander and analyzes it to understand the behavior of the city. The main components of this platform are:

- The agents, which collect data from the SmartSantander platform;
- The Big Data repository for storing the data;
- The Big Data processing for intensive data processing and analytics;
- CityModel server, responsible for interfacing with external applications.

This platform uses Apache Spark to process the data (Cheng et al. 2015; Zaharia et al. 2010).



Vilajosana et al. (Vilajosana et al. 2013) present a platform for Smart Cities based on Cloud Computing and Big Data, with the main components:

- Data management and service hosting; which includes an Open Data API allowing third-party applications to access the data stored on the platform.
- Big Data tools, which are used to collect data streams and analyze data, such as prediction and inference

Scallop4SC (SCALable LOgging Platform for Smart City) uses Big Data to process a large volume of data gathered from smart buildings. The platform uses information about building, such as water and energy consumption, temperature, air humidity, and the amount of garbage generated. Periodically, the buildings send data to the platform for processing. The objective is to analyze smart building data, for which it uses the MapReduce algorithm (Takahashi et al. 2012; Yamamoto et al. 2013).

The platform WindyGrid of Chicago aims at presenting real-time and historical data with a unified view of city operations. Big Data technologies, such as the MongoDB NoSQL database and parallel data processors are used in this platform (Thornton 2013).

SMARTY is a project aimed at providing tools and services for mobility and flexible city transport systems. The platform collects data from multiple sources, such as traffic flow, user location, transport service delays, and parking availability. A network of low-cost sensors collects data from the city and social networks are continuously monitored to get data from citizens (Anastasi et al. 2013).

The platform proposed by Girtelschmid et al. uses semantic technologies to create a platform for Smart Cities, adding flexibility in system configuration and adaptation. However, to overcome the performance bottlenecks normally associated with ontology repositories and reasoning tools, the authors combine their semantic techniques with Big Data processing methods (Girtelschmid et al. 2013).

Khan et al. propose a Smart City architecture based on Big Data to achieve the necessary availability and scalability required for a Smart Cities platform. The architecture has three layers:

- Layer 1: to collect, analyze, and filter data;
- Layer 2: to map and aggregate data to make it semantically relevant;
- Layer 3: to enable users to browse and recover the data processed from the other two layers.

The platform uses only open source projects (Khan et al. 2015).

The main functional requirements identified for this group of platforms were:

- Data management, such as collecting, analyzing, and visualizing data;
- Large scale data processing, such as batch and real-time processing;
- And the use of semantic techniques combined with Big Data.

Most of the platforms in this section do not have an IoT layer, and do not indicate how the data is collected from the city; the exception is CiDAP, which uses the Smart Santander testbed as an IoT middleware. Another drawback is that most of the platforms do not include a discussion about security concerns.

#### 2.4.1.4 Cloud Computing platforms

U-City is a platform for the creation of smart ubiquitous cities. It offers several service management features, such as autonomic service discovery, service deployment, and context-aware service execution. It also offers predefined services such as an inference engine, a context-aware data service, and a portal for the management of the platform (Y. W. Lee and Rho 2010a).

Civitas is a middleware to support the development of Smart Cities services (Villanueva et al. 2013). It is used to facilitate the development and deployment of Smart City applications and to avoid the emergence of "information islands", i.e., disconnected applications that do not share relevant information. Citizens connect to the middleware via a special device called the Civitas Plug, which ensures the privacy and the security. The middleware has two main design principles to facilitate the application integration: Everything is a Software Object, which promotes the consistency of the software design and reusability of the middleware; and Independence of the City Layout, meaning that city services should not work with just one city layout.

Piro et al. present a two-layered service platform for the creation of Smart City applications. The first is a low-level layer that controls the communication among the city WSN devices. The second layer collects the data from the devices and provides services for the development of applications that use the data from the city (Piro et al. 2014).

Gambas, a middleware for the development of Smart City applications, supports data acquisition, distribution, and integration. The platform also provides an application runtime to facilitate the development and deployment of services using city data and a service registry. The middleware supports context-awareness, so that Smart City services can adapt to the citizen situation, behavior, and intent. All communication in the platform is encrypted to ensure citizen's privacy and security (Apolinarski, Iqbal, and Parreira 2014).

The main functional requirements identified for this group of platforms are:

- Service management
- Data management.



The non-functional requirements are:

- Security,
- Privacy
- Context awareness.

None of the presented platforms use known frameworks to implement components, such as the inference engine and processing tools, which might make difficult the maintenance of the platform. In addition, they do not describe external access to the platform data.

## 2.4.2 Essential Requirements

From works and developments presented in the previous section, we propose the following functional and non-functional requirements (Table 2.9).

Table 2.9: Functional and non-functional requirements for Smart City platforms

| **Functional requirements** | **Non-functional requirements** |
|---|---|
| WSN management | Interoperability |
| Data management | Scalability |
| Data processing | Security |
| Real-time monitoring | Privacy |
| External data access | Flexibility and Extensibility |
| Service management | Configurability |
| | Simplicity |
| | Social aspects |

In the following sections, we present these requirements.

### 2.4.2.1 Functional requirements

- **WSN management**

The platform must have a layer to manage the city device activities, such as adding, removing, and monitoring the sensors and adapters. Many of analyzed platforms have a Wireless Sensor Network (WSN) management to control and monitor the devices installed in the city using IoT concept (Tei and Gurgen 2014). Padova Smart City (Zanella et al. 2014) with 3000 sensors and SmartSantander (Sanchez et al. 2014) with 20000 sensors described a WSN deployed in a city.



- **Data management**

The backbone for any smart city platform is this requirement, which includes data collection and storage, many platforms are used different techniques for this requirement such as relational databases such as (MySQL, SQL Server, ..), non-relational databases (MongoDB, VoltDB, ..), big data tools (Hadoop), and customized tools can be developed for specific goals.(Hernández-Muñoz et al. 2011; Y. W. Lee and Rho 2010b).

- **Data processing**

In the smart city context, the sources of data are different, the amount of incoming data will be huge, and this data will be constantly modified, either by natural factors or by human activities. Thus, all data picked up has the potential to become relevant, as long as it is somehow associated to other data. Therefore the platform should include efficient processing components to process large data sets, data mining algorithms, storage and retrieval mechanisms for analyzing historical data, verify, aggregate, and filter the data from the city. A platform must have the ability to analyze historical data, which is useful to enhance the results if it obtained from a data mining algorithms. Some previous analyzed platforms use specific processing components, such as big data processing tools (Takahashi et al. 2012) and workflow processing (Wu et al. 2014) and some platforms provide real-time data analysis (Girtelschmid et al. 2013) (Cheng et al. 2015).

- **Real-time monitoring**

Real-time data monitoring (RTDM) is a process through which managers can review, evaluate and modify the addition, deletion, modification and use of data on software, a database or a system. It enables data managers to review the overall processes and functions performed on the data in real time, or as it happens, through graphical charts and bars on a central interface/dashboard. This is the valuable instrument to provide relevant information that can be used to predict phenomena. (Petrolo, Loscri, and Mitton 2014) proposed a platform, which provides tools to develop real-time applications.

- **External data access**

One of the main goals of building a platform is to prepare the environment and provide tools and interfaces to facilitate access to information and services by external applications. The most common approach is an Application Programming Interface (API), which allows access to the data generated in a city. Some platforms used Representational state transfer (REST) (Elmangoush et al. 2013), others propose open data platform (Zanella et al. 2014). In addition, some use cloud-computing concepts to provide the city data as a service.

- **Service management**

Since a platform is offering services so, it has to have the ability to manage these services such as developing, deleting, and maintaining services. Some platforms provide creating new services by using existing service composition (Piro et al. 2014) to provide specific features to applications, such as access to analyzed data (Zanella et al. 2014), others allow developers to customize services and make them available to other applications (Apolinarski, Iqbal, and Parreira 2014).

#### 2.4.2.2 Nonfunctional requirements

- **Objects interoperability**

One of the most discussed and studies requirements is the interoperability of objects, where the object of an abstraction of sensors, actuators, surveillance cameras, monitoring, displays, vehicles and all these components must operate in an integrated environment. In fact, this is a critical requirement to the consolidation of any platform that uses a range of objects with different technical specifications and communication protocols. For example, systems that implemented in different languages and legacy systems that have to communicate with the new platforms. The vast majority of platforms designate a module or layer to meet this requirement. They used several techniques such as: applying Semantic Web to integrate all platform entities (Girtelschmid et al. 2013), interoperable objects (Villanueva et al. 2013), adopting generic and standard interfaces (Gurgen et al. 2013), and using naming mechanism to recognize the different data source or devices (Cheng et al. 2015).

- **Scalability**

The amount of data, services, and users of a smart city platform will be massive, and it will increase more and more over the time. A platform must be prepared to handle this increasing data without any effect on the performance. Some platforms such as CiDAP collected more than 50 GBs of data in three months (Cheng et al. 2015), in the SmartSantander tested, there were more than 20,000 sensors, in a city of 178,000 inhabitants collecting a huge amount of data (Sanchez et al. 2014). This non-functional requirement is relevant to many functional requirements, such as data management (Takahashi et al. 2012), WSN management (BALLON, Cunningham, and Cunningham 2011), and service management.

- **Security**

Since data in a smart city platform includes critical data, providing a high level of security for sensitive information for citizen, governments, and enterprises when they use the platform services is a major requirement. The security system should be applied to all components of a platform. Malicious users can make deceitful use of services and data provided by the platform. Some platforms have a module or mechanisms to handle security, avoiding attacks to the city infrastructure and information theft (Hernández-Muñoz et al. 2011; Petrolo, Loscri, and Mitton 2014; Piro et al. 2014).

- **Privacy**

A smart city platform collects and manipulates several citizen-sensitive data, such as medical records, user localization and consuming habits. The goal of the platform is to provide users with services. If users deem a platform as insecure for his/her sensitive information (privacy); they will not use it. Thus, in order to achieve user consent and trust in, integration of privacy preserving mechanisms must be a key concern for a platform. Some of the strategies used to achieve this requirement are anonymization (Mylonas, Theodoridis, and Muñoz 2015), token to control the access to the data that user can manipulate (Apolinarski, Iqbal, and Parreira 2014) and cryptography (Villanueva et al. 2013).

- **Flexibility and Extensibility**

The capability to add and change services, components, and applications to the platform is important to assure that it meets evolving system requirements and user needs. These operations should avoid the complexity. CiDAP (Cheng et al. 2015) offers extensibility to enable the use of the platform in the cities in different scales, some platforms just apply open source tools for facilitating the platform's extensibility (Khan et al. 2015)

- **Configurability**

A Smart City platform has many configuration options and parameters that define its behavior at execution time, such as defining pollution and congestion thresholds and the priority of services. Thus, it is important to allow (re)configuration of the many variables of the platform. Two platforms highlighted the importance of self-configurability capacities, because of the huge amount of configurations needed in a Smart City platform (Privat, Zhao, and Lemke 2014; Wan et al. 2012). Other platforms provide a portal to centralize the configurations (Kim and Lee 2014; Y. W. Lee and Rho 2010b).

- **Simplicity**

A smart city platform is not just for city managers, it also provides citizens with useful information about city services, each service in the city may have an interface to present the analyzed data, these interfaces should be simple to interact with it even from non-specialist users. The information that is presented on the interface should be clear and easy to understand for all citizen levels.



- **Social aspects**

A smart city platform should include a communication space to let users contact directly with the city managers to let them make discussions, involve them in decision-making, and the more important is to let users to connect to each other and share their ideas, which makes the life more sociable. Sometimes citizens can be a good source of data, since they are in the event more than the city managers are.

## 2.5 Conclusion

This chapter included a presentation the role of data in smart cities as well technologies used to manage these data. The chapter presented also important issues concerning the Smart City architectures and platforms. It showed the existence of high diversity of these architectures ad platforms, which are related to the large variety of smart city projects.

This analysis allowed the identification of major functional and non-functional requirements for building any smart city platform. The functional requirements concern WSN management, data management, data processing, real-time monitoring, external data access, and service management. The non-functional requirements include interoperability, scalability, security, privacy, flexibility and Extensibility, configurability, simplicity and social aspects.

In the following chapter, we will present the implementation at the Scientific Campus of Lille University of a large-scale demonstrator of the Smart City (SunRise) (Shahrour et al. 2016, 2017). After the presentation of this demonstrator, we will use the literature review of this chapter to figure out the requirements for SunRise platform and then discuss the implementation of this platform.



# Chapter 3

# Presentation of SunRise Project



# Chapter 3 – Presentation of SunRise Project

This chapter presents the "SunRise" Smart City project, which aims to build a large-scale demonstrator of a Smart City at the Scientific Campus of the University of Lille. The chapter presents successively the scientific campus, the buildings assets and the urban networks (drinking water, sewage, district heating and electrical grid), which were monitored within SunRise project.

## 3.1 Introduction

The SunRise Smart City project was initiated in 2011 by a consortium of academic, industrial and local government partners to build a large-scale demonstrator of the Smart City, with a particular focus on urban infrastructures. Through this project, the consortium aimed at developing an international expertise, bringing together experts of governmental agencies, industry and academia, for the assessment of the environmental, economic and operational impacts of the Smart City concept in improving the current state of practice and the city capacity building in the field of sustainability. The demonstrator was established at the Scientific Campus of the University of Lille, which stands for a town of about 25 000 inhabitants.

The originality of SunRise project lies on the following:

- It concerns a large-scale experimentation that of a small town.
- It covers the totality of urban infrastructures as well as buildings.
- A large local government, industry and academic partnership support it.
- It is used as a living lab for both research, education and PhD programs.
- It is conducted within an international environment.

This research aims to implement two professional platforms on SunRise project.

## 3.2 Scientific Campus of the University of Lille

SunRise Smart City demonstrator is established at the Scientific Campus of the University of Lille, which is located near the City of Lille in the North of France. The campus stands for a small town with about 25 000 inhabitants. It was constructed between 1964 and 1966. Later on, some buildings were renovated and others were constructed. The campus includes 145 buildings with a total construction area of 325 000 $m^2$ Figure 3.1. Buildings are used for research, teaching, administration, students' residences and entertainment activities. The campus is deserved by 100 km of urban networks: district heating and roads, drinking water, electrical grid, public lighting, storm water, sanitation.

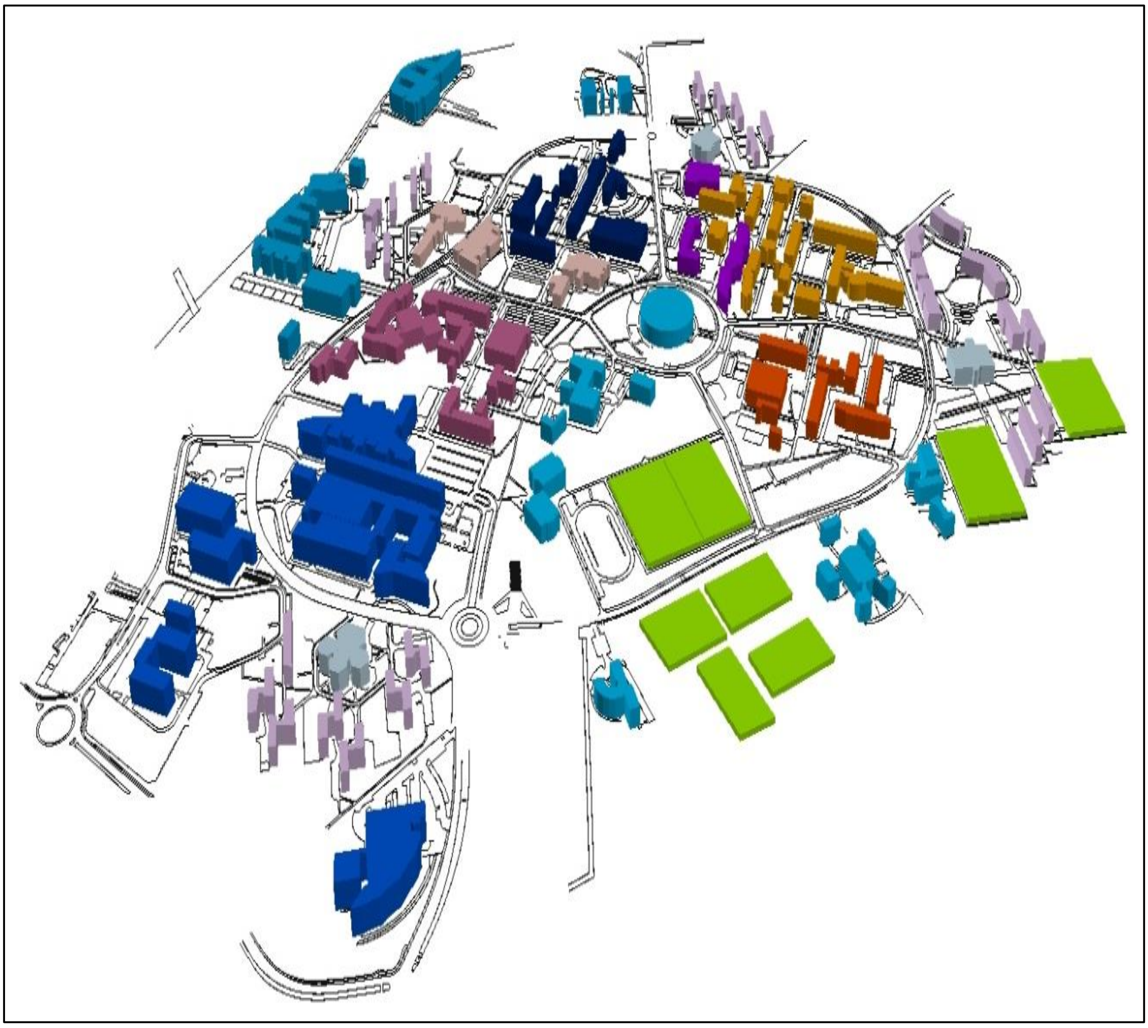


Figure 3.1: Scientific Campus of the University of Lille, support of SunRise demonstrator (145 buildings)

The entire infrastructure has been presented in a geographic information system (GIS) by the SunRise team as layers. The following sections present briefly the building assets and the urban networks of the campus with their presentations in GIS layers.

### 3.2.1 Building Assets

The campus includes around 150 buildings (324,000 $m^2$). The construction data of different buildings varies from zero to 50 years. The buildings' age is a major factor of the quality of construction.

The campus buildings are classified by type of usage to the following sectors with the percentage of surface each sector covers:

- Education, teaching and research sector,
- Administrative and services sector,
- University residences sector,
- University restaurants sector,
- Sports sector.

Figure 3.2 shows the distribution of the buildings in the campus in Sunrise GIS layer, the buildings are represented as polygons and it is colored depending on their sector. This layer has attributes about each building such as building name, usage type, year of construction, floors number, and the building's sector. As can be noticed, the education and research sectors cover more than half of the campus area these sectors are divided to departments as the following:

Engineering schools, physics, chemistry, natural sciences, mathematics, Institute of technology IUT, and social sciences. The following sections provide brief details about these sectors.

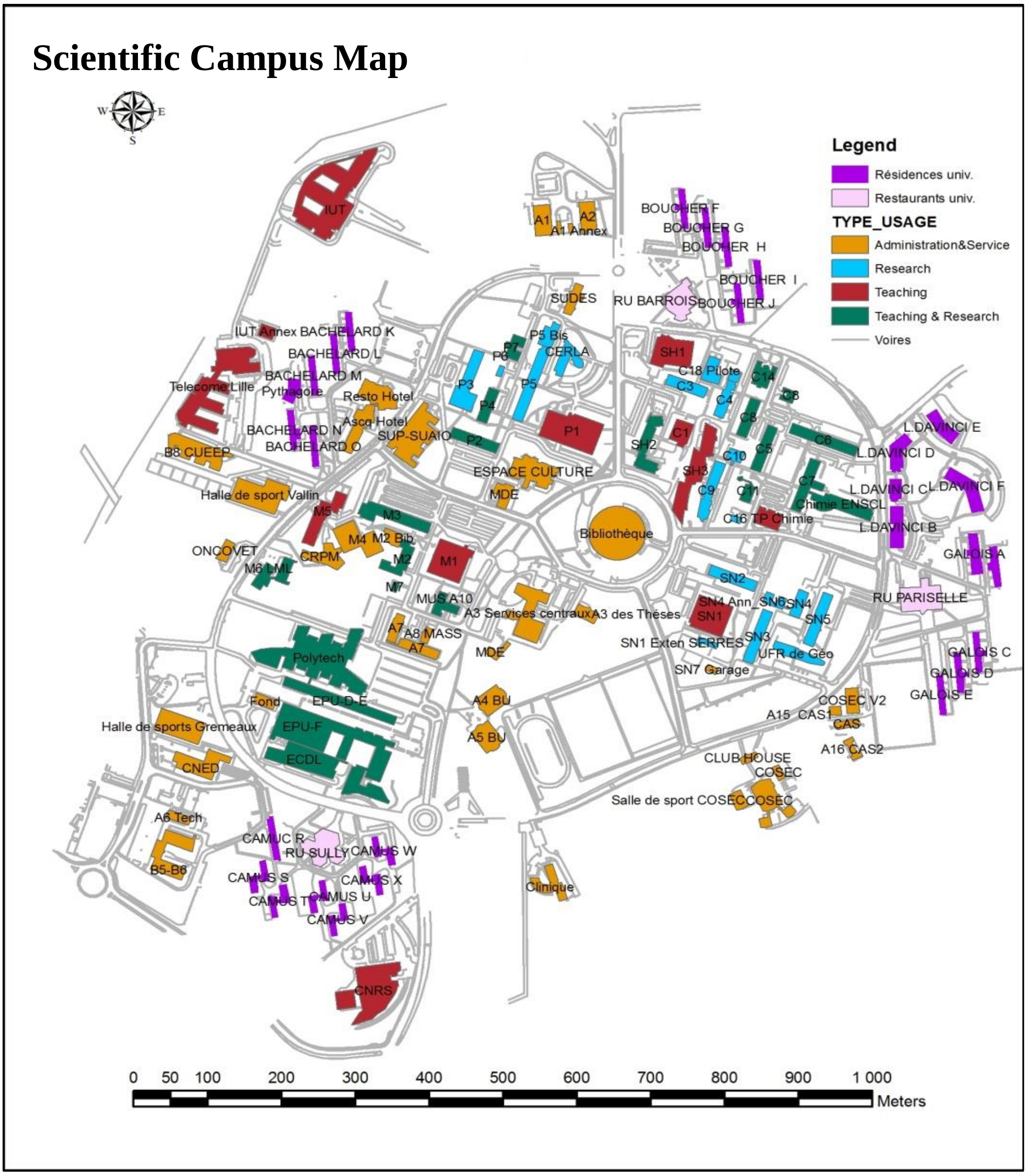



Figure 3.2: The distribution of campus buildings by sector

## 3.2.2 Drinking water network (FARAH 2016)

### 3.2.2.1 Physical description

The drinking water network is constructed in 1964; it consists of Pipes, 49 Hydrants designed according to the fire frightening, and 250 isolation valves. The length of the water network in the campus is equal to 15 km; it is divided into 13 km for the Campus (private sector) and 1.5 km for the public sector (owner Eaux Du Nord). This network is presented in SunRise GIS in separated layers as shown in Figure 3.3. The lines represents the pipes and the yellow and red shapes represents the hydrants. Each layer has attributes

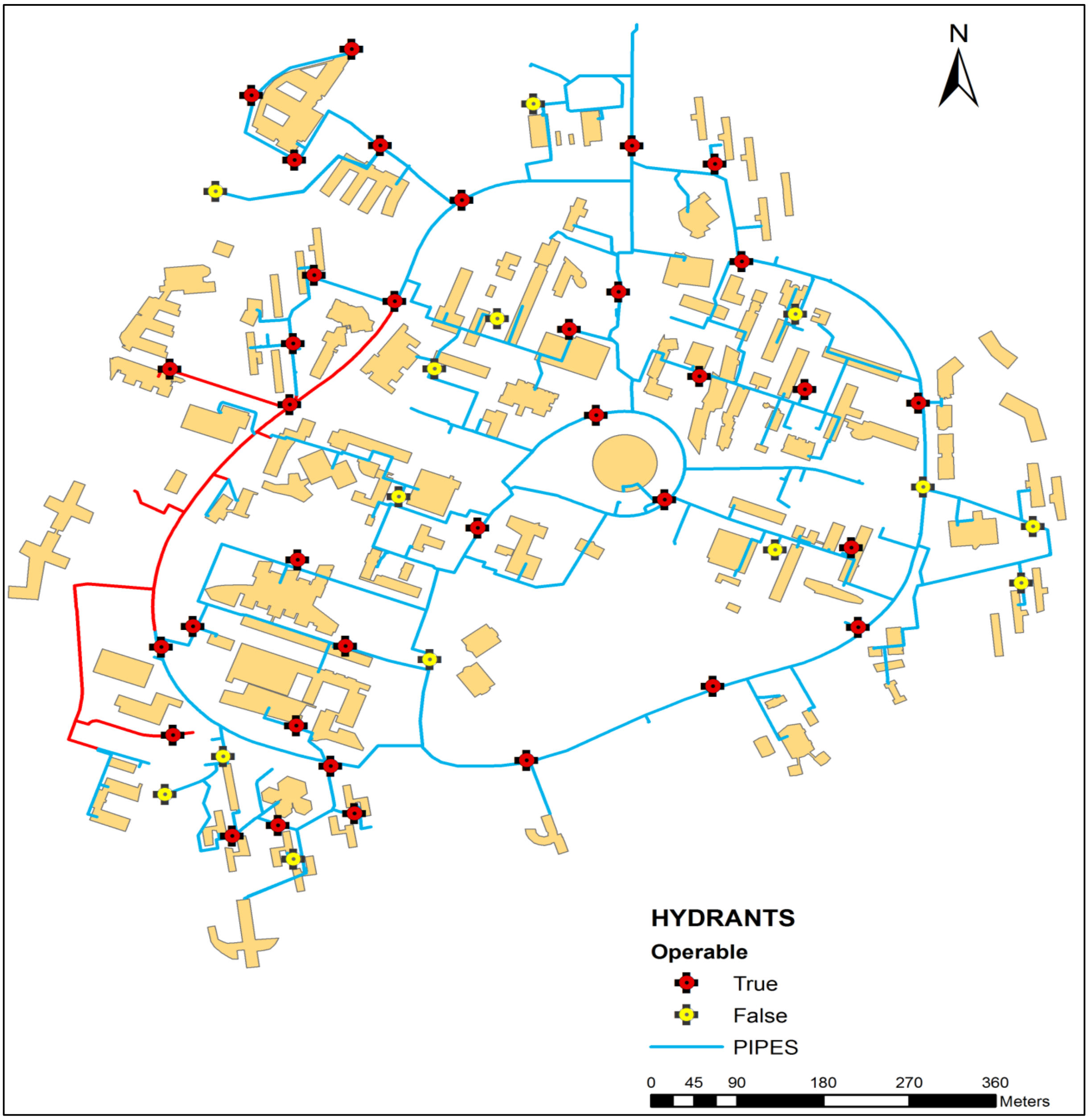



Figure 3.3: Pipes and hydrants distribution in the campus

about the water network such as pipe diameter, length, material, hydrant geo-location, hydrants building and status.

### 3.2.2.2 Smart monitoring

- **Automatic Meter Reader (AMRs)**

The water distribution network is monitored by 93 (AMRs) to measure the water consumption hourly allowing abnormal consumption detection related to leakage or abnormal use.

The water supply of the campus is determined from 13 general meters divided to two groups as following: (Figure 3.4)

- The first group is looped network, which includes 5 AMRs 4CANTONS, ECL, BACHLARD, M5 and the fifth one CITE SCIENTIFIQUE is composed of five AMRs (CITE_1, CITE_2, CITE_3, CITE_4, CITE_5).
- The second group is branched network, which comprises 4 AMRs CUEEP, LML (M6), DELETEC_ICARE and HALL_VALLIN.

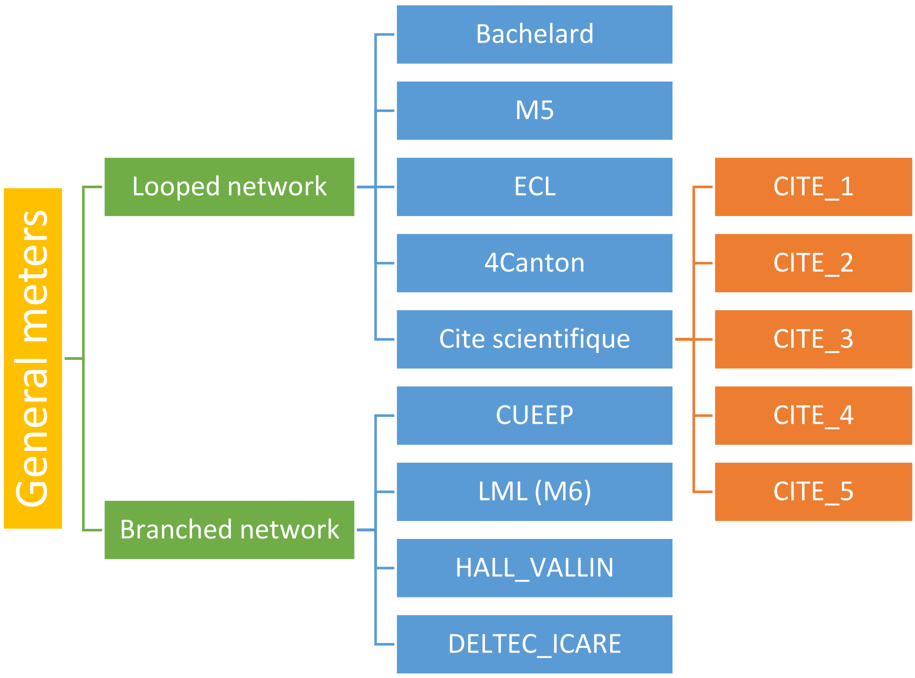



Figure 3.4: General meters

The consumption of the main buildings is measured by 80 AMRs (sub-meters) distributed as following:

- University of Lille1 (55).
- CROUS (Centre régional des œuvres universitaires et scolaires) (14).
- ECL (Ecole Centrale de Lille) (6).
- Reeflex (2).
- Bonduelle company and the Clinique (2)
- ENSCL (Ecole Nationale Supérieure de Chimie de Lille) (1).

The following Figure 3.5 shows the distribution of the general and sub-meters in the campus:



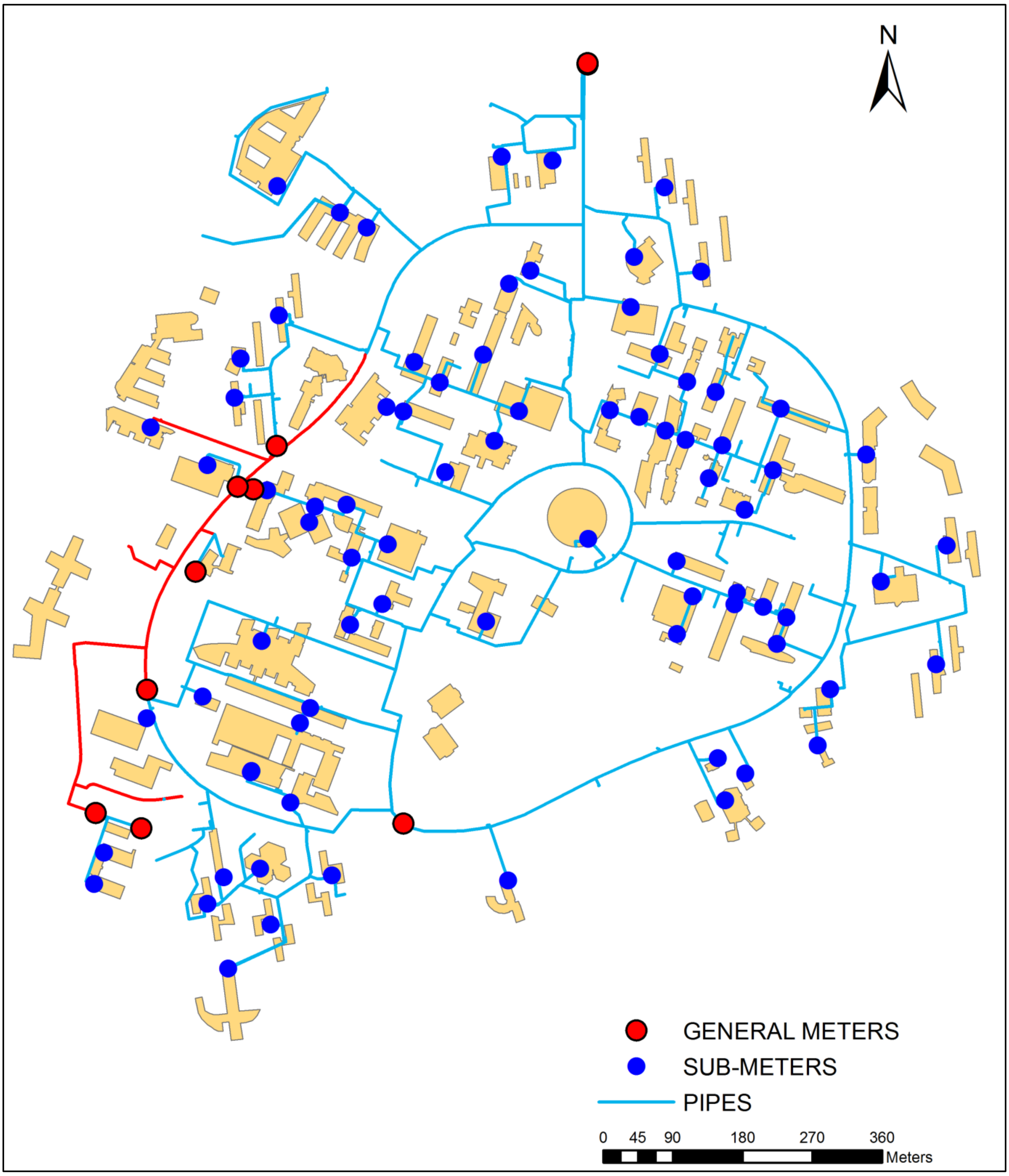



Figure 3.5: Distribution of the general and sub-meters in the campus

➢ **Pressure sensors**

A set of five pressure sensors are installed in the campus in the following buildings covering the major campus zones: (C1 chemistry, SN5 biology, and Polytech'Lille) Buildings, BACHELARD L residence, and BARROIS restaurant. Each sensor is connected to a data logger used to remote and store the pressure values measured each 15 minutes, the data loggers send their gathered data by SMS at certain periods of time, it can be defined manually by a user.



## 3.2.3 Heating network (AYARI 2014)

### 3.2.3.1 Physical description

The heating network was built in 1967. Originally, it was high pressure/temperature. Some renovation works were carried out in 2002 in the heating network, which was converted into low pressure/temperature. The other rehabilitation was carried out in 2011 when all mechanical meters were replaced by ultrasonic meters.

The heating network includes the pipes and the equipment needed to transport the fluid. In other words, it transfers the heat from the boiler room to the different buildings. The network heats the majority of campus buildings with the exception of a few buildings with individual heating (SN6, Halle Vallin, Halle Gremaux, F6, Masse and T10). It also provides domestic hot water. It is divided into primary and secondary networks and 57 substations.

The primary network is about 5 km long. It consists of two tubes (go & return). It has a branched architecture: it deploys from the production plant to the delivery point.

The secondary network is estimated to be approximately 3.7 km long. A large part of the secondary network was installed at the time of constructing the Campus in 1966. Part of the network is recent. It is related to the extension of the existing network to new campus buildings. These pipes have the same characteristics as those of the primary network.

Each network is presented as a layer in SunRise GIS as shown in Figure 3.6, the red lines represent the primary network and the purple lines represents the secondary network.

### 3.2.3.2 Smart monitoring (Substations)

A substation is used to transfer heat to buildings connected to the network through plate heat exchangers. It makes it possible to separate the secondary network from the primary one. It can heat a building or several buildings. For example, the IUT primary substation only heats the IUT building, while the P1 primary substation heats its building but also the "Espace culture" buildings, P5 and P5 Bis. These substations are connected to data loggers, which store and monitor pressure and temperature and send these data to a server, which is controlled by university’s technical staff.

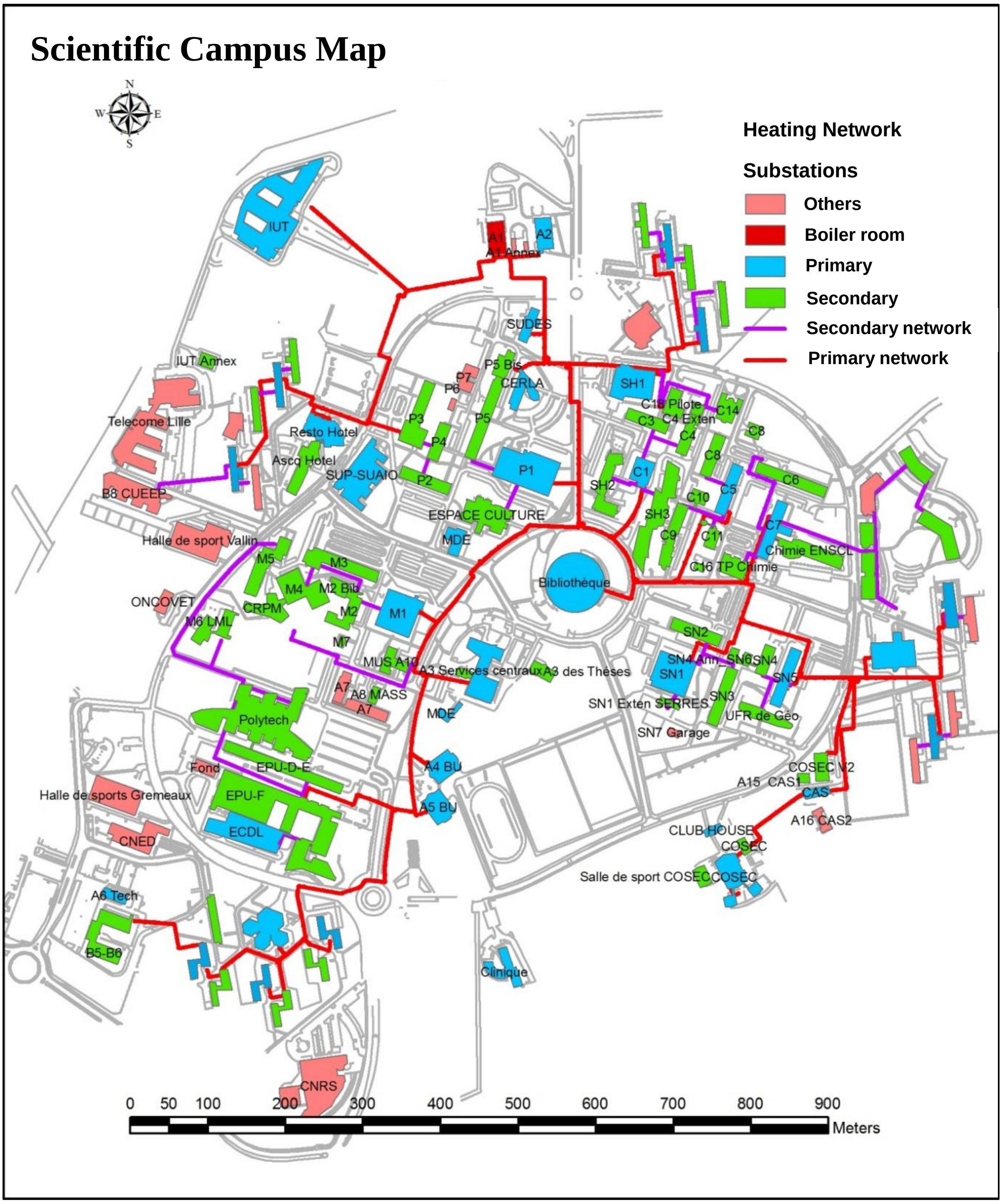



Figure 3.6: The heating network in the campus

Figure 3.6 shows the locations of the primary and secondary substations in SunRise GIS the blue polygons represents the primary substations and the green polygons represents the secondary network.



## 3.2.4 Electrical network (SAKR 2017)

### 3.2.4.1 Physical description

The electrical system ensures the distribution of the electricity for all the buildings and facilities of the campus. It is completely managed by the technical staff of the university. The architecture of the electrical system is composed of:

- A supply station
- Substations
- A Low Voltage grid (HV)
- A High Voltage grid (HV)
- Advanced Metering Infrastructure

The supply station of the campus is located in building A2, north of the campus; the French Electrical Company supplies it with 20 kV. The High Voltage Grid at 20 kV then transmits the electrical power to the remaining substations. The substations include transformers, which transform the high voltage power to low voltage power (220 or 440 V) to supply the buildings and the facilities through the Low Voltage Grid (LV).

The High Voltage Grid includes a main substation (building A2-supply station) and 19 other substations, which are installed in the following buildings:

- Administrative buildings: SUDES, SUAIO, A, COSEC
- Restaurants: Barrois, Pariselle, Sully
- Residence: Bachelard
- Academic buildings: M1, M6, P1, P5, C5, BU, SN3, Polytech, B5, IUT.

Each substation includes a high-voltage component and a low-voltage component, as well as the digital devices needed to execute the necessary tasks.

The Low Voltage network refers to the distribution network (secondary network) that supplies the buildings after the transformation of the electric power from High Voltage to Low Voltage takes place at the substations.

A separated layer in SunRise GIS represents each of these components. Figure 3.7 shows all layers together.



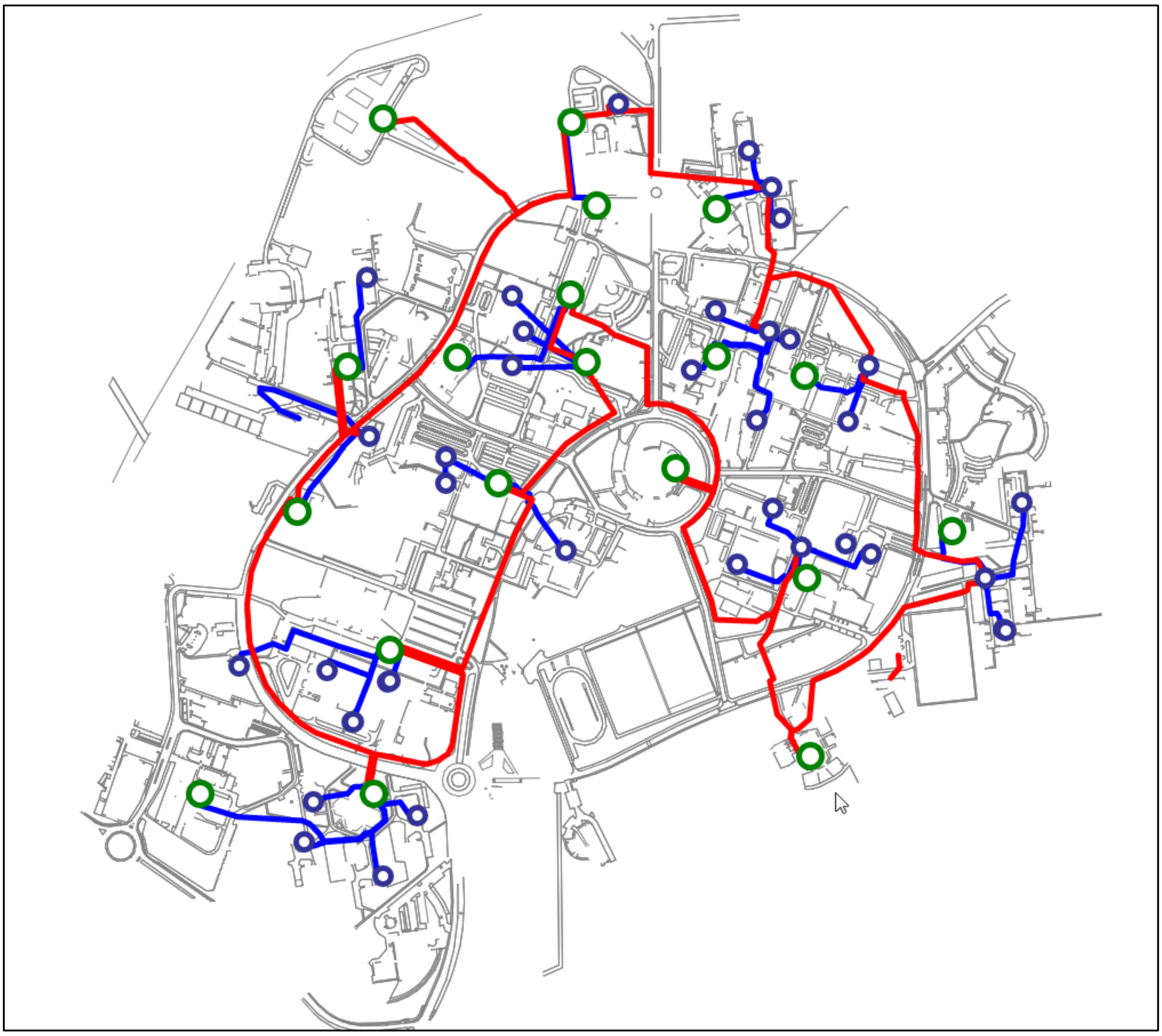


Figure 3.7: The electrical grid in the scientific campus

### 3.2.4.2 Smart monitoring

Figure 3.8 illustrates the entire electrical grid as well as the fiber optic communications network, which is responsible for data transmission. The two-way fiber optic communications network gives the central server access to the totality of the smart sensors and switches in the substations. The electronic switches can be automatically controlled (open/closed) by the server, as well as by the network manager (remotely/onsite), who can configure, monitor and manage the network remotely.

The fiber optic network is the basis for the two-way communication between the control system and the smart meters located in substations as well as in the buildings. The fiber optic network lines move in parallel with the High Voltage Network, passing through each of the H.V substation. Fiber-optic communication is what is used for communication between the H.V substations, distribution stations and the buildings (end users).

This allows the main server to communicate with all the buildings located on the campus. The fiber optic network is connected to the output of the smart meters (located in the low voltage distribution panel), which enables communication to and from serial devices over a wired, or wireless Ethernet network (serial to TCP/IP conversion). The smart meters monitor the electrical consumption, along with the following parameters, which are used for the supervision and the control of the electrical grid:

- Consumption
- Voltage
- Current
- Power (P, Q)
- Frequency

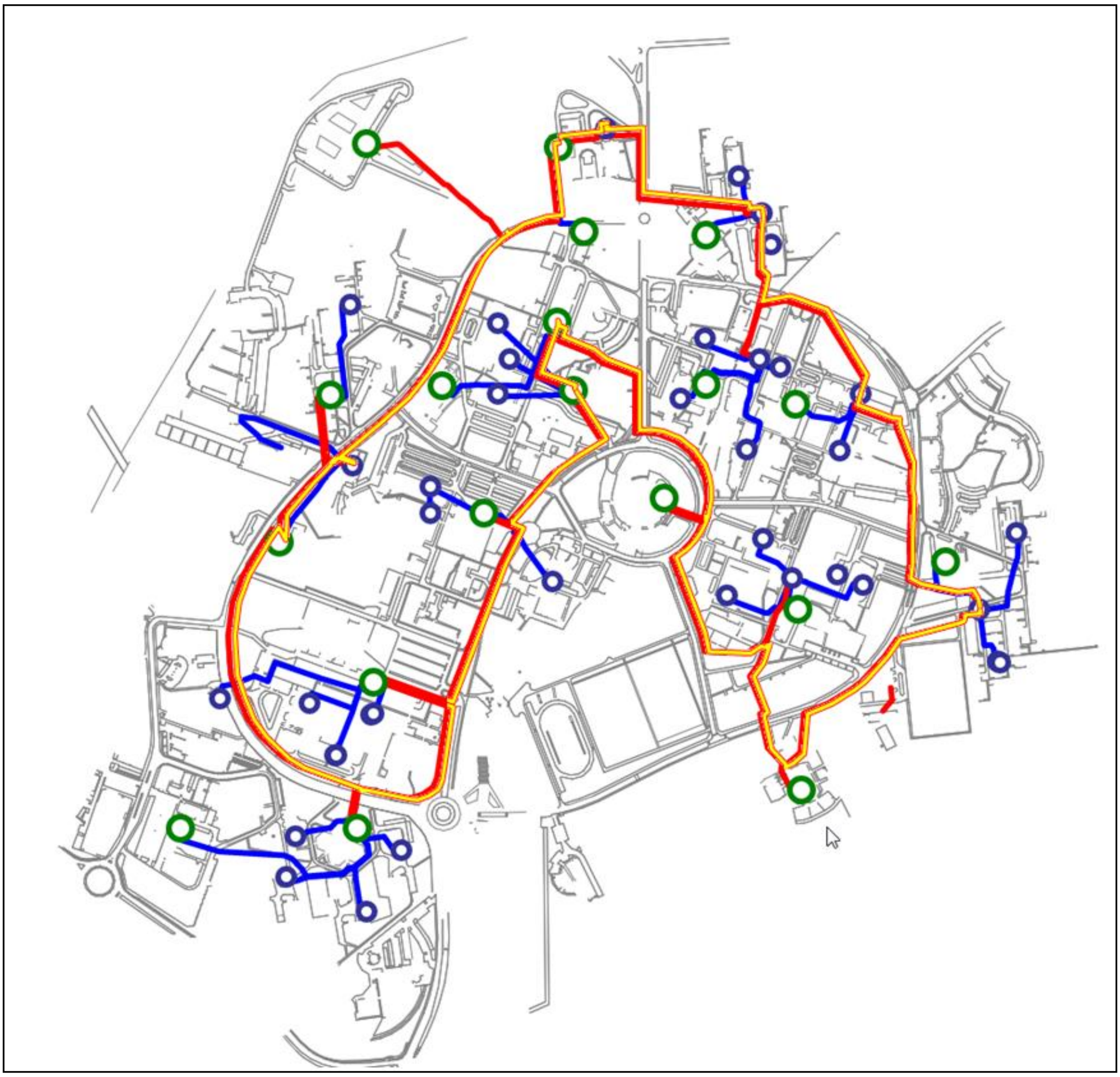


Figure 3.8: Fiber optic communication network (in yellow)

#### 3.2.4.3 Public lighting network

The public lighting network covers the whole area of the campus. It is presented as points in the GIS layer. Figure 3.9 shows this layer.




Figure 3.9: The public lighting network in the campus

### 3.2.5 Sewage network

Sewage network in the University Campus is conducted in two separated systems. Stormwater system, which collects rainwater runoff, while wastewater system collects sewages from buildings. Both of the collecting systems release their contents, after exiting the Campus area, in a combined network managed by Métropole Européenne de Lille (MEL).

### 3.2.5.1 Stormwater system (ABOU RJEILY 2016)

➢ **Physical description**

The stormwater system in this area is composed of 31 km of pipelines with diameters ranging from 150 to 1200 mm. The system consists of:

- A primary network, which is around 7 km in length and managed by Lille Metropolis.
- A secondary network, which is around 24 km in length and managed by University of Lille1.

Each network has been presented in a separate layer as lines in the Geographic information system of SunRise as shown in Figure 3.10:

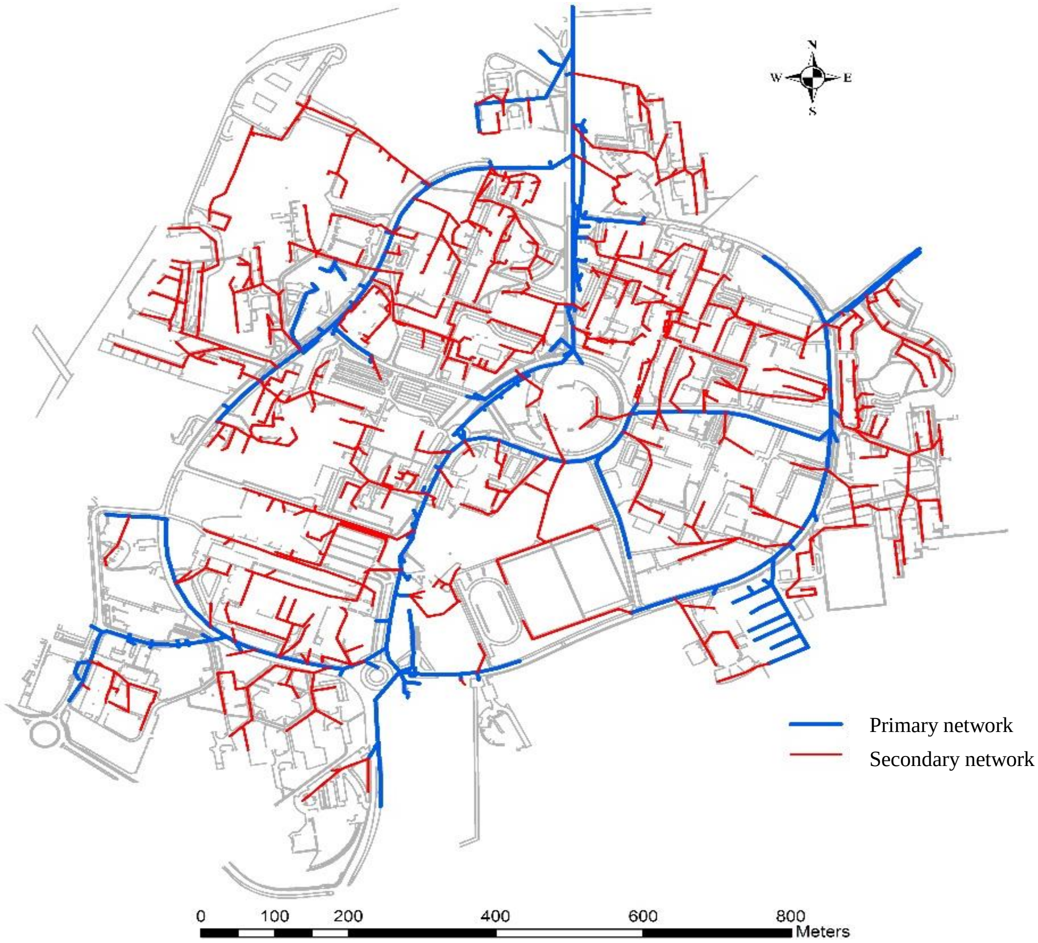



Figure 3.10: Stormwater network in the Campus of university Lille1

The campus is divided into two watersheds (Figure 3.11). The first is located in the north of the campus. It has a surface of 50 ha. The second one is located in the south of the campus. It has a surface of 80 ha.

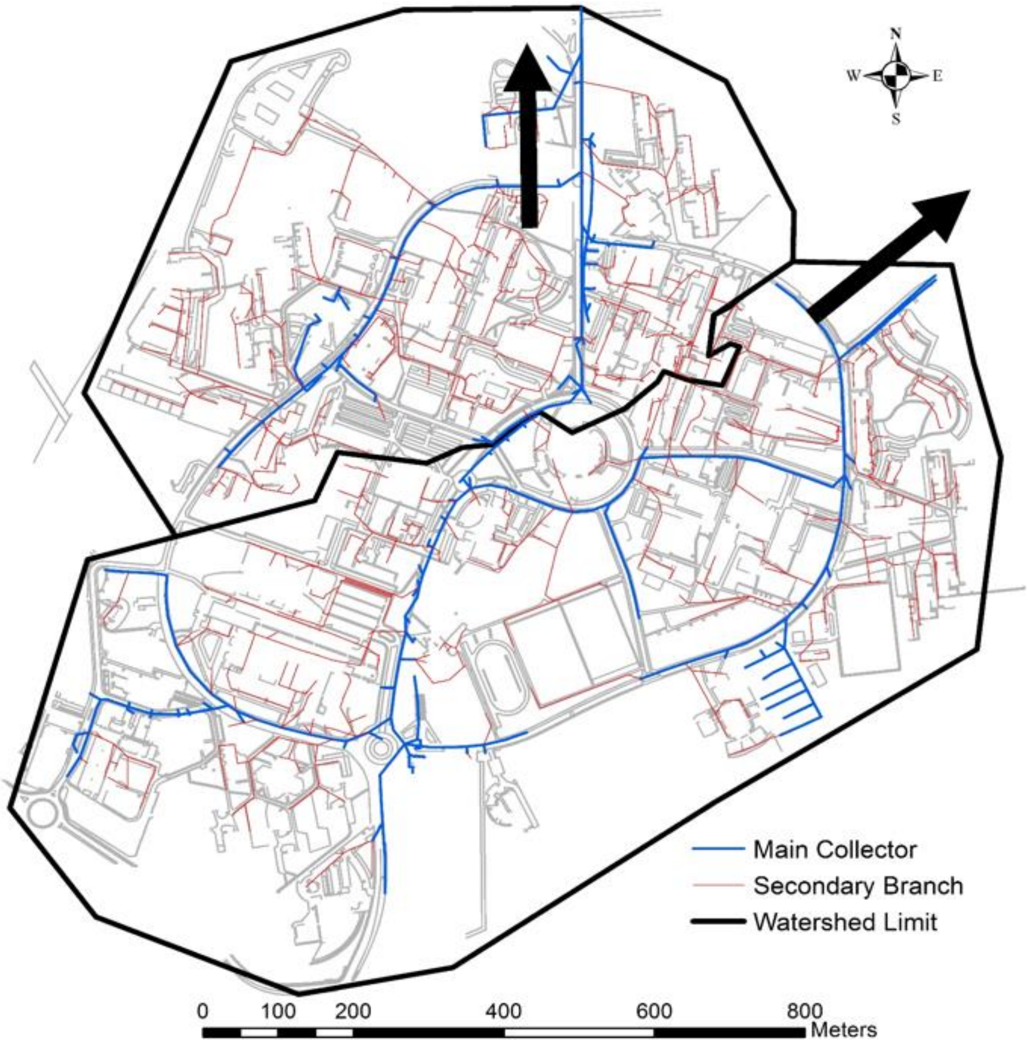



Figure 3.11: The stormwater system with watersheds limit

- **Smart monitoring**

In order to monitor the Stormwater system operation and evaluate its capacity different types of sensors are installed in a sector of the system, which has an area of 30 hectares and contains different types of surfaces and buildings.

The weather station located in Polytech'Lille building, it measures water parameters, as rain intensity, wind speed, temperature etc. In parallel, the system was equipped with inline sensors for system analysis and model calibration.

Two depth meters were installed in the network:

- The first was placed in the retention basin to measure the water-filling ratio during the rainfall events.
- The second depth meter was located at the outfall of the studied sector, and aims to measure the hydraulic downstream boundary condition.

In addition, two flow meters were implemented to monitor the system operation:



- The first was installed at the outfall, and measures the runoff generated from all the studied sector area,
- The second is located in the main collector downstream the retention basin, and is dedicated to measure runoff generated from a part of the studied sector.

A turbidity sensor was implemented inline the network, for measuring the pollution degree of the runoff during the rainfall events.

The monitoring system was scheduled to measure at a one-minute time step, and sends the measurements each one hour to a server, where collected data is stored, filtered and analyzed.

#### 3.2.5.2 Wastewater (Sanitation) system (ABBAS 2015)

➢ **Physical description**

The wastewater system in the campus in composed of two networks:

- A primary network, its length is about 4 km and Lille Metropolis manages it. This network transports the wastewater from the campus to the public sewage network.
- A secondary network, its length is about 12 km and the university manages it. This network transports the wastewater from the buildings of the campus to the primary network.

(Figure 3.12) shows the two networks in separated layers represented as lines in SunRise geographic information system.

➢ **Smart monitoring**

The same flowmeters and turbidity sensors, which are mentioned above were used in monitoring the Wastewater network.


Figure 3.12: Wastewater system in the Campus

## 3.3 Conclusion

In this chapter, we presented the SunRise project. The aim of this project is to build a large-scale demonstrator of a Smart city. We presented the Scientific Campus of the University of Lille1, which is used for implementing this project. We also presented briefly the building assets and the existing urban networks in the campus (drinking water, district heating, electrical grid and sewage). They have been presented as layers in the GIS-based Urban Information System, which has been constructed by the team of SunRise project.

In the following chapter, we are going to present a professional platform called PI system then present the methodology of implementing this platform in the SunRise project.



# Chapter 4

# Implementation of Professional Platforms on SunRise smart city



# Chapter 4 – Implementation of professional platforms in SunRise Smart City Demonstrator

This chapter describes the use of two professional platforms for the management of SunRise Smart City project: PI system and OpenDataSoft. After the presentation of each platform, we describe its implementation for the management of SunRise demonstrator. The conclusion discusses lessons learned from these installations and figure out the requirements for the development of a dedicated platform.

## 4.1 Introduction

The management of the smart city requires the development or the use of platforms, which conduct all the operations related to the management of the Smart City such as data collection, data storage, data security, data analysis, urban systems regulation, data visualization and interaction with stakeholders. The development of these platforms require an important effort and multidisciplinary skills. This chapter presents the use of two professional platforms (PI System and OpenDataSoft) for the management of SunRise demonstrator. The objective is to study the implementation of these platforms and to explore their capacity for the management of a large-scale demonstrator of the Smart City. Lessons learned from this use will help us to figure put the requirements for the development of a platform for SunRise demonstrator.

## 4.2 Use of PI System

The PI system is an appellation for a software tool developed by an American company (OSIsoft, LLC) founded in 1980. It is a highly scalable open data infrastructure to connect sensor-based data, operations, and users. It consists of groups of programs, which can be operated together or separately. PI system is used in business infrastructure for data collection, historicizing, finding, analyzing, delivering, visualizing and event management in real time from various data sources.

PI system can be divided to three main blocks; (i) data source block, it uses PI Interfaces and Connections to represent the physical interconnection of data sources with the control system. (ii) server block (PI server), it receives these data and provide storing, managing, analyzing, and distributing of received data. (iii) client block, it contains PI visualization tools used by clients to visualize the analyzed data ("OSIsoft").

The PI System is used for data collection, historicizing, finding, analyzing, delivering, and visualizing. It comprises of three major parts (Figure 4.1) PI Interfaces & Connectors, PI server and PI Visualization.

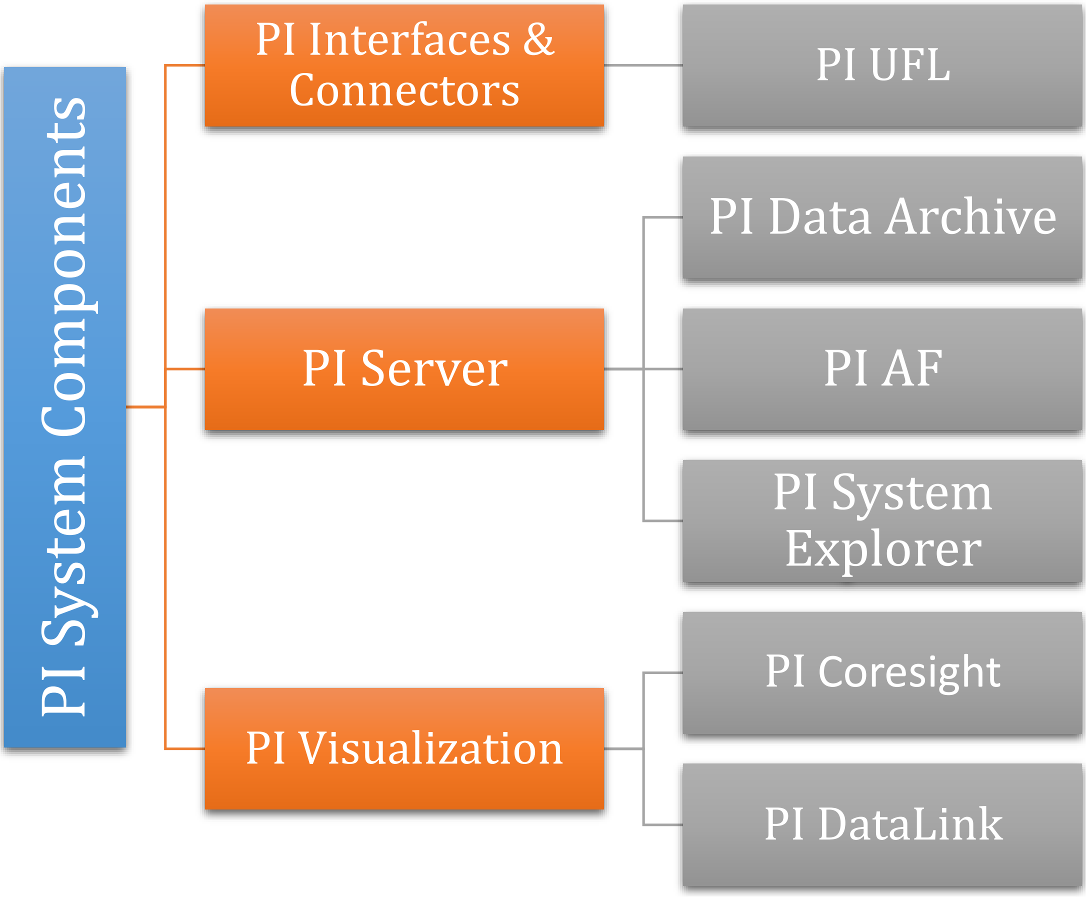



Figure 3.1: PI System components

### 4.2.1 PI Interfaces & Connectors

PI Interfaces collect data from external data sources, providing real-time, fault-tolerant data to the PI System. More than 400 standard PI Interfaces provide connectivity to most distributed control systems, SCADA, PLC, lab, and other business information systems.

PI Connectors simplify the process of adding new data to the PI System by scanning data sources and discovering data items. Data streams are then auto-configured on the PI Server.

The most important interface, which is used in this research, is PI Interface for Universal File and Stream Loading (UFL).

#### 4.2.1.1 PI Interface for Universal File and Stream Loading (UFL)

The PI Interface for Universal File and Stream Loading (PI UFL) reads data from ASCII data sources and writes data to PI Data Archive. The interface parses and transforms the incoming data, and updates PI points, which is a unique storage point for data in the PI Server. Sometimes it called "tag".



### 4.2.2 PI Server

PI Server is the core of the PI System, it operates the real-time data storage and distribution engine that powers the PI System and provides a comprehensive real-time and historical view into all operations, it has the following functions:

- Receives data from disparate sources and consolidates it into a single system.
- Transforms raw data into actionable information and makes it accessible to users at all levels.
- Stores and secures data.
- Proactively monitors data to deliver real-time alerts when critical events occur.

The PI Server uses two components, the Data Archive and Asset Framework (AF) to collect, consolidate, organize, and contextualize the sensor-based data. In addition, it uses two more components: Event Frames and Notifications to deliver real-time alerts when critical events occur.

#### 4.2.2.1 PI Data Archive

The PI Data Archive is a component of the PI Server that provides efficient storage and archiving of time series data. It is the cornerstone of the PI System and all data infrastructure, enabling high-performance data storage and retrieval by client software. Users can perform many tasks with their time series data, including, monitoring their processes, data analytics, process optimization, and so on.

#### 4.2.2.2 PI Asset Framework (AF)

PI Asset Framework (PI AF) is a single repository for asset-centric models, hierarchies, objects, and equipment (hereafter referred to as elements). It integrates, contextualizes, refines, references, and further analyzes data from multiple sources, including one or more PI Data Archives and non-PI sources such as external relational databases. Together, these metadata and time series data provide a detailed description of equipment or assets.

PI AF can expose this rich data to PI System components, such as PI DataLink, where it can be used to build displays, run calculations, deliver important information, and more. PI AF also includes a number of basic and advanced search capabilities to help users sift through static and real time information.

PI Asset Framework hierarchies and models consist of elements grouped by specific relationships (parent-child, connectivity). An element is an asset-centric object that can expose a number of attributes or properties such as:

- Name plate information
- Flow rate
- Temperature
- Density
- Calculations
- PI points
- Data stored in external tables



Furthermore, each attribute can be assigned a specific unit of measure. PI Asset Framework can then automatically convert values between units of measure. The product ships preloaded with numerous standard unit-of-measure classes and conversion factors based on the International System of Units (SI). It also supports user defined classes and units of measure.

PI Asset Framework contains asset analytics, which is used to configure, schedule, and run calculations written using PI Performance Equation (PE) syntax acting on existing PI Asset Framework (PI AF) attributes. PE expressions, rollup calculations, and the generation of PI Event Frames based on trigger conditions are all supported analysis types.

PI Asset Framework also includes features to simplify building elements including:

- Support for templates
- Object-level security via Identities similar to the PI Data Archive.
- Support export to and/or import from XML files
- A sandbox area where an individual can work on changes without impacting other users

#### 4.2.2.3 PI System Explorer PSE

PI System Explorer provides a graphical user interface for creating, editing, and managing PI AF objects including PI AF databases, elements, and templates. It is the configuration and management tool for Notifications and Event Frames as well.

### 4.2.3 PI Visualization

PI visualization tools allows data presentation on multiple formats and different devices. Two tools were used in this research.

#### 4.2.3.1 PI Coresight

PI Coresight is an intuitive web-client visualization tool that delivers fast, easy and secure access to all PI System data. It can easily perform ad hoc analysis, discover answers, and share insights with others. It allows: (i) to search and display time-series or other PI data, (ii) to create a process visualization with a possibility to record the data for further analysis, (iii) to share screen with other authorized users.

#### 4.2.3.2 PI DataLink

PI DataLink is a Microsoft Excel add-in that enables to retrieve information from PI System directly into a spreadsheet. It can:

- Retrieve PI point and AF attribute values.
- Retrieve system metadata to create a structured view of PI data.
- Reference items using PI DataLink functions to calculate and filter data.
- Keep values updated when the spreadsheet recalculates.
- Retrieve PI Event Frames.



- Retrieve PI Notifications.

PI DataLink provides a graphical interface to retrieve data and build functions and calculations. Its functions are embedded in spreadsheet cells and can provide active updates of real-time data from the PI Server.

## 4.3 Implementation of PI System in SunRise

The implementation of this platform passes through multiple stages:

- Data collection.
- Data connection to PI UFL to uniform its format.
- Data storage in PI Data Archive as “tags” or PI Points.
- Data structure creation in PI Asset Framework.
- Analyses creation.
- Results visualization.

### 4.3.1 Data collection

As we presented in the last chapter, the campus contains several urban networks such as water, heating, electric, waste water, and storm water networks. The following sub-sections present a brief overview of the data collection of these networks.

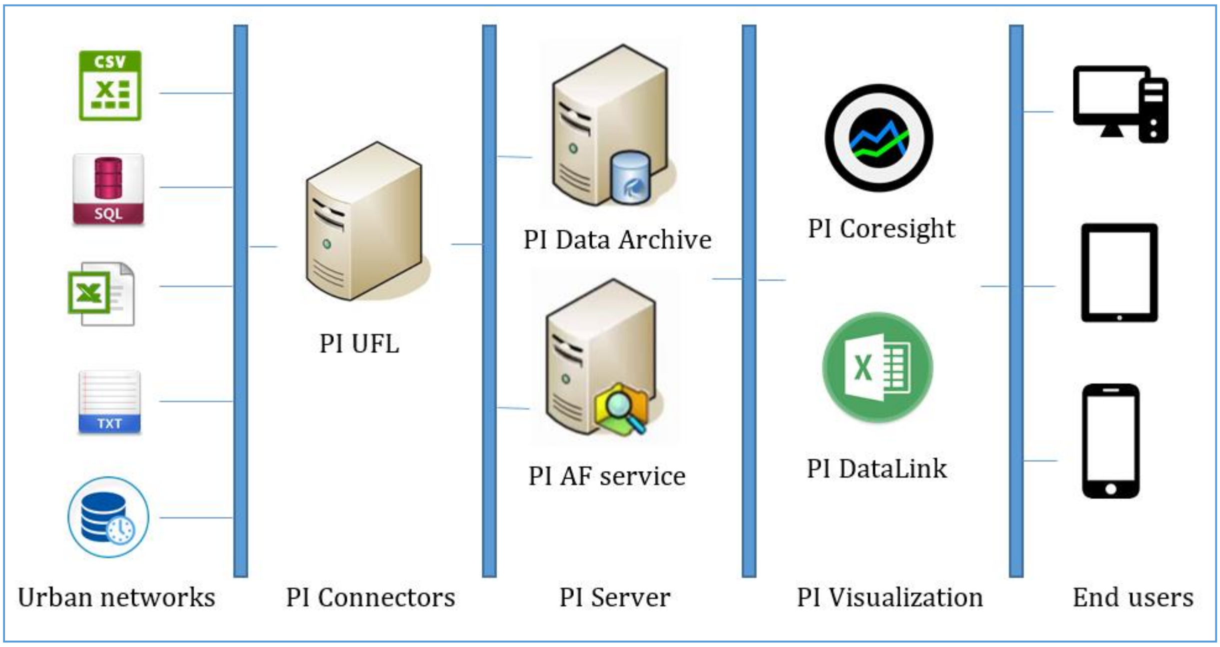



Figure 4.2: PI System implementation steps

#### 4.3.1.1 Water network

The water distribution network contains 93 Automatic Meters Readers (AMRs) to measure the water consumption hourly. They allow detecting abnormal consumption related to leakage or abnormal use.



The 93 AMRs are integrated in the GIS model by their IDs, coordinates, meter number and associate sensor serial number and the building reference.

The water supply of the campus is determined from 13 general meters whereas the consumption of the main buildings is measured by 80 AMRs.

The Automatic Meter Reading (AMR) technology is used for the remote reading of water consumption. This technology consists of collecting automatically consumption data and their transfer to a central server. The AMR system consists of low-power radio transmitters. Each water meter has an impulse sensor and a VHF radio transmitter. The index of the water consumption is read by the impulse sensor, which converts it to an electronic index. The impulse counter is connected to a microcontroller unit to store the cumulative readings for transmission. The readings are then transmitted via a radio frequency (169 MHz) to the collectors "receivers" or the base stations. The radio receivers are installed on four buildings: M1, P5, C7 and Residence Camus. These receivers gather all the indexes transmitted within a maximum range of 300 meters in urban area. The base stations send data via the mobile network to a central information system with 4 signals per day of 1/10th of a second. The telemetry principle of the AMRs is described in Figure 4.3.


Figure 4.3: Telemetry system

A small script has been written to download and aggregate easily the water consumption at different time scales from the central information system of the sensors owners. The data transmitted via the communication channels are stored in a csv files.

The same methodology has been used for the heating network.

#### 4.3.1.2 Electrical network

Electrical meters are installed in the substations and buildings. These meters record parameters related to the electrical grid such as electrical consumption, voltage, voltage, frequency and temperature. The frequency of which the data is recorded is by 10-minute intervals. Recorded data are transmitted to a central server using the fiber-optic capabilities of the electrical grid. Since this part is very sensitive, and it controls the electrical supply of the campus buildings, infrastructures and research devices, SunRise team did not work on the server. Data recorded in the electrical grid server are exported as SQL tables.

#### 4.3.1.3 Stormwater network

The stormwater network contains different types of sensors weather station, two water level meters, two flow meters and a turbidity sensor.

The weather station automatically collects and transfers detailed meteorological data. Measurements are transmitted to a display/receiver console with a distance up to 300m through a powerful 900MHz RF link.

The water level meter, which is installed in the retention tank, has a measuring range from 0.2 to 3m of water level. Collected data from this sensor is transferred manually to a PC through the Avelour software connected to a connection Kit.

The second depth meter measures the water level up to 6m. In addition, this sensor was equipped by a GSM/GPRS transmission potential in order to transmit data to the Ijitrack website. Ijinus is a manufacturer of instrumentation, process control and metrology for wireless remote management and monitoring.

The first flow meter data transmission made through the logger/transmitter “IjiLog”, which records data up to 15 devices in his radion Ijinus field and deliver them via GSM/GPRS to the Ijitrack website.

The second flow meter a transmitter “IjiLog” was installed next to it for transmitting data by a GSM/GPRS system to the Ijitrack website.

Turbidity Meter data transmission was accomplished through a transmitter installed next to the logger of this sensor.

Data retrieval is done manually through a connection kit and through the Ijitrack website; this data is saved in Microsoft Excel files.

#### 4.3.1.4 Wastewater network

This same network uses a monitoring system similar to that used in the Stormwater network.

The PI Connectors provides the ability to connect directly with data source such as sensors, control units, PLC, etc. But it has not been used in this research for privacy reasons.

### 4.3.2 Data connection and storage

As we have seen in the previous section, data collected from urban networks in the campus are saved in different formats. In order to store this data in one structure, a format unifying is needed. This step is done using PI interface Configuration Utility (PI ICU), which is an application that aids in PI System management by consolidating the setup and configuration options required for new and existing PI interfaces. It allows users to:

- Configure all interface parameters.
- Manage, Start, Stop an interface service, and Start/Stop an interface interactively.
- Manage multiple PI Interfaces.



For each data format, an UFL configuration file with the extension of (.ini) has been created. The configuration file is composed of sections that define how data is split into fields, processed, and written to PI tags. The configuration file is composed of the following sections:

**[INTERFACE] section:**

Specifies the plug-in to be used to process the data, according to the type of data (text file, serial port or POP3 server), the PI UFL interface provides a plug-in in the form of a *.dll* file (ASCIIFiles.dll, Serial.dll, and POP3.dll). Each plug-in has a logic for processing, for this research just text file (ASCIIFiles.dll) has been used.

**[PLUG-IN] section:**

This section contains plug-in-specific settings. The following table describes the settings.

Table 4.1: PLUG-IN section

| Setting | Description |
|---|---|
| **IFM** | Required: The path to specify the location of input files to be processed. |
| **IFS** | Specifies the order in which input files are processed. Valid arguments are C: Creation date, M: Modification date, n: File name. |
| **REN** | Specifies the extension to be assigned to successfully process input files. |
| **RBP** | Optional: Rename Before Process: to insure that the file is processed only once if multiple instances of the interface are processing the same directory |
| **ERR** | File extension to be assigned to files that caused errors during processing. |
| **PURGETIME** | Specify the amount of time to wait before purging processed data files |
| **PFN** | Prepend File Name. To include the filename as the first line in the input stream |
| **PFN_PREFIX** | Precedes the filename with specified text. |
| **NEWLINE** | Specifies line-end character(s). |



**[SETTING] section:**

This section specifies various operational settings

Table 4.2: SETTING section

| Setting | Description |
|---|---|
| **DEB** | Debug level. The interface maintains its own log file, where it redirects all kinds of information messages. The higher the debug level the more detailed is the printout |
| **LOCALE** | Specifies how the interface transforms the string representation of numbers to the native numeric form. |
| **MSXLOGSIZE** | Maximum size of log files, in MB. When a log file reaches the specified size, the interface creates a new log file. |
| **MAXLOG** | Maximum number of log files |
| **MSGINERROR** | Specify the path and filename for the log file containing lines that were not successfully processed |
| **OUTPUT** | Specify the path and file name for the interface log file, which contains debugging output. |

**[FIELD] section:**

The statements in this section assign a name and data type to fields; it is mandatory and must follow the [INTERFACE], [PLUG-IN], and [SETTING] sections. In this section the names of PI points 'tags' are defined; in the following section we will assign the value of each tag. Tags name must be unique and can be in different types DateTime, Time, String, Int32 and Number.

**[MSG] section:**

The PI UFL interface filters incoming data to catch messages, which are assigned names. For each message name, the same name is used to define a section that parses and processes the message. This section is responsible of creating and assigning values to the defined tags in (FIELD) section.

Each sensor provide a set of measurements; each measurement is assigned to a tag name depending on defined messages, then created tags are sent and stored in PI Data Archive using *StoreInPIPoints()* function. Figure 4.4 shows an example of PI UFL file which has been created for the Stormwater network.

```
[INTERFACE]
PLUG-IN=AsciiFiles.dll
[PLUG-IN]
IFM=C:\Program Files\PIPC\Interfaces\PI_UFL\Data_depth\*.csv
IFS=N
REN=_OK
ERR=BAD
PURGETIME=1d
PFN=True
NEWLINE=13,10
[SETTING]
DEB=0
MAXLOG=10
MAXLOGSIZE=20
MSGINERROR=C:\Program Files\PIPC\Interfaces\PI_UFL\Logs\err-yevs.log
OUTPUT=C:\Program Files\PIPC\Interfaces\PI_UFL\Logs\out-yevs.log
LOCALE=en-us
[FIELD]
FIELD(1).NAME="Tagname"
FIELD(1).TYPE="String"
FIELD(2).NAME="TimeStamp"
FIELD(2).TYPE="DateTime"
FIELD(2).FORMAT="dd/MM/yyyy hh:mm"
FIELD(3).NAME="Value"
FIELD(3).TYPE="Int32"
FIELD(4).NAME="Tagname1"
FIELD(4).TYPE="String"
[MSG]
MSG(1).NAME="Header"
MSG(2).NAME="Skipline"
MSG(3).NAME="Data"
[Header]
Header.FILTER=C1=="S"
Tagname=C1 - C20
[Skipline]
Skipline.FILTER=C1=="D*"
[Data]
Data.FILTER=C1=="*/*"
TimeStamp=["(*);*"]
Value=["*;(*)"]
Tagname1="Sunrise "+Tagname
StoreInPI(Tagname1, ,TimeStamp,Value, , )
```

Figure 4.4: Example of an UFL file

### 4.3.3 Data structure creation

After all tags have been created and stored in PI Data Archive. A data structure has been created using PI System Explorer (PSE) as follows.

The structure is built in multiple levels, there is no standard structure to follow it. The levels of this structure are built according to needs of this research. Some networks were organized by categories. For example, the drinking water network has five levels, while the heating network has just two levels.



The first level represents the urban networks. Each urban network is represented as a parent element Figure 4.5. Other levels contain parent elements as well, which represent the network sections, parts or categories and so on until the last level. It contains child elements, which represent the sensors of the network as shown in Figure 4.6. The drinking water network contains pressure, and water quality sensors. The water sensors are divided into general and sub-meters, then sub-meters are divided into multiple sections, etc.

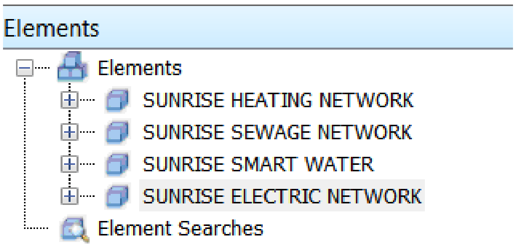



Figure 4.5: Elements that represents all networks

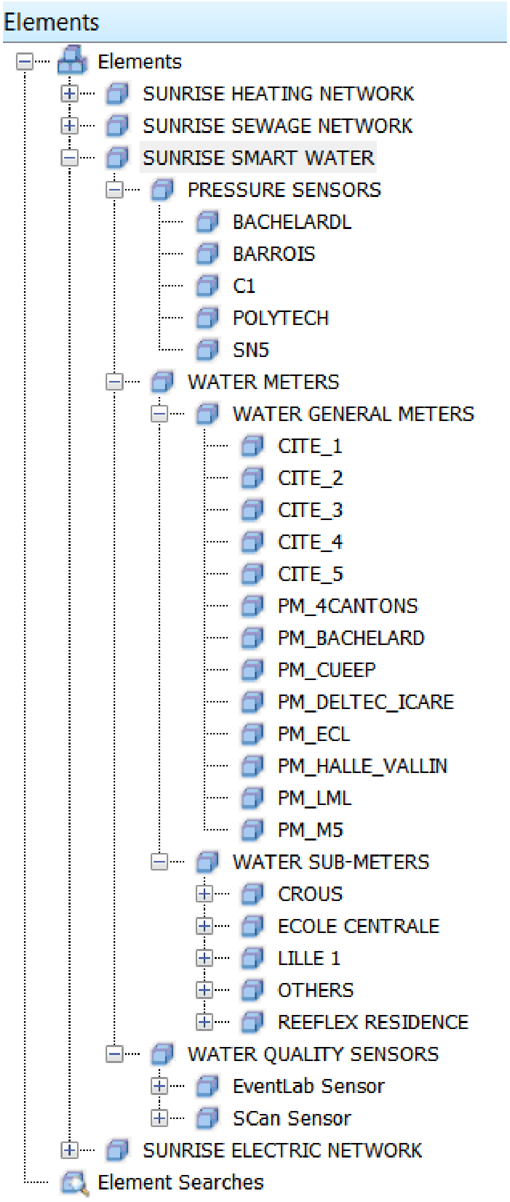



Figure 4.6: Structure of drinking water network

For each element in the structure, a unique name, description, attributes and analysis were added. These attributes vary between static data such as geo-location, serial number, and type, or dynamic data such as consumption, temperature and pressure Figure 4.7.

For each attribute a name, description, category, type, unit of measure, default value, and Data Reference have been added. The Data Reference defines from where to get the data for the attribute Figure 4.8. The Data Reference has different types such as:



- **PI Point:** Refers to a measurement from the PI Data Archive. This measurement can be a direct value from the data source or the result of some analysis, which will be explained in the next subsection.
- **Table lookup:** Refers to a static value from a table created in AF or imported from a data source outside the PI system such as a SQL table or an Excel sheet.
- **Formula:** Enables to perform custom calculations.
- **String Builder:** Enables to apply string manipulation.

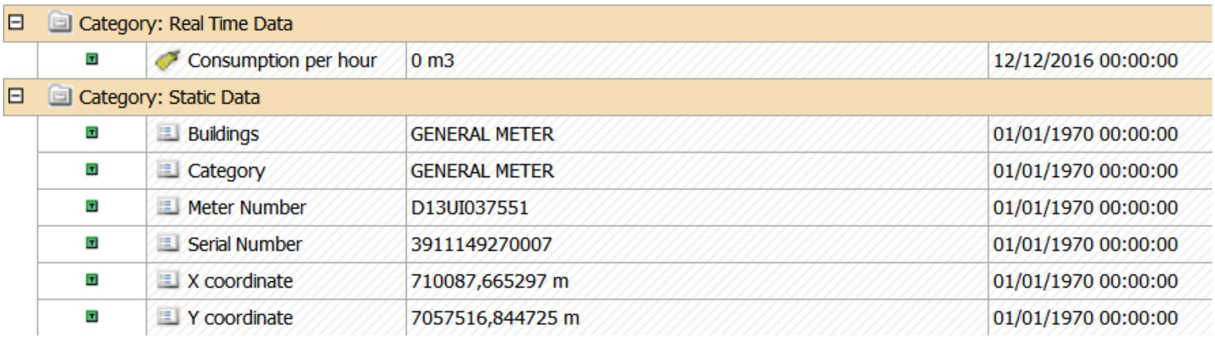


Figure 4.7: Example of an element attributes

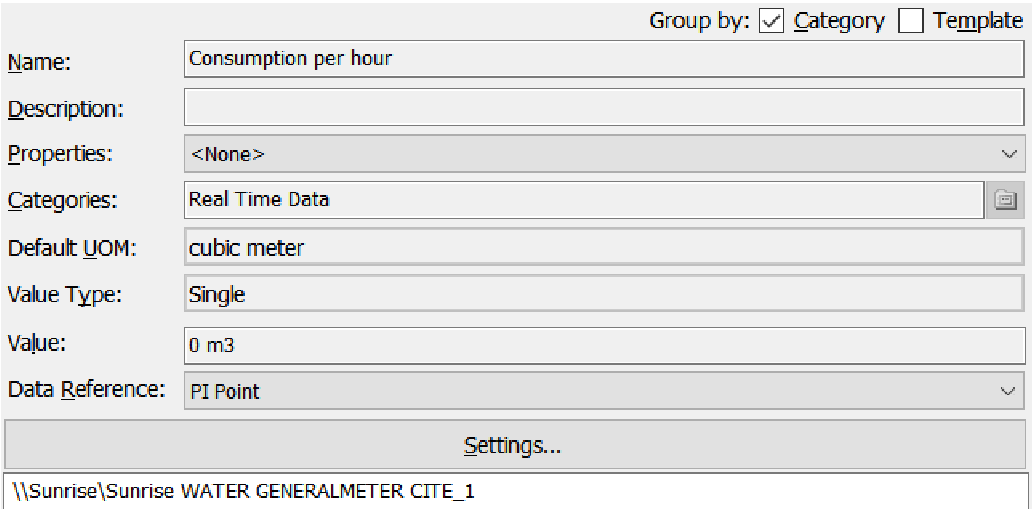


Figure 4.8 : An attribute settings

To facilitate building the other elements, some elements were converted to templates. They were used for similar elements, which have the same characteristics and attributes. All templates are saved in the library section in PSE (Figure 4.9). In the same section, many tables were defined, to save the static data about sensors from different networks. The content of these tables were imported from outside the PI system such as Excel files, XML and SQL tables, or it can be filled manually.



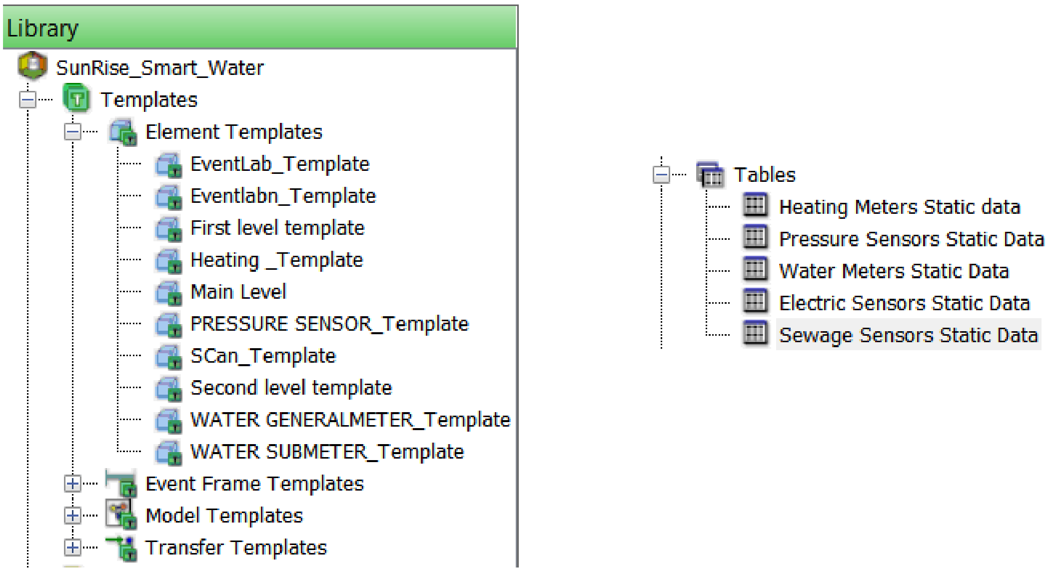



Figure 4.9 : Created templates and tables

A water meters table is shown in (Table 4.3).

Table 4.3: Water meters static data table

| ID | X (m) | Y (m) | SERIAL_NUMBER | METER_NUMBER | BUILDINGS | CATEGORY |
|---|---|---|---|---|---|---|
| WATER SUBMETER A_B | 710551,31124 | 7056894,59088 | SREA0000699 | D09UG206021 | GALOIS A; GALOIS B | STUDENTS_RESIDENCE |
| WATER SUBMETER A1 | 709976,796364 | 7057396,185855 | SREA0000654 | 08FE032426 | A1; A1 Annex | SERVICE |
| WATER SUBMETER A10 | 709822,528439 | 7056818,962722 | SREA0000652 | D08AB004962 | MUS A10 | SERVICE |
| WATER SUBMETER A16 | 710384,672269 | 7056636,375734 | SREA0000658 | D08LA571132 | A16 CAS2 | SERVICE |
| WATER SUBMETER A2 | 710042,335712 | 7057391,420152 | SREA0000655 | 02PE048699 | A2; A2 Annex | SERVICE |
| WATER SUBMETER A3 | 709956,773384 | 7056796,368779 | SREA0000689 | 08UD367193 | A3 Services centraux; A3 Ann; A3 des Théses | ADMINSTRATION |
| WATER SUBMETER A7_PCET | 709781,020849 | 7056792,155425 | SREA0000653 | D07LA038971 | A7 | SERVICE |
| WATER SUBMETER B5 | 709463,529327 | 7056498,017715 | SREA0000663 | D08AE037546 | B5-B6 | INSTITUTE |
| WATER SUBMETER B6 | 709450,504501 | 7056457,635106 | SREA0000664 | D08AE037546 | B5-B6 | INSTITUTE |
| WATER SUBMETER B8_CUEEP | 709523,427922 | 7057047,012889 | SREA0000688 | 08AE041550 | B8 CUEEP | INSTITUTE |
| WATER SUBMETER BARROIS | 710147,704617 | 7057267,104172 | SREA0000702 | D09AE190909 | RU BARROIS | CATERING |
| WATER SUBMETER BONDUELLE | 709623,531304 | 7056348,313952 | SREA0000709 | D09AB009854 | Bonduelle | COMPANY |
| WATER SUBMETER BU | 710088,529109 | 7056903,130876 | SREA0000657 | 08FE017686 | Bibliothèque | LIBRARY |

## 4.3.4 Analysis creation

The analysis tool reads values of PI AF attributes, performs calculations and writes results to other attributes. For the very low level of elements, Expression analyses have been created such as consumption statistics. Inputs and calculations are specified as expressions. Each expression entered in a row (Figure 4.10). This figure shows some expression analyses, which have been applied on a drinking water sensor (building L in



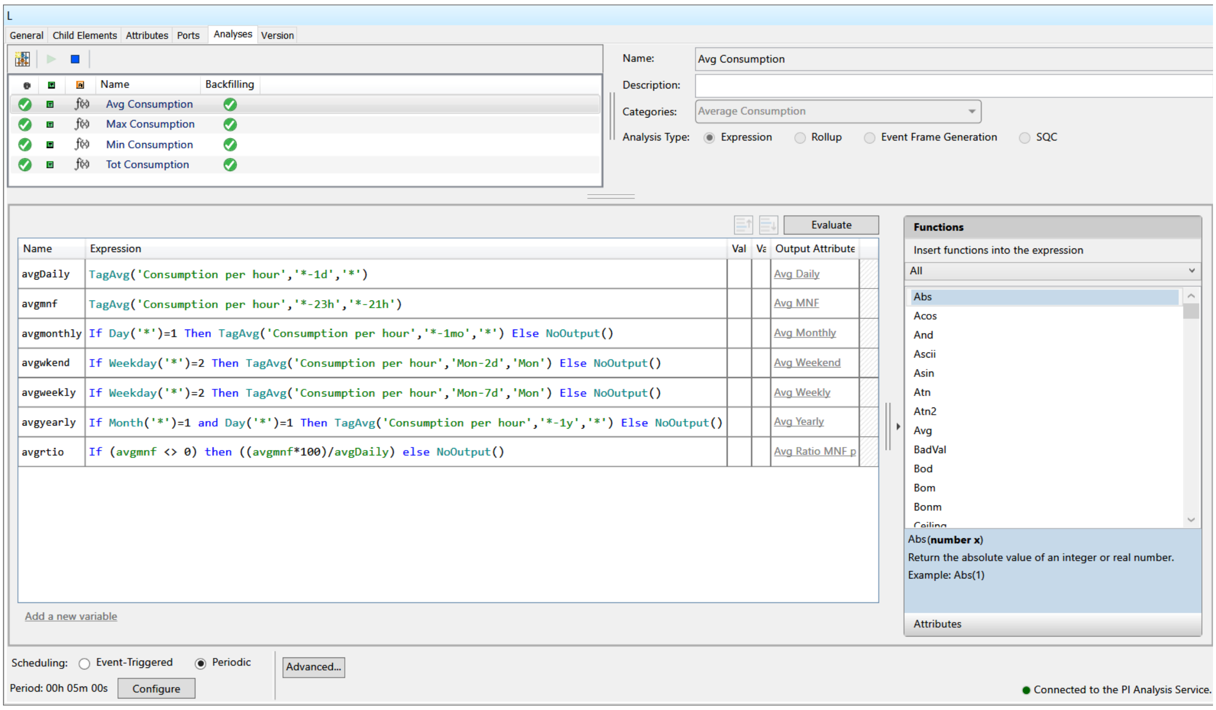


Figure 4.10 : Examples of expression analyses

the university residences). These expressions calculate the average values for the water consumption daily, from 2AM to 4AM, weekly, during weekends and yearly. Each row has many columns such as expression name, the expression, the output attribute, which is saved then in the PI Data archive Figure 4.11. Build-in functions are provided in this tool, some of them have been used to build the expressions:

- TagAvg: Find the average of values for an attribute during a specific time range.
- TagMax: Find the maximum of values for an attribute during a specific time range.
- TagMin: Find the minimum of values for an attribute during a specific time range.
- TagTot: Find the total of values for an attribute during a specific time range.
- Month: extract the month from a time expression.
- Day: Extract the day of the month from a time expression.
- Weekday: Extract the day of the week from a timestamp.

All expressions are configured to run every day at 00:00. Expressions can be configured to run when an event occurs as well.



The results of these expression analyses are saved in the PI Data Archive, the output attributes are presented in Table 4.4.

Filter

| Name | Default Value | Unit Of Measure | Data Reference |
|---|---|---|---|
| Category: Average Consumption | | | |
| Avg Daily | 0 m3 | cubic meter | PI Point |
| Avg MNF | 0 m3 | cubic meter | PI Point |
| Avg Monthly | 0 m3 | cubic meter | PI Point |
| Avg Ratio MNF per day | 0 % | percent | PI Point |
| Avg Weekend | 0 m3 | cubic meter | PI Point |
| Avg Weekly | 0 m3 | cubic meter | PI Point |
| Avg Yearly | 0 m3 | cubic meter | PI Point |
| Category: Maximum Consumption | | | |
| Max Daily | 0 m3 | cubic meter | PI Point |
| Max MNF | 0 m3 | cubic meter | PI Point |
| Max Monthly | 0 m3 | cubic meter | PI Point |
| Max Ratio MNF per day | 0 % | percent | PI Point |
| Max Weekend | 0 m3 | cubic meter | PI Point |
| Max Weekly | 0 m3 | cubic meter | PI Point |
| Max Yearly | 0 m3 | cubic meter | PI Point |
| Category: Minimum Consumption | | | |
| Min Daily | 0 m3 | cubic meter | PI Point |
| Min MNF | 0 m3 | cubic meter | PI Point |
| Min Monthly | 0 m3 | cubic meter | PI Point |
| Min Ratio MNF per day | 0 % | percent | PI Point |
| Min Weekend | 0 m3 | cubic meter | PI Point |
| Min Weekly | 0 m3 | cubic meter | PI Point |
| Min Yearly | 0 m3 | cubic meter | PI Point |
| Category: Real Time Data | | | |
| Consumption per hour | 0 m3 | cubic meter | PI Point |
| Category: Static Data | | | |
| Buildings | | <None> | Table Lookup |
| Category | | <None> | Table Lookup |

Figure 4.11: Output attributes of applied analyses

To avoid the repetition of analyses creation for each element. The created expression analyses have been converted to an analysis template, and then it applied to other elements in the sensor level.

Other analyses were applied on parent elements called Rollup analyses. For each parent element, the inputs of its analyses are the attributes of its child elements; the output of these analyses were saved in new attributes for the parent elements, which stored in PI Data Archive. Figure 4.12 shows an example for the implementation of rollup analyses on a parent element.



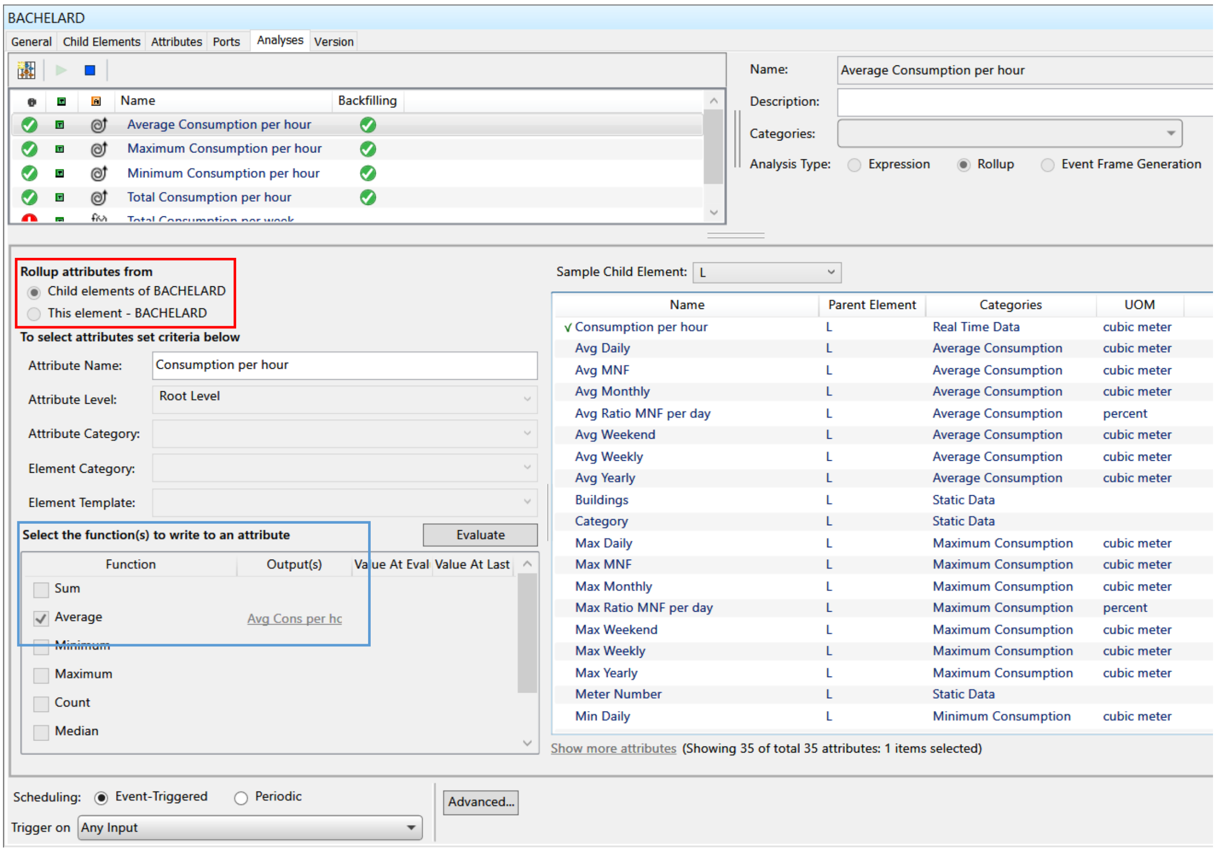


Figure 4.12 : Rollup analysis setting example

As shown in the red rectangle, analysis input for this element "BACHELARD" was selected the attributes of its child elements. The child element L was selected as a sample to pick up an attribute as input such as "Consumption per hour". The blue rectangle shows the applied function in this analysis and the output attribute.

This analysis calculates the average value of the attribute "Consumption per hour" of all child element under "BACHELARD" element. The same steps were applied to calculate the maximum, minimum and total values for each parent elements in different times.

The time of running all rollup analyses varies between every day at midnight, every week, and every month. All analyses can be seen in the Analyses tab in PSE; they can be filtered as shown in Figure 4.13.



The figure shows: Template name\Analysis name (number of analysis created).

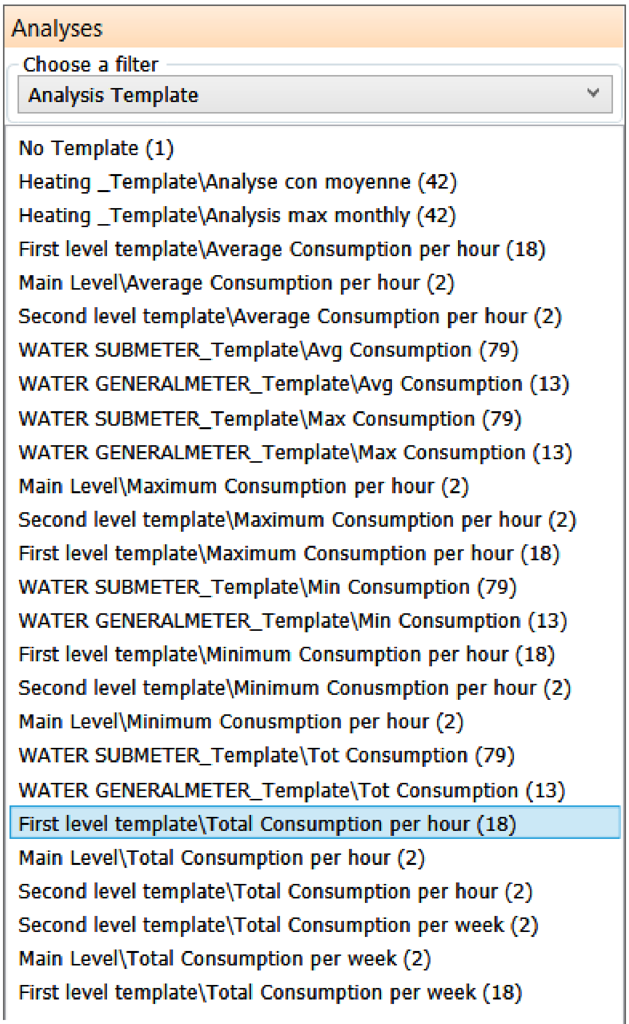


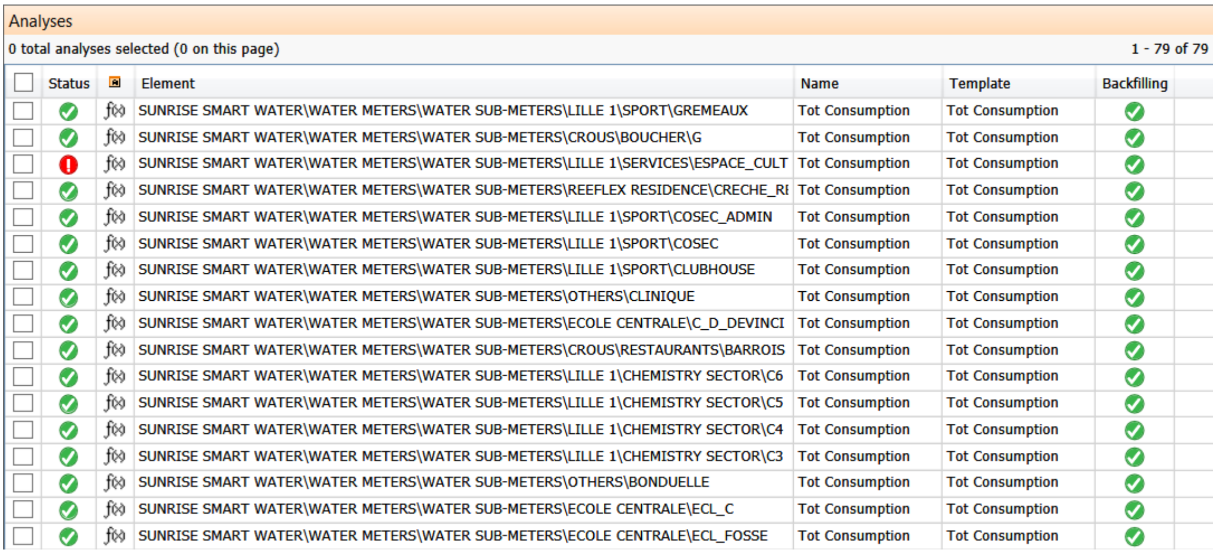

Figure 4.13 : Created analyses

The status of these analyses are shown in Figures 4.14 and 4.15, which contains the following columns:

- Status: shows the status of the analysis if there are errors or warnings during running the analysis.
- Analysis type:  for expression analysis,  for rollup analysis.
- Element: The path of the element, which the analysis running on.
- Name: Analysis name.
- Template: Analysis template
- Backfilling: shows the status of the backfilling.



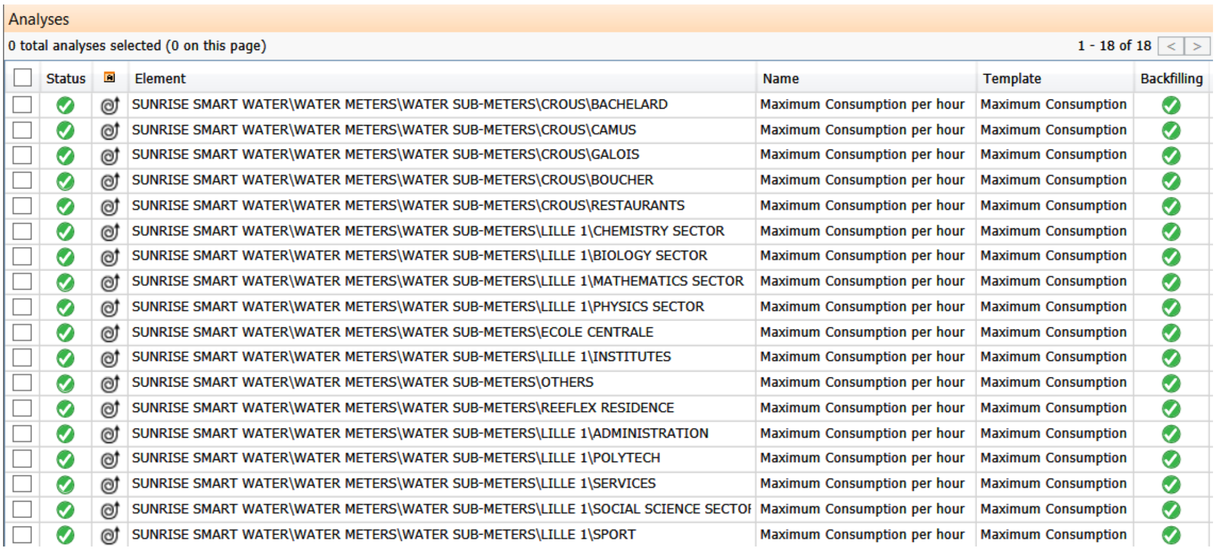


Analyses

0 total analyses selected (0 on this page) 1 - 79 of 79

| Status | | Element | Name | Template | Backfilling |
|---|---|---|---|---|---|
| ✓ | f(x) | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\SPORT\GREMEAUX | Tot Consumption | Tot Consumption | ✓ |
| ✓ | f(x) | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\CROUS\BOUCHER\G | Tot Consumption | Tot Consumption | ✓ |
| ! | f(x) | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\SERVICES\ESPACE_CULT | Tot Consumption | Tot Consumption | ✓ |
| ✓ | f(x) | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\REEFLEX RESIDENCE\CRECHE_RI | Tot Consumption | Tot Consumption | ✓ |
| ✓ | f(x) | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\SPORT\COSEC_ADMIN | Tot Consumption | Tot Consumption | ✓ |
| ✓ | f(x) | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\SPORT\COSEC | Tot Consumption | Tot Consumption | ✓ |
| ✓ | f(x) | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\SPORT\CLUBHOUSE | Tot Consumption | Tot Consumption | ✓ |
| ✓ | f(x) | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\OTHERS\CLINIQUE | Tot Consumption | Tot Consumption | ✓ |
| ✓ | f(x) | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\ECOLE CENTRALE\C_D_DEVINCI | Tot Consumption | Tot Consumption | ✓ |
| ✓ | f(x) | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\CROUS\RESTAURANTS\BARROIS | Tot Consumption | Tot Consumption | ✓ |
| ✓ | f(x) | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\CHEMISTRY SECTOR\C6 | Tot Consumption | Tot Consumption | ✓ |
| ✓ | f(x) | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\CHEMISTRY SECTOR\C5 | Tot Consumption | Tot Consumption | ✓ |
| ✓ | f(x) | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\CHEMISTRY SECTOR\C4 | Tot Consumption | Tot Consumption | ✓ |
| ✓ | f(x) | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\CHEMISTRY SECTOR\C3 | Tot Consumption | Tot Consumption | ✓ |
| ✓ | f(x) | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\OTHERS\BONDUELLE | Tot Consumption | Tot Consumption | ✓ |
| ✓ | f(x) | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\ECOLE CENTRALE\ECL_C | Tot Consumption | Tot Consumption | ✓ |
| ✓ | f(x) | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\ECOLE CENTRALE\ECL_FOSSE | Tot Consumption | Tot Consumption | ✓ |

Figure 4.14: Example of expression analyses



Analyses

0 total analyses selected (0 on this page) 1 - 18 of 18

| Status | Element | Name | Template | Backfilling |
|---|---|---|---|---|
| ✓ | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\CROUS\BACHELARD | Maximum Consumption per hour | Maximum Consumption | ✓ |
| ✓ | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\CROUS\CAMUS | Maximum Consumption per hour | Maximum Consumption | ✓ |
| ✓ | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\CROUS\GALOIS | Maximum Consumption per hour | Maximum Consumption | ✓ |
| ✓ | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\CROUS\BOUCHER | Maximum Consumption per hour | Maximum Consumption | ✓ |
| ✓ | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\CROUS\RESTAURANTS | Maximum Consumption per hour | Maximum Consumption | ✓ |
| ✓ | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\CHEMISTRY SECTOR | Maximum Consumption per hour | Maximum Consumption | ✓ |
| ✓ | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\BIOLOGY SECTOR | Maximum Consumption per hour | Maximum Consumption | ✓ |
| ✓ | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\MATHEMATICS SECTOR | Maximum Consumption per hour | Maximum Consumption | ✓ |
| ✓ | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\PHYSICS SECTOR | Maximum Consumption per hour | Maximum Consumption | ✓ |
| ✓ | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\ECOLE CENTRALE | Maximum Consumption per hour | Maximum Consumption | ✓ |
| ✓ | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\INSTITUTES | Maximum Consumption per hour | Maximum Consumption | ✓ |
| ✓ | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\OTHERS | Maximum Consumption per hour | Maximum Consumption | ✓ |
| ✓ | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\REEFLEX RESIDENCE | Maximum Consumption per hour | Maximum Consumption | ✓ |
| ✓ | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\ADMINISTRATION | Maximum Consumption per hour | Maximum Consumption | ✓ |
| ✓ | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\POLYTECH | Maximum Consumption per hour | Maximum Consumption | ✓ |
| ✓ | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\SERVICES | Maximum Consumption per hour | Maximum Consumption | ✓ |
| ✓ | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\SOCIAL SCIENCE SECTOI | Maximum Consumption per hour | Maximum Consumption | ✓ |
| ✓ | SUNRISE SMART WATER\WATER METERS\WATER SUB-METERS\LILLE 1\SPORT | Maximum Consumption per hour | Maximum Consumption | ✓ |

Figure 4.15: Example of rollup analyses



Backfilling is used for the analysis of historical data. In our case, it concerned the last three years (Figure 4.16).

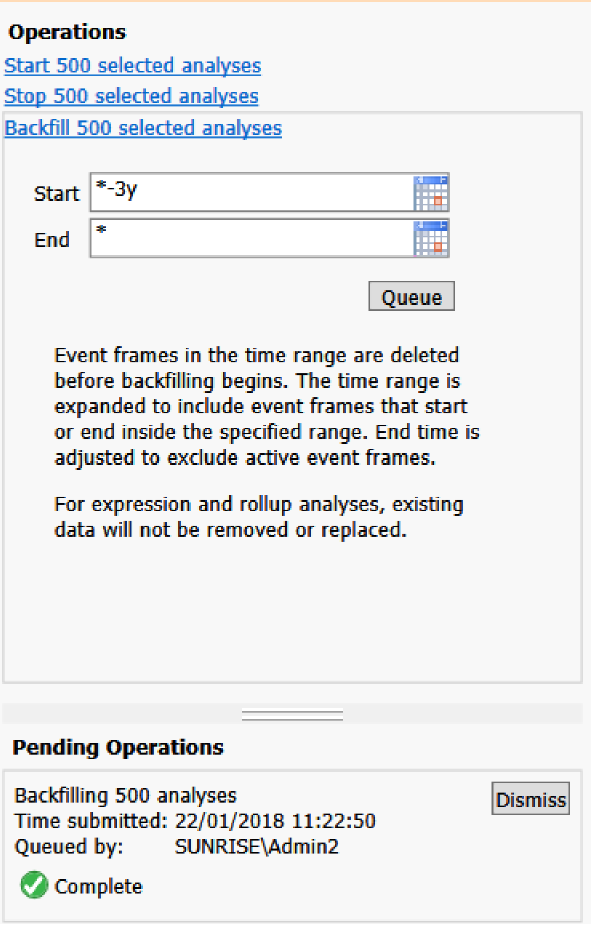



Figure 4.16 : Backfilling operation settings

In Start field * presents the current date and time and y presents years.

### 4.3.5 Results visualization

The results of the previous steps are visualized in different manners:

(i) AF displaying tool

PSE has a powerful feature; it allows checking the results of attributes by displaying multiple trends for attributes at once, it allows displaying time data series of each attribute. This feature has been used to compare the results of two or more elements by displaying trends of their attributes in the same window an example shown in Figure 4.17. This figure shows the comparison between the hourly consumption for the buildings (R, S, U, and W) of the residence "CAMUS" during the first week of March 2016.



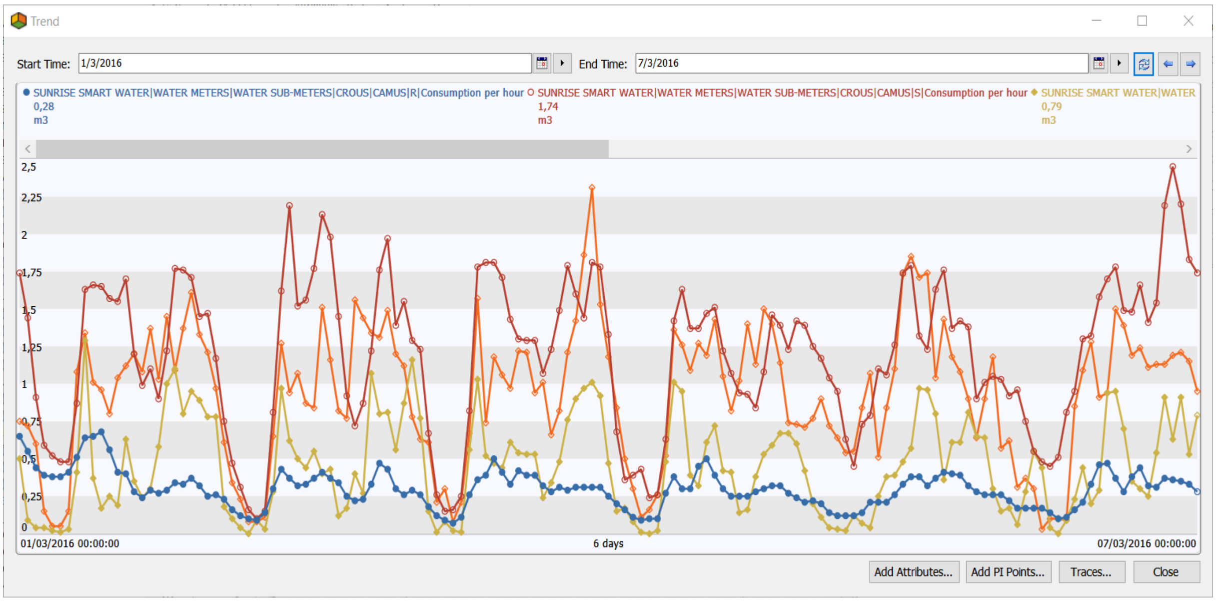



Figure 4.17: Water consumption compression for building of "CAMUS"

Another example is shown in Figure 4.18, which displays the hourly water consumption (the blue trend) and three analysis output attribute of restaurant “BARROIS” in March 2016. These output attributes are the maximum, minimum and average consumption per day.

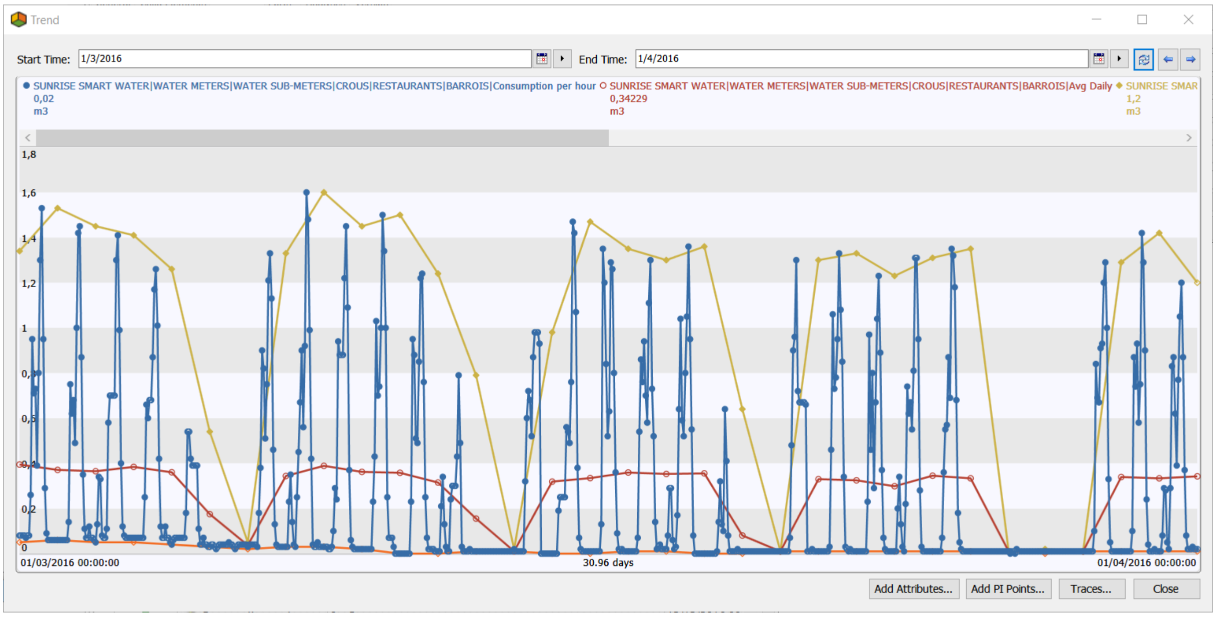



Figure 4.18: Analysis output attributes for restaurant "BARROIS"

(ii) PI Coresight

After creating and checking the basic analyses output attributes, the results are displayed on the web-based tool called PI Coresight.

(iii) PI DataLink

All existing attributes in PI Data Archive can be easily displayed in Microsoft Excel sheets using PI DataLink Plug-in for the users who are not familiar with web or PSE application.

This plug-in contains tools to facilitate retrieving the data from PI Data Archive (Figure 4.19).

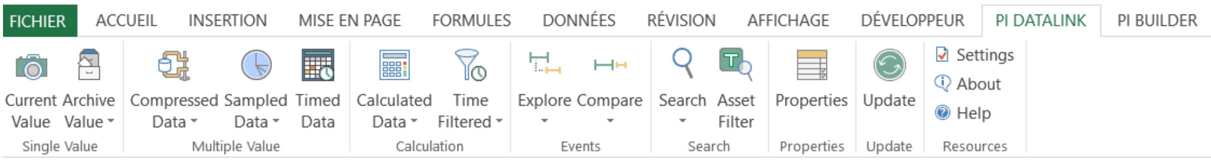



Figure 4.19: PI DataLink ribbon in Excel

Some of above tools are used in the visualization of analyses:

- Search: Is the most important tool, which allows to find PI Items and copy them to the worksheet. It is used to find specific items to be copied to the worksheet. Figure 4.20 shows an example of retrieving Maximum daily consumption attributes for different sensors. The (*) replaces any character.

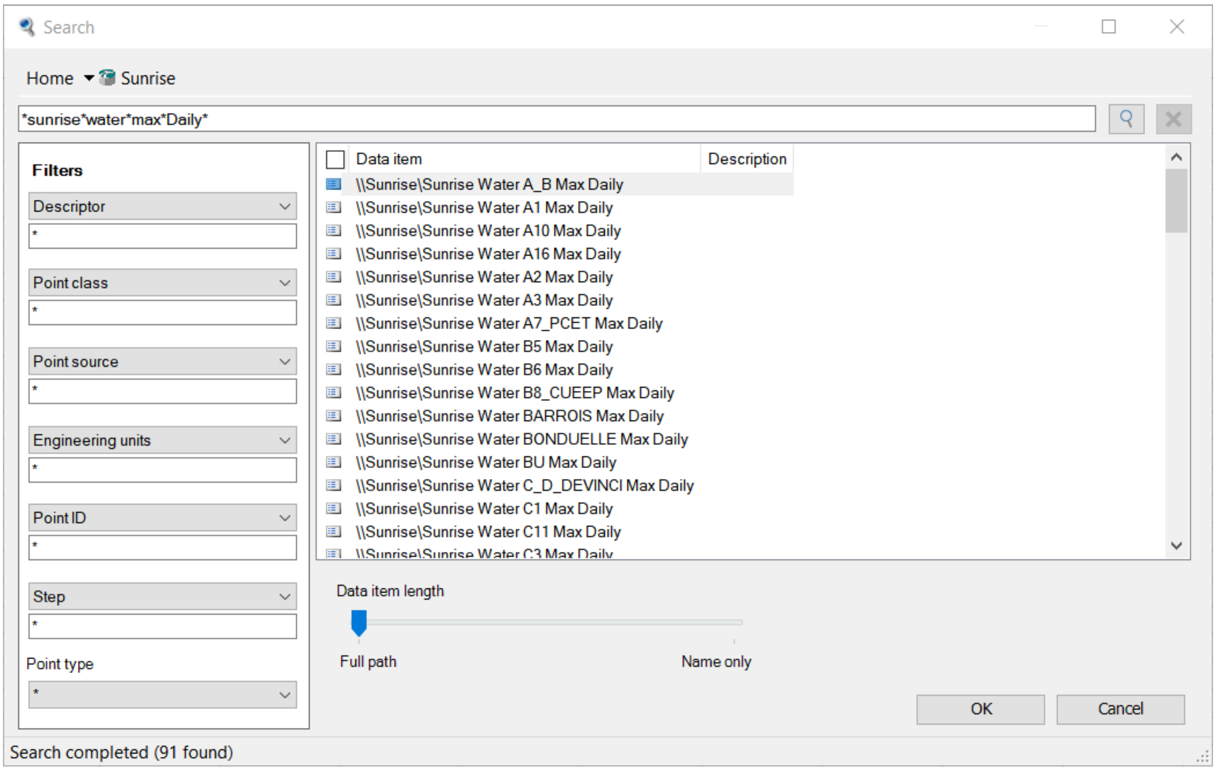
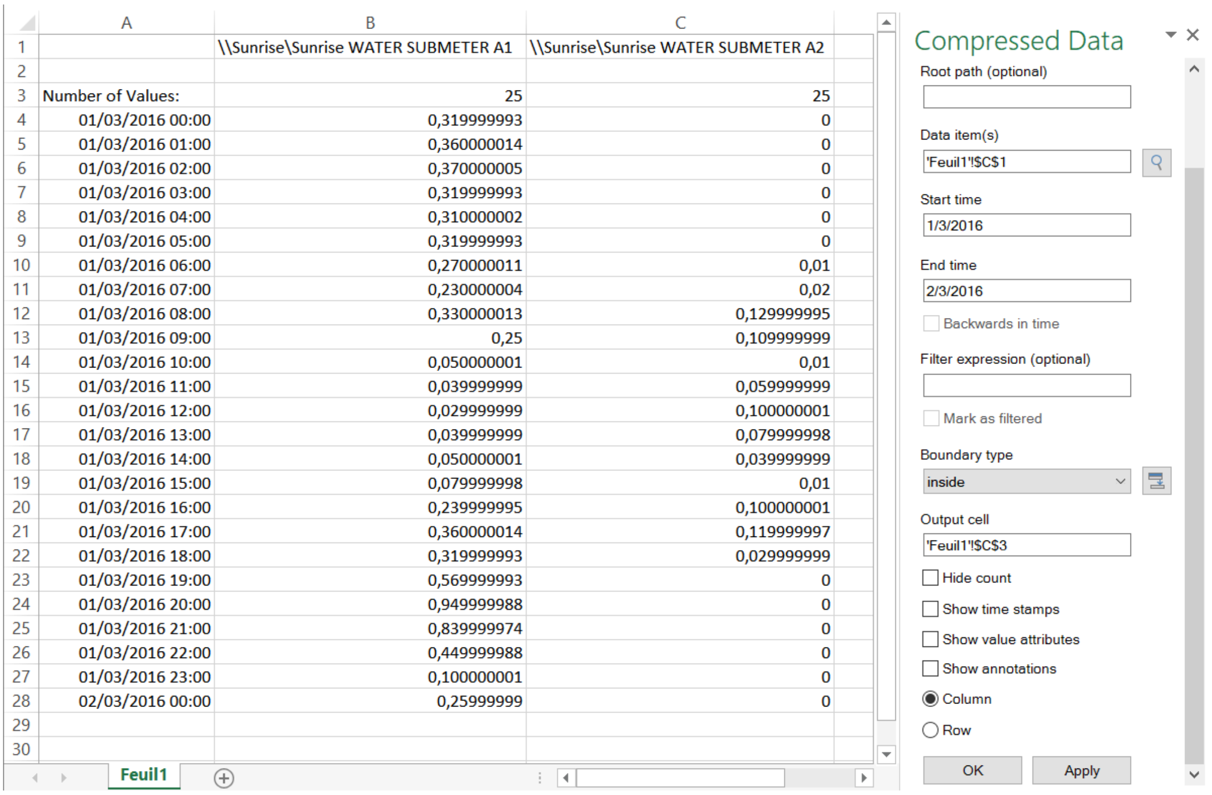



Figure 4.20: An example of searching specific items

- Current value: Retrieve the most recent value for an item with a time stamp.
- Archive value: Retrieve a data item value corresponding to a specific time.
- Compressed Data: Retrieve all values of data item occurring within specified time range. It is used to retrieve data for two or more items to compare them or draw curves.



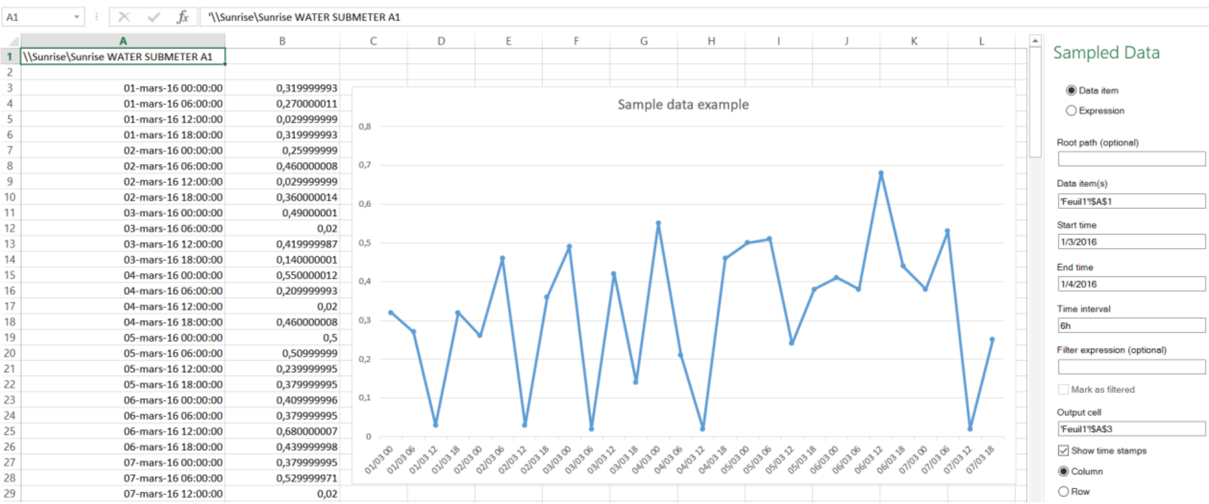


| | A | B | C |
|---|---|---|---|
| 1 | | \\Sunrise\Sunrise WATER SUBMETER A1 | \\Sunrise\Sunrise WATER SUBMETER A2 |
| 2 | | | |
| 3 | Number of Values: | 25 | 25 |
| 4 | 01/03/2016 00:00 | 0,319999993 | 0 |
| 5 | 01/03/2016 01:00 | 0,360000014 | 0 |
| 6 | 01/03/2016 02:00 | 0,370000005 | 0 |
| 7 | 01/03/2016 03:00 | 0,319999993 | 0 |
| 8 | 01/03/2016 04:00 | 0,310000002 | 0 |
| 9 | 01/03/2016 05:00 | 0,319999993 | 0 |
| 10 | 01/03/2016 06:00 | 0,270000011 | 0,01 |
| 11 | 01/03/2016 07:00 | 0,230000004 | 0,02 |
| 12 | 01/03/2016 08:00 | 0,330000013 | 0,129999995 |
| 13 | 01/03/2016 09:00 | 0,25 | 0,109999999 |
| 14 | 01/03/2016 10:00 | 0,050000001 | 0,01 |
| 15 | 01/03/2016 11:00 | 0,039999999 | 0,059999999 |
| 16 | 01/03/2016 12:00 | 0,029999999 | 0,100000001 |
| 17 | 01/03/2016 13:00 | 0,039999999 | 0,079999998 |
| 18 | 01/03/2016 14:00 | 0,050000001 | 0,039999999 |
| 19 | 01/03/2016 15:00 | 0,079999998 | 0,01 |
| 20 | 01/03/2016 16:00 | 0,239999995 | 0,100000001 |
| 21 | 01/03/2016 17:00 | 0,360000014 | 0,119999997 |
| 22 | 01/03/2016 18:00 | 0,319999993 | 0,029999999 |
| 23 | 01/03/2016 19:00 | 0,569999993 | 0 |
| 24 | 01/03/2016 20:00 | 0,949999988 | 0 |
| 25 | 01/03/2016 21:00 | 0,839999974 | 0 |
| 26 | 01/03/2016 22:00 | 0,449999988 | 0 |
| 27 | 01/03/2016 23:00 | 0,100000001 | 0 |
| 28 | 02/03/2016 00:00 | 0,25999999 | 0 |
| 29 | | | |
| 30 | | | |



Figure 4.21: An example of compressed data

- Sampled Data: Retrieve interpolated sample values for data item over a time range as shown in Figure 4.22.



| | A | B |
|---|---|---|
| 1 | \\Sunrise\Sunrise WATER SUBMETER A1 | |
| 2 | | |
| 3 | 01-mars-16 00:00:00 | 0,319999993 |
| 4 | 01-mars-16 06:00:00 | 0,270000011 |
| 5 | 01-mars-16 12:00:00 | 0,029999999 |
| 6 | 01-mars-16 18:00:00 | 0,319999993 |
| 7 | 02-mars-16 00:00:00 | 0,25999999 |
| 8 | 02-mars-16 06:00:00 | 0,460000008 |
| 9 | 02-mars-16 12:00:00 | 0,029999999 |
| 10 | 02-mars-16 18:00:00 | 0,360000014 |
| 11 | 03-mars-16 00:00:00 | 0,49000001 |
| 12 | 03-mars-16 06:00:00 | 0,02 |
| 13 | 03-mars-16 12:00:00 | 0,419999987 |
| 14 | 03-mars-16 18:00:00 | 0,140000001 |
| 15 | 04-mars-16 00:00:00 | 0,550000012 |
| 16 | 04-mars-16 06:00:00 | 0,209999993 |
| 17 | 04-mars-16 12:00:00 | 0,02 |
| 18 | 04-mars-16 18:00:00 | 0,460000008 |
| 19 | 05-mars-16 00:00:00 | 0,5 |
| 20 | 05-mars-16 06:00:00 | 0,50999999 |
| 21 | 05-mars-16 12:00:00 | 0,239999995 |
| 22 | 05-mars-16 18:00:00 | 0,379999995 |
| 23 | 06-mars-16 00:00:00 | 0,409999996 |
| 24 | 06-mars-16 06:00:00 | 0,379999995 |
| 25 | 06-mars-16 12:00:00 | 0,680000007 |
| 26 | 06-mars-16 18:00:00 | 0,439999998 |
| 27 | 07-mars-16 00:00:00 | 0,379999995 |
| 28 | 07-mars-16 06:00:00 | 0,529999971 |
| 29 | 07-mars-16 12:00:00 | 0,02 |



Figure 4.22: An example of sampled data



## 4.4 Application of PI Analyses to water leak detection

This section presents the detection of water leakage using PI Analyses. Two methods are used (i) Global Balance Method and (ii) Threshold water consumption profile.

### 4.4.1 Global Balance Method

The global balance method GBM aims to account the volume of water lost in water distribution networks during a period of time. It allows identifying the components that contribute to water loss in a standardized format. This method aims to compute overall annual real losses. It requires data from bulk (genera) meters and customer sub-meters. Bulk meters measure the amount of water supply $W_I$. The authorized consumption $W_C$ is determined from the sub-meters. The water losses $W_L$ are deduced.

$$\text{Water losses } W_L = \text{System input volume } W_I - \text{Authorized Consumption } W_C$$

The ration of the leakage R is calculated then as:

$$R = \frac{System\ input\ volume\ Wi - Authorized\ Consumption\ Wc}{\text{System input volume Wi}} * 100$$

### 4.4.2 Global balance - SunRise water system

The campus annual supply is calculated from data collected by the 13 general meters. In 2016, the supply volume $W_I$ is equal to 235 740 m$^3$. The total water consumption is measured by a set of 80 AMRs. According to data collected, the authorized consumption $W_C$ is equal to 232 238 m$^3$. Figure 4.23 shows the water supply and the water consumption in 2016.

The ration of the leakage R is calculated as follows:

$$R = \frac{(Wi{=}235\ 740) - (Wc{=}232\ 238)}{(Wi{=}235\ 740)} * 100 = 1.48\ \%$$



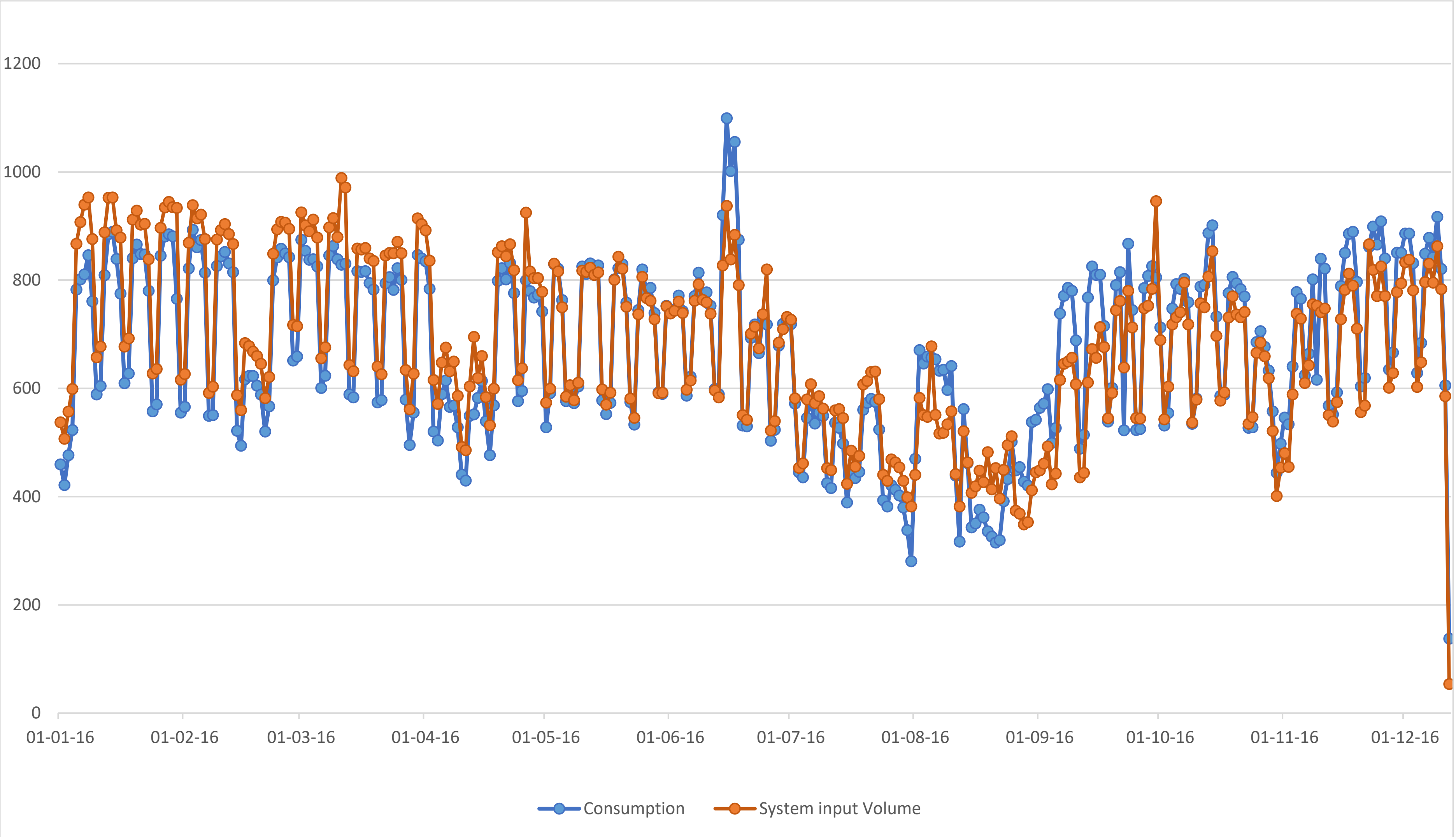



Figure 4.23: Comparison between the system input volume and the buildings consumption in 2016

### 4.4.3 Threshold Water Consumption Profile

In order to improve leak detection in quasi real time, the Threshold Water Consumption Profile (TWCP) method is used. This method consists in building a model from the historical values. The raw data is statistically analyzed to set a threshold based on its history. A distinction between the water consumption during working days, Saturdays, Sundays, and holidays is necessary. The water consumption values measured by the AMRs are then compared to the limit to detect any consumption anomaly or leakage. A pre-processing step is applied to filter data from any abnormal events. The model is based on the computation of the mean and the standard deviation of the daily consumption data. A corresponding simplified model is calculated based on the variation of the consumption over the day between morning, midday, afternoon and night. Steps of the TWCP method are summarized in Figure 4.24.

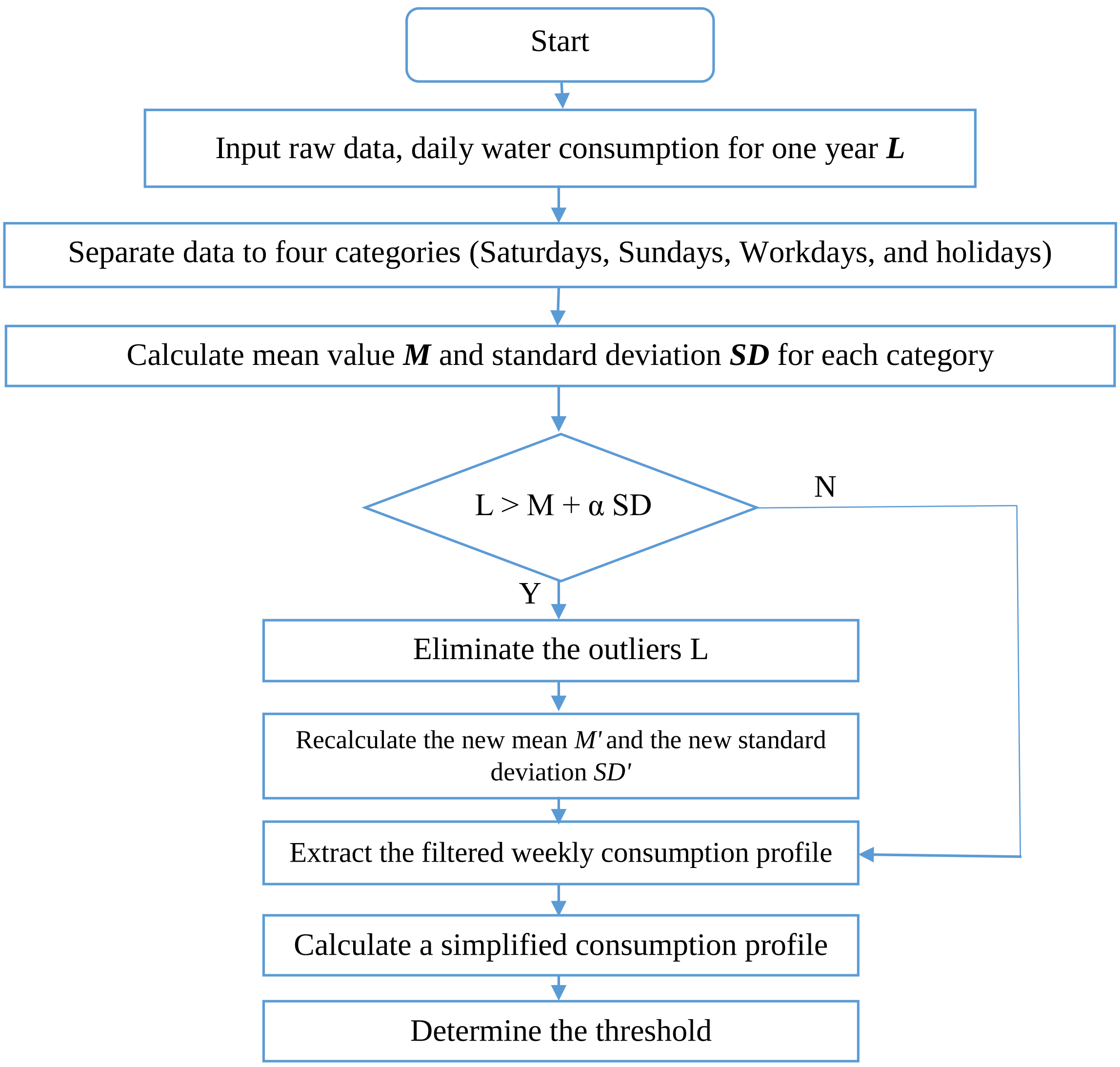



Figure 4.24: Flow chart of TWCP methodology



### 4.4.4 TWCP – SunRise water system (2016)

The first step consists in separating the daily consumption in 2016 into four categories (Workdays, Saturdays, Sundays, Holidays). Then the mean value M and the standard deviation SD are evaluated for each category. Table 4.4 shows the results with $\alpha = 1$, while Table 4.5 shows results with $\alpha = 2$.

Figures 4.25 to 4.32 show the results of analysis.

Table 4.4: TWCP with ($\alpha = 1$) (values are given in m3)

| | $M_B$ | $SD_B$ | $L_1 = M_B + SD_B$ | Events exceeding L1 |
|---|---|---|---|---|
| Working Days | 740 | 133 | 873 | 43 |
| Saturdays | 701 | 135 | 837 | 9 |
| Sundays | 552 | 74 | 627 | 7 |
| Holidays | 556 | 95 | 651 | 21 |

Table 4.5: TWCP with ($\alpha = 2$) (values are given in $m^3$)

| | $M_B$ | $SD_B$ | $L_2 = M_B + 2\ SD_B$ | Events exceeding L2 |
|---|---|---|---|---|
| WD | 740 | 133 | 1006 | 0 |
| Saturdays | 701 | 135 | 972 | 0 |
| Sundays | 552 | 74 | 701 | 1 |
| Holidays | 556 | 95 | 746 | 5 |

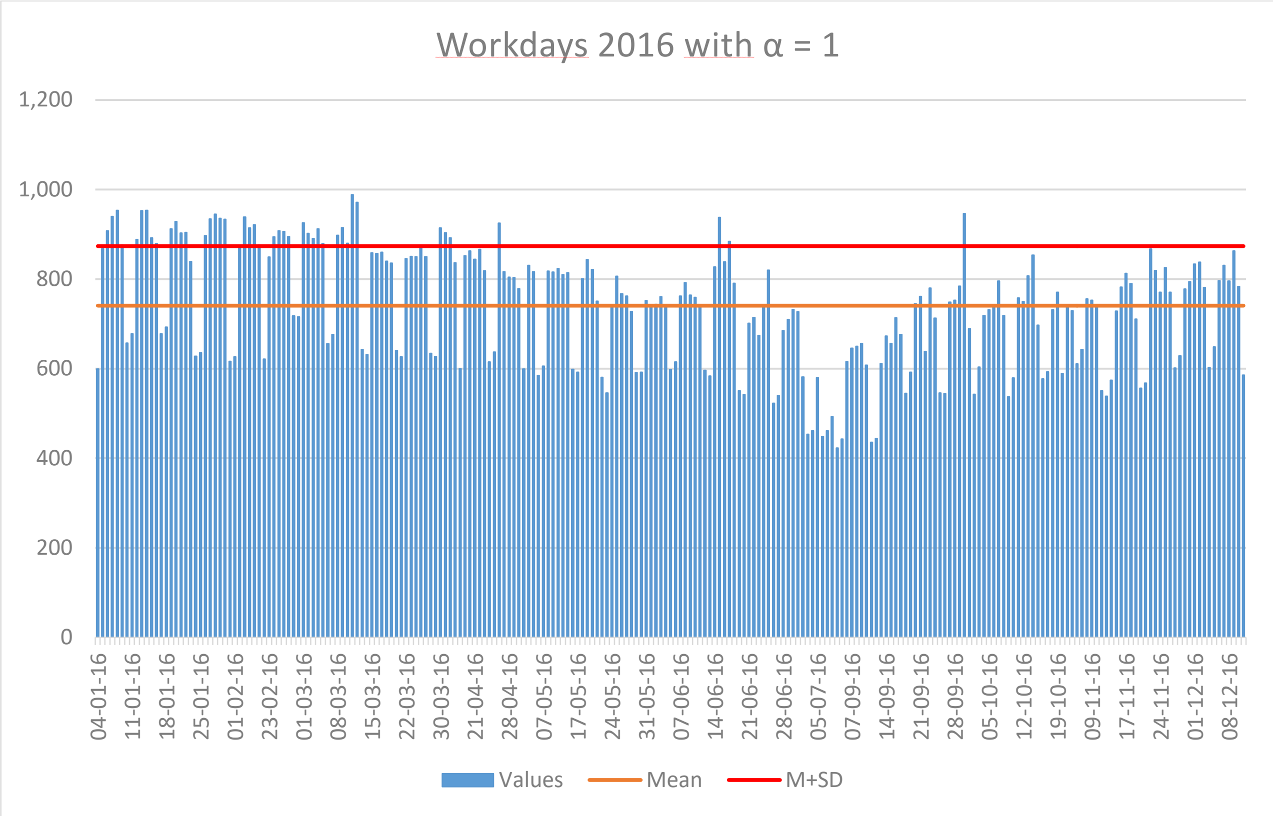



Figure 4.25: Daily consumption in workdays in the year 2016 with the factor a = 1

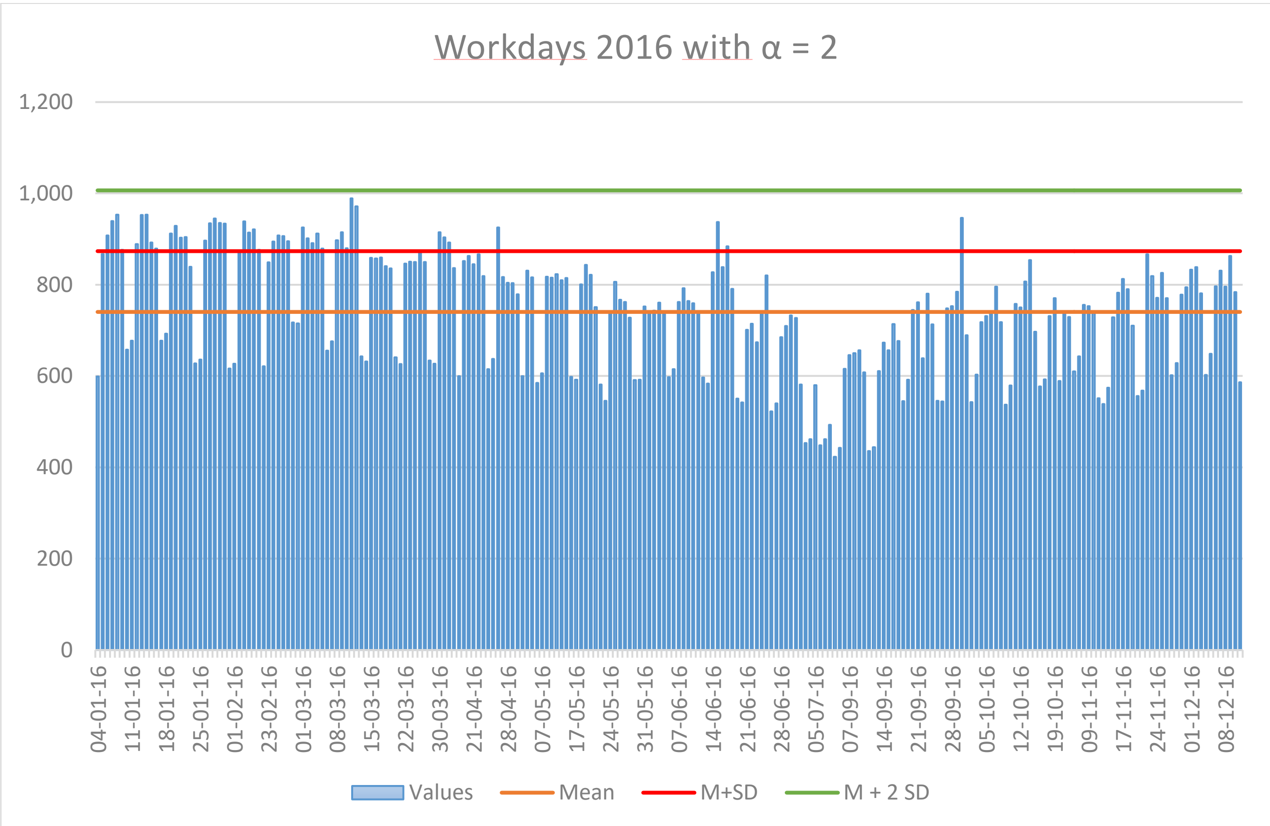



Figure 4.26: Daily consumption in workdays in the year 2016 with the factor a = 2

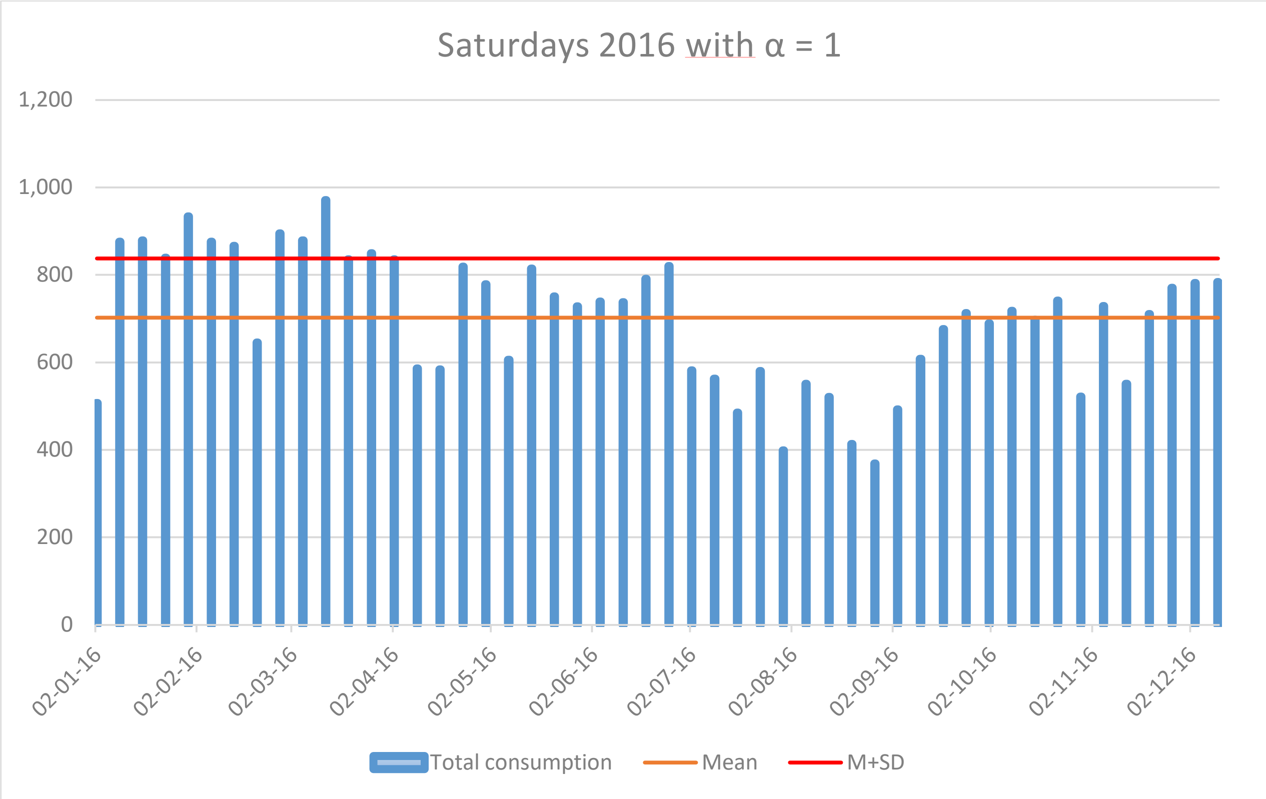



Figure 4.27: Daily consumption in Saturdays in the year 2016 with the factor a = 1

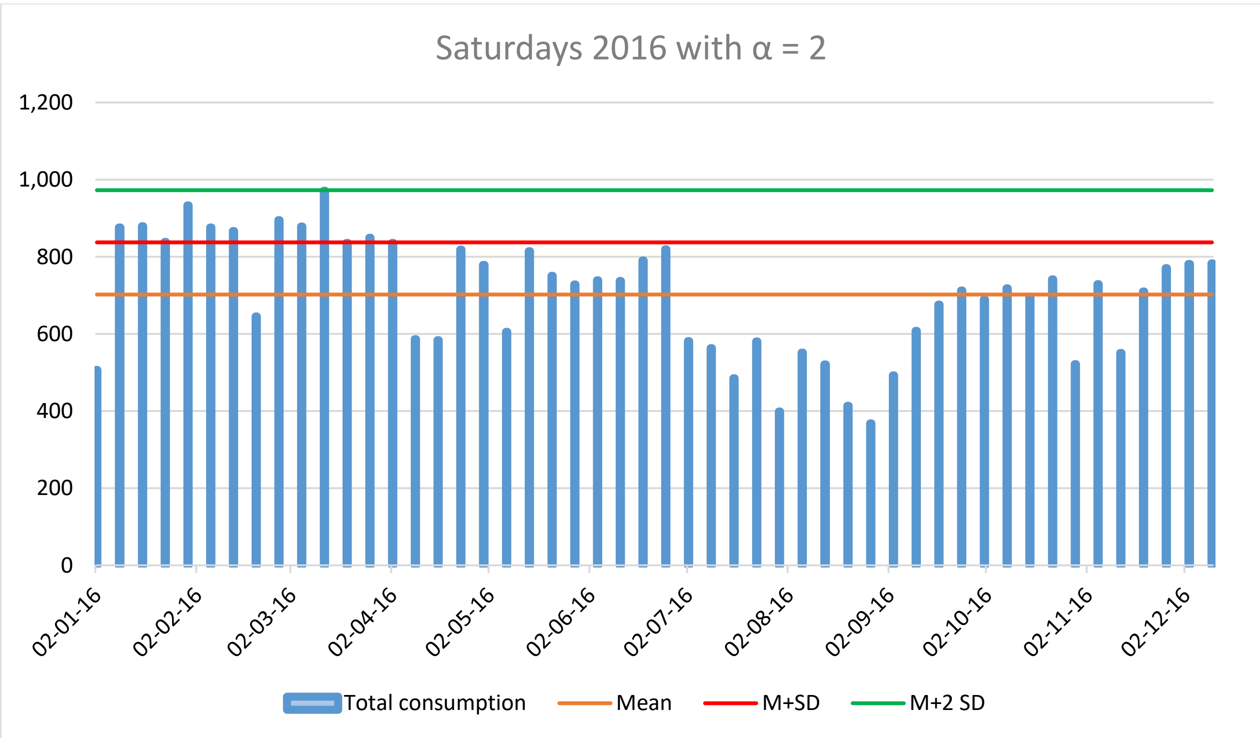



Figure 4.28: Daily consumption in Saturdays in the year 2016 with the factor a = 2

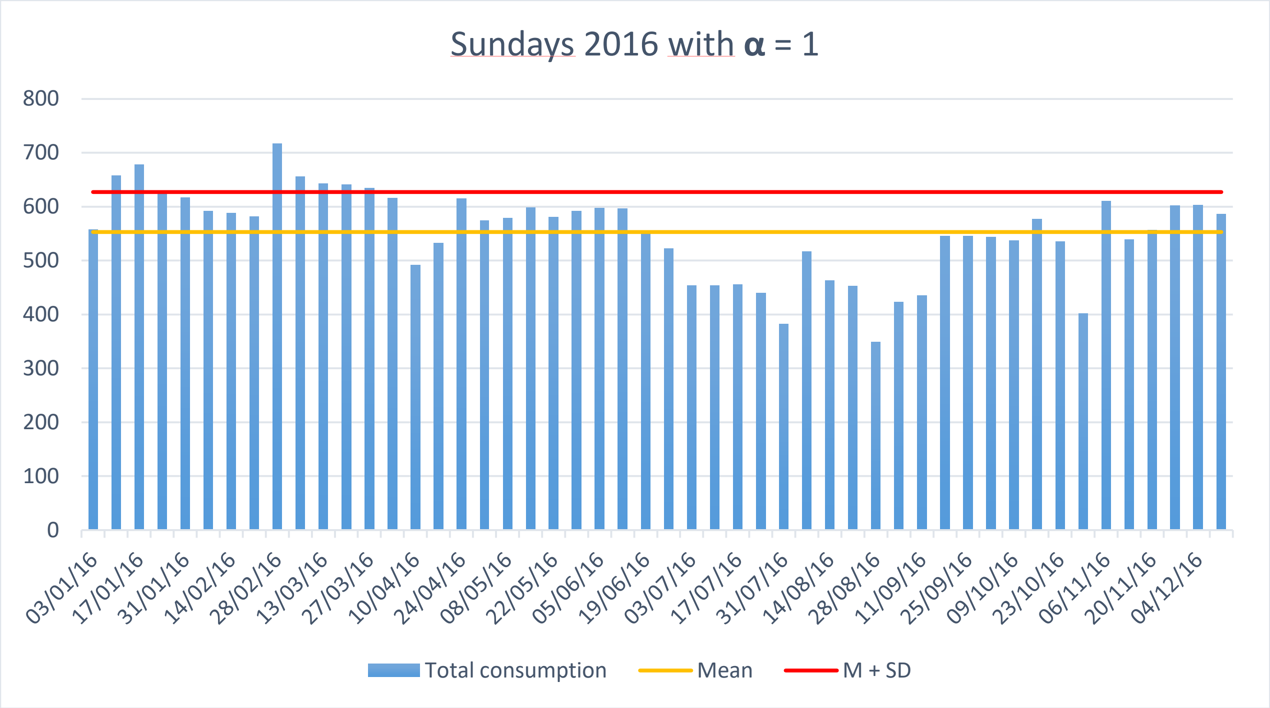



Figure 4.29: Daily consumption in Sundays in the year 2016 with the factor a = 1

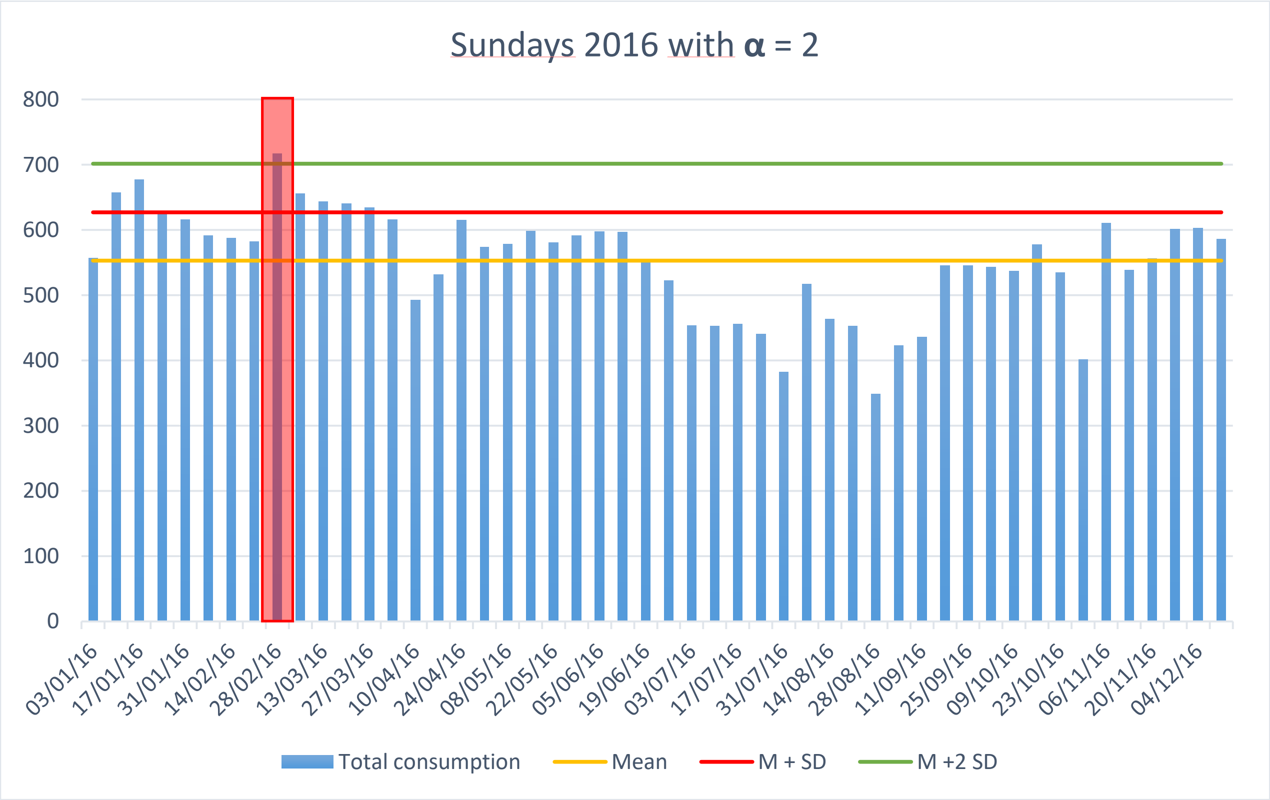



Figure 4.30: Daily consumption in Sundays in the year 2016 with the factor a = 2

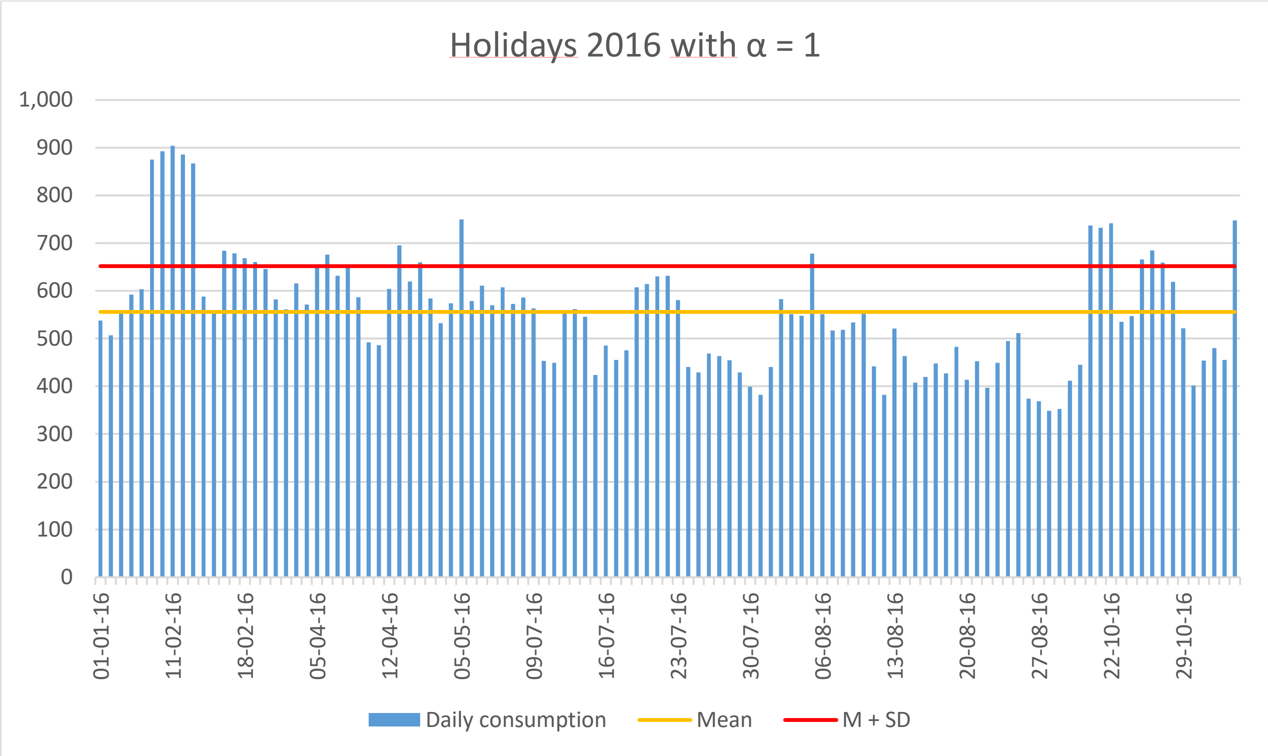



Figure 4.31: Daily consumption in Holidays in the year 2016 with the factor a = 1

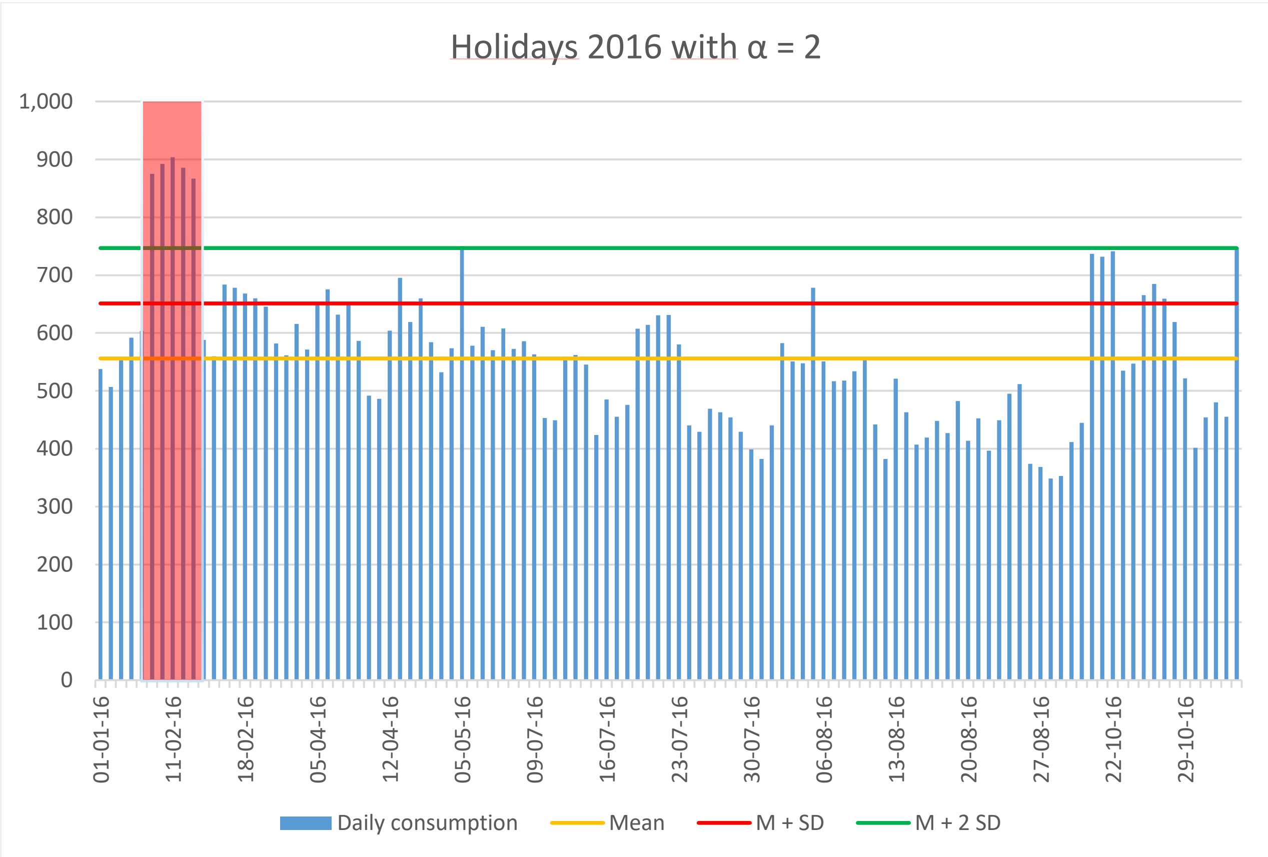



Figure 4.32: Daily consumption in Holidays in the year 2016 with the factor a = 2



We observe some values exceeds the threshold. Since these values could be related to leaks, they are eliminated then analyses are conducted with the new values. Results of these analyses are summarized in tables 4.6 and 4.7 as well as in figures 4.33 and 4.34.

Figure 4.36 shows a high probability of leak during the holidays between February 9 and 13, 2016. The water consumption exceeds the threshold during this period. The onset of this leak is detected clearly on February 9. An abnormal consumption is also observed between October 20 and 22 2016. Two abnormal consumption are also reported May 5, and November 11

We can observe that the consumption in Sundays and Holidays are close, so they can be combined in one category.

Table 4.6: TWCP after eliminating with (α = 1)

| | $M_A$ | $SD_A$ | $L_1 = M_A + SD_A$ | Events exceeding L1 |
|---|---|---|---|---|
| **WD** | 740 | 133 | 873 | 43 |
| **Saturdays** | 701 | 135 | 837 | 9 |
| **Sundays** | 549 | 71 | 621 | 7 |
| **Holidays** | 536 | 74 | 610 | 29 |

Table 4.7: TWCP after eliminating with (α = 2)

| | $M_A$ | $SD_A$ | $L_2 = M_A + 2\ SD_A$ | Events exceeding L2 |
|---|---|---|---|---|
| **WD** | 740 | 133 | 1006 | 0 |
| **Saturdays** | 701 | 135 | 972 | 0 |
| **Sundays** | 549 | 71 | 692 | 0 |
| **Holidays** | 536 | 74 | 684 | 11 |



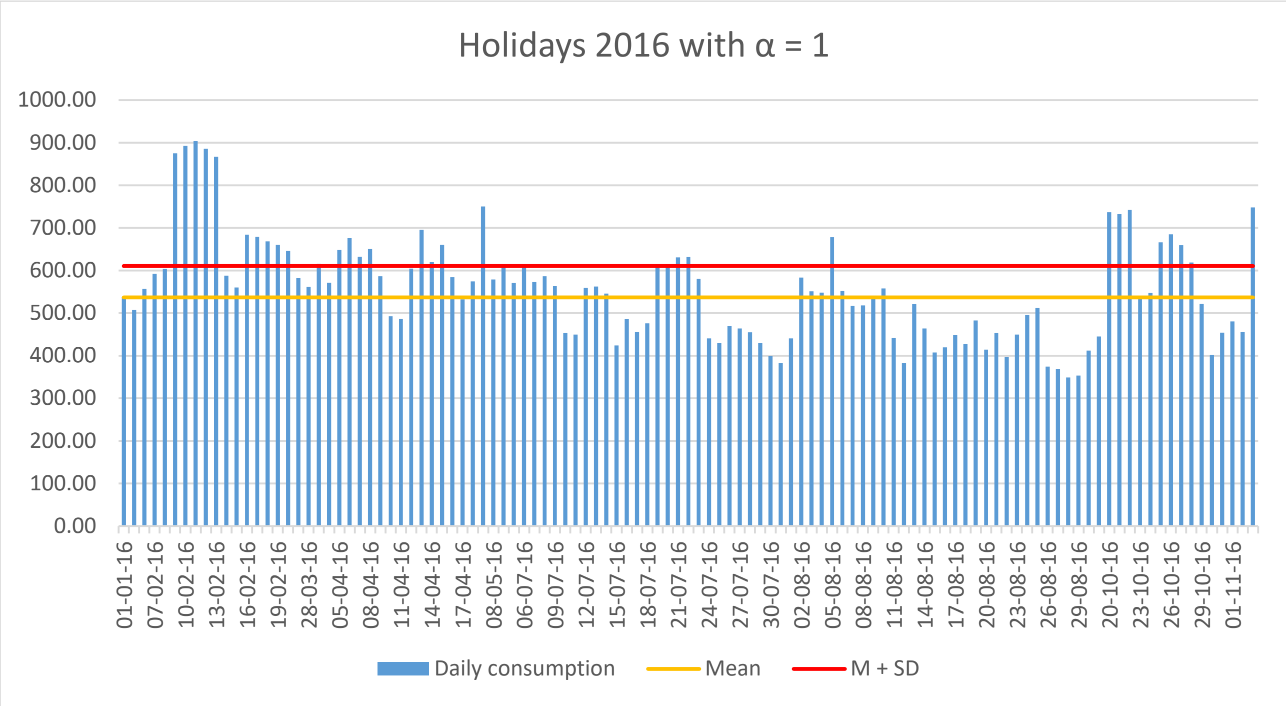



Figure 4.33: New mean and standard deviation

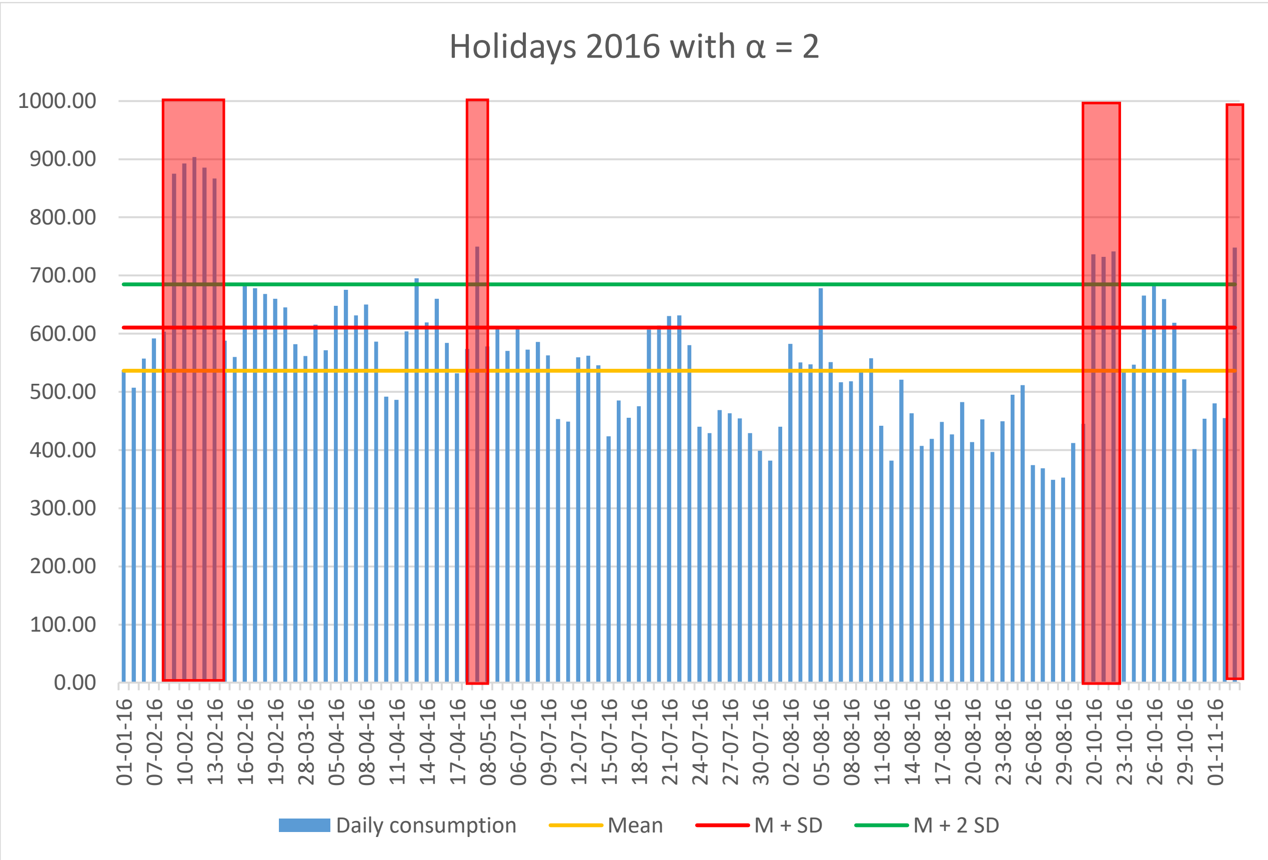



Figure 4.34: High probability of leakage detection



## 4.5 OpenDataSoft

### 4.5.1 Presentation

OpenDataSoft is a Software as a service (SaaS) platform. It is considered the next generation of data sharing. It allows publishing, interaction, visualization and management of all types datasets-including geospatial formats-by generating RESTful APIs with each dataset automatically. It leverages Elastic search and ensures near real-time search and analysis ("OpenDataSoft").

ODS store all data NoSQL database, which is non-relational database management system, it supports flexible schema to store the data. It is different from traditional relational database system, which provides structured schema in form of tables. NoSQL databases supports large scale of data storing by providing distributed data stores (Rautmare and Bhalerao 2016). Hence, NoSQL databases are supposed to be suitable for storing the data generated by IoT applications. Most of the NoSQL databases are based on storing key value pairs, the value is block of data and the key is used to access the data. This way provides easy scalability and good performance.

Its ability to process large-scale, real-time data from IoT objects, to transform these data into interactive visualizations like maps and charts, and its Application Programming Interface (API)-centered design makes it suitable for Smart Cities. Data can be imported from files or can be programmed to search for the data from another data source at a set time interval to then publish it onto the platform and update the dataset. ODS platform provide users with a dashboard, which allow them upload all types of datasets, it supports the most common file extensions such as CSV, XLS, SHP, JSON, XML, etc. It has built-in sets of processors that help to treat each dataset before saving it in the database. The processors are divided to four sets as following:

- Geographical mapping.
- Dates handling.
- Text transformation.
- Generic operations.

The most important processor is "Join Datasets". It facilitates the connection between all datasets such as static and dynamic values.

After the data stored in the database, a RESTful API is automatically created for each dataset. Through this API, the users can manage their datasets, create analyses, and create interactive maps and curves.

Since the data is ready, ODS provides web page creation for data visualization. Each dataset can be easily shared as a URL, or converted to a widget to reuse it in any web page.

### 4.5.2 Implementation of OpenDataSoft in SunRise

The use of OpenDataSoft passes through the following stages:

- Data collection.



- Data processing.
- Data management.
- Data analyses and visualization.

### 4.5.3 Data collection

Data collected using communication channels as explained before are stored in different databases, structure, and formats. For example, the water data is stored in PostgreSQL database, electric data stored in SQL Server database. The water data table is composed of four elements: Start Date, End Date, Meter IDs, and the consumption value. All the meters are defined in a static table that contains the coordinates of the meters, the serial number of the sensor, the meter number and the category of the building associated to the meter. The architecture of the water meter tables are illustrated in Figure 4.35.

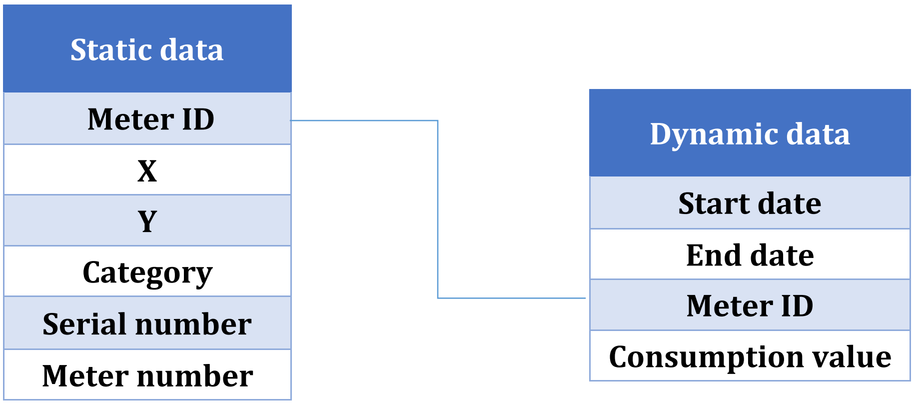



Figure 4.35: The architecture of water data tables

### 4.5.4 Data processing

After the data has been collected from all urban networks in the campus, it is uploaded to the platform using ODS dashboard. ODS built-in Processors facilitate (i) integrating all data and uniform its format, (ii) generating new values depending on an original value, (iii) separating data to different categories. Some built-in processors has been used to integrate the data with the platform such as:

- Replace text: used to replace the bad values with empty value.
- Set timezone: used to standardize the time format for all uploaded data.
- Replace via regular expression: used to extract hours and months from dates.
- Expression: used to extract specific datasets such as separating Saturdays from other days.
- Join datasets: used to combine the static and dynamic data for each network. They combined depending on common key between both of them, which is Meter ID.



Figure 4.36 shows an example of applying some processors on a dataset; the columns on the right are extracted from End date column.

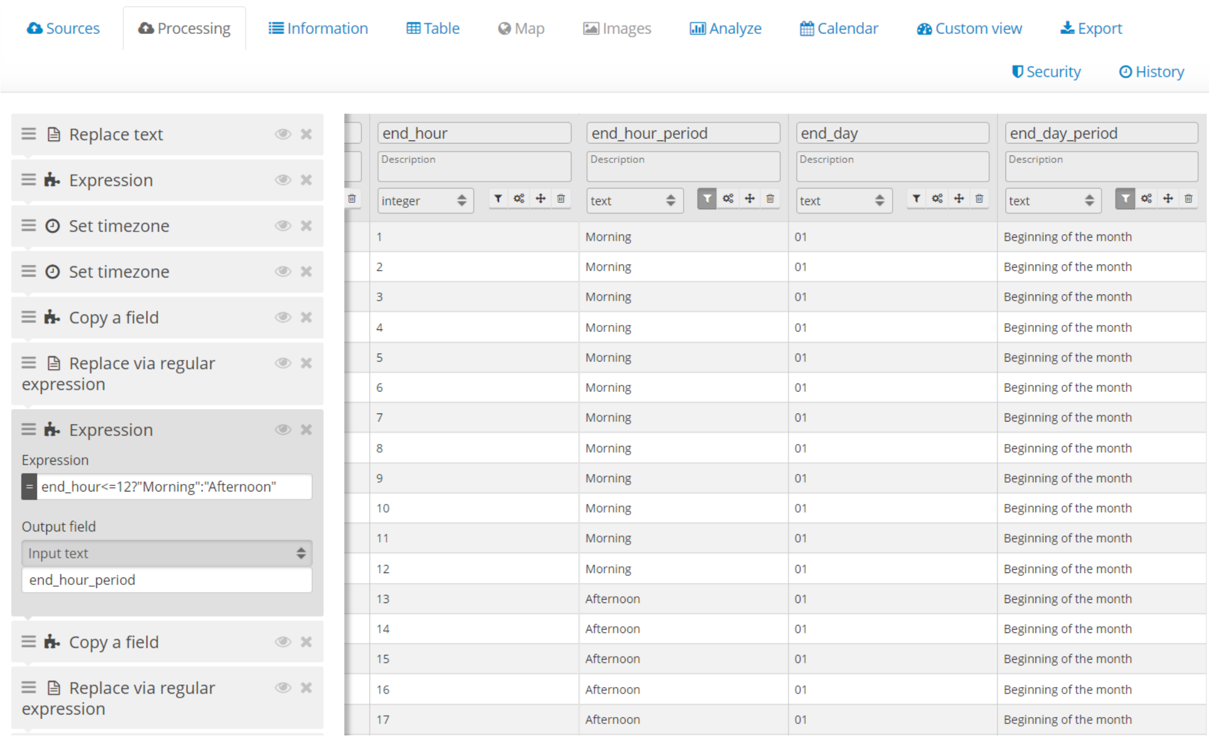



Figure 4.36: An example of applying ODS built-in processors

## 4.5.5 Data storage

After data processing, data are stored in NoSQL database; RESTful APIs are automatically created for each dataset. These APIs help to manage the datasets such as adding, modifying, and deleting processors, etc. Then it can be published again. As we can see in Figure 4.37, the created API automatically classifies the data and calculates its total records. Map and Chart builder are used for analyses. They will be explained henceforth.

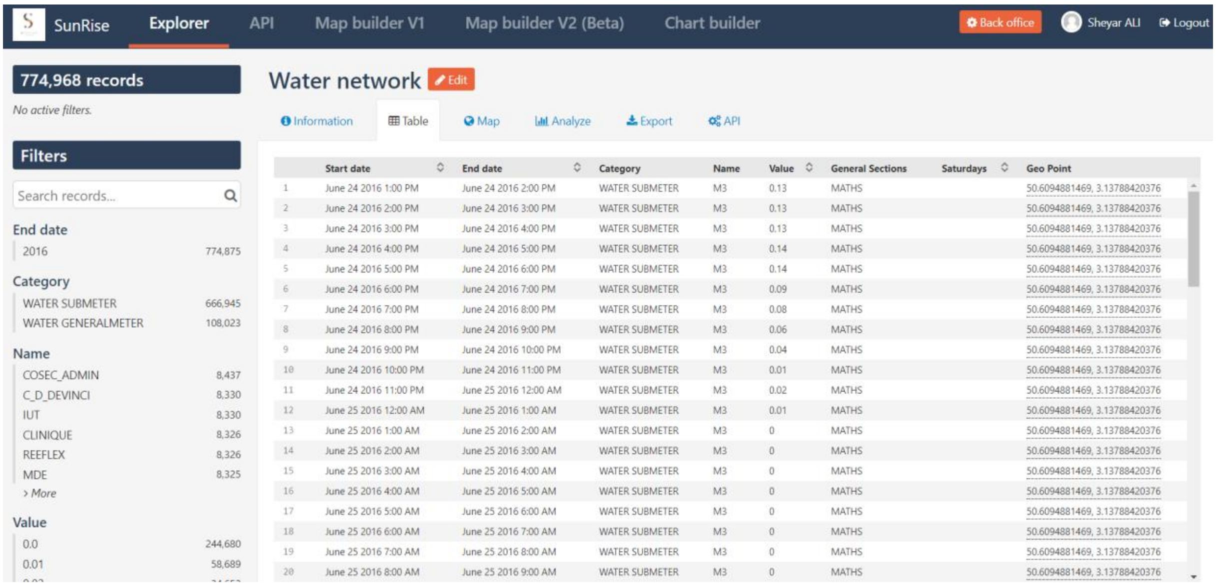



Figure 4.37 : Water data API



### 4.5.6 Data analyses and visualization

ODS has built-in functions, which helps to describe data usage of each sensor such as: Standard deviation, Average, Total value, etc. on different time scales: hourly, daily, weekly, and yearly.

The water data has been taken as an example to implement the analysis; the same methodology could be applied to the other networks data.

The water network consists of 93 meters divided to two major parts: GENERAL METERS (Suppliers) 13 meters, SUB-METERS (Consumers) 80 meters. The total consumption for each part can be easily calculated using chart builder. Figure 4.38 shows a big difference between the water supply and consumption in 2015 due to the water leakage. This difference decreased in 2016.

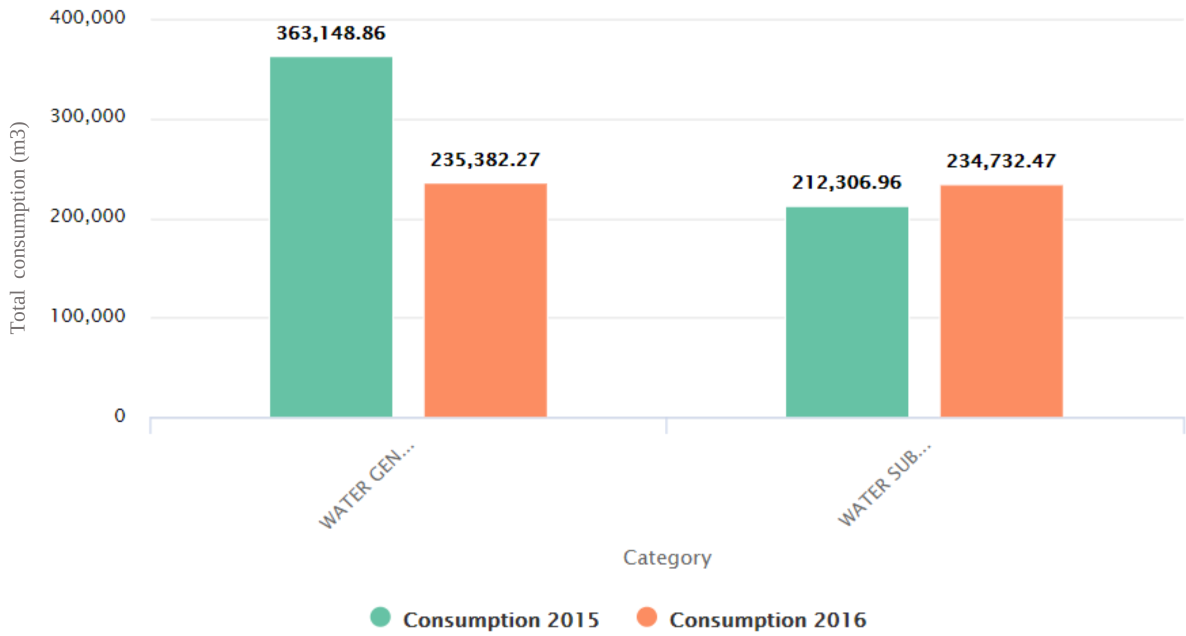



Figure 4.38: A comparison between the general and sub meters consumption in 2015 and 2016

Figure 4.39 shows the distribution of the water consumption on the campus map. The dark blue circles represent the general meters (suppliers), while red circles represent the sub-meters (consumers). Figure 4.40 shows the percentage of the water consumption for the general meters.



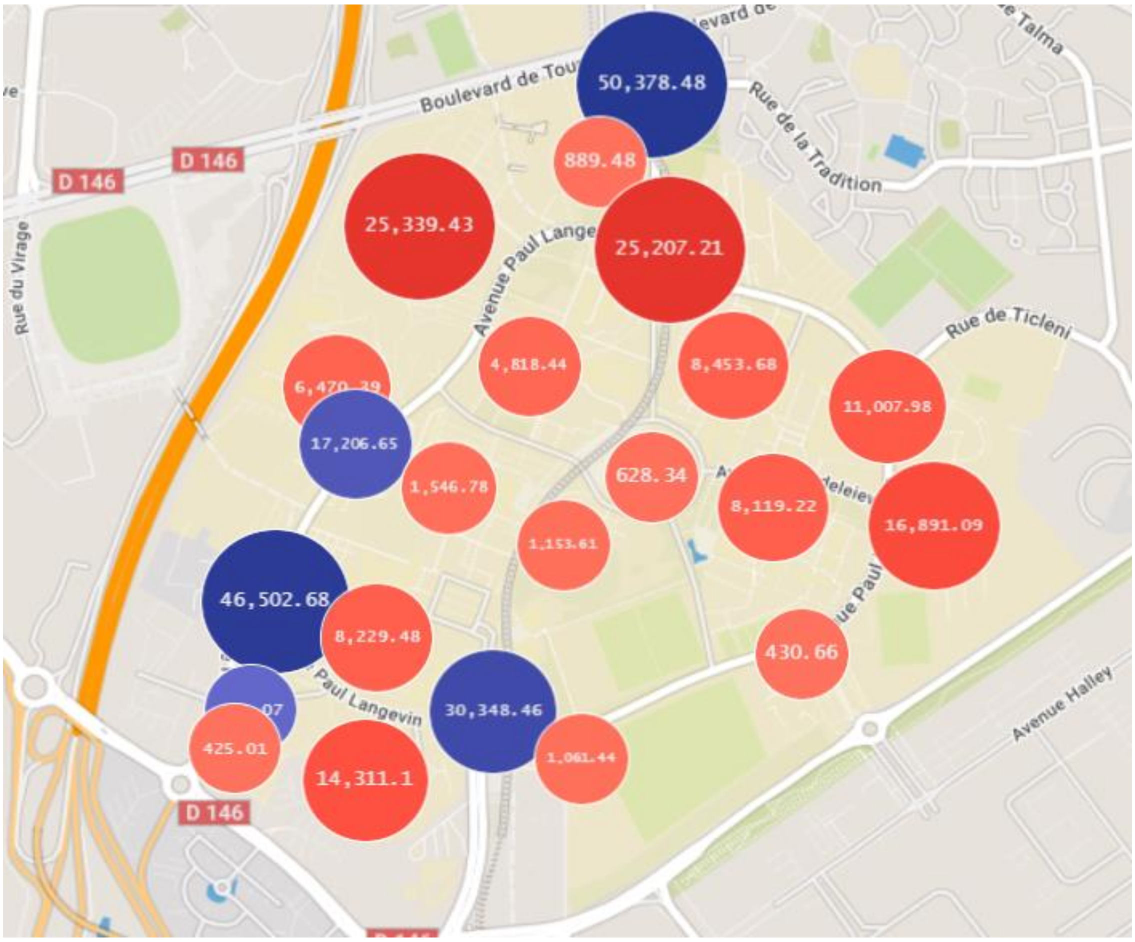



Figure 4.39: Distribution of the water consumption over the general meters in 2016

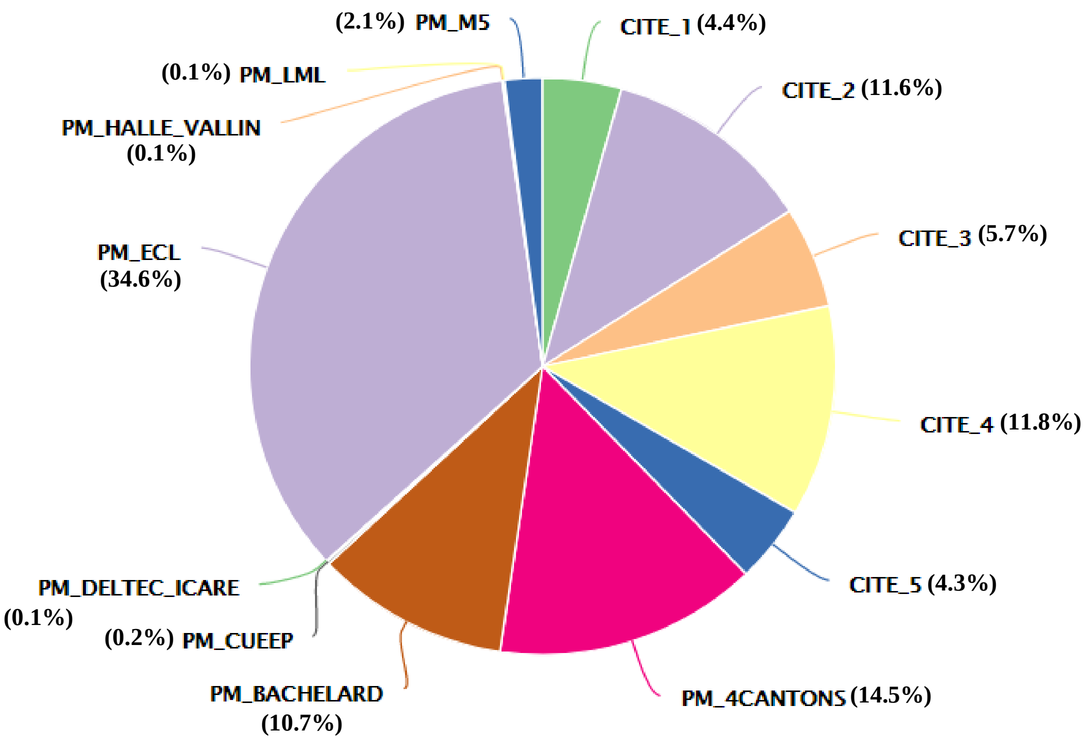



Figure 4.40: The consumption of each general meter

The distribution of the water consumption for the sub-meters in 2016 is illustrated in Figure 4.41. The CROUS and LILLE1 consume around 80% of the campus water supply.

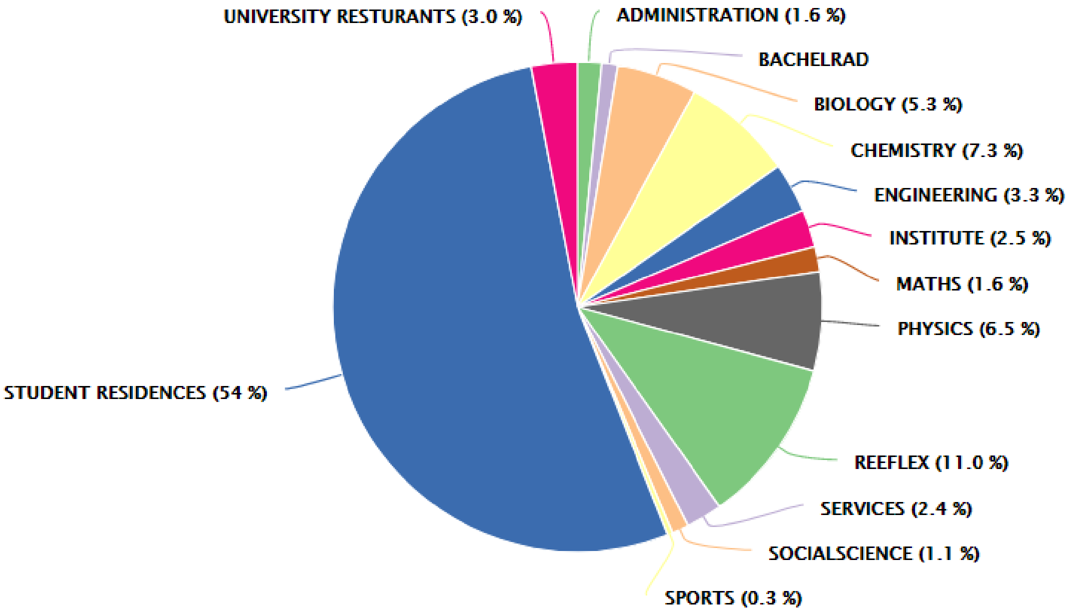



Figure 4.41: The distribution of the water consumption for the sub-meters in 2016

- **CROUS buildings (56% of the total consumption)**

The CROUS domain includes 4 students' residences and 3 restaurants. Figure 4.42 shows the water consumption of these buildings in 2016.

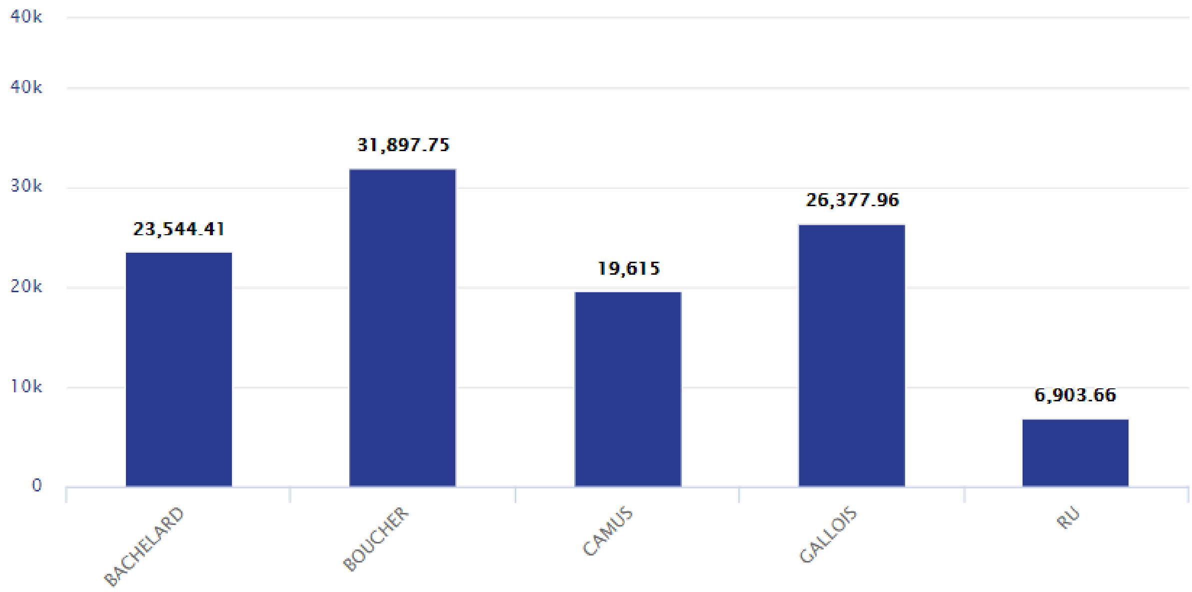



Figure 4.42: Water consumption for the CROUS domain



Figure 4.43 shows the water consumption repartition between the campus buildings.

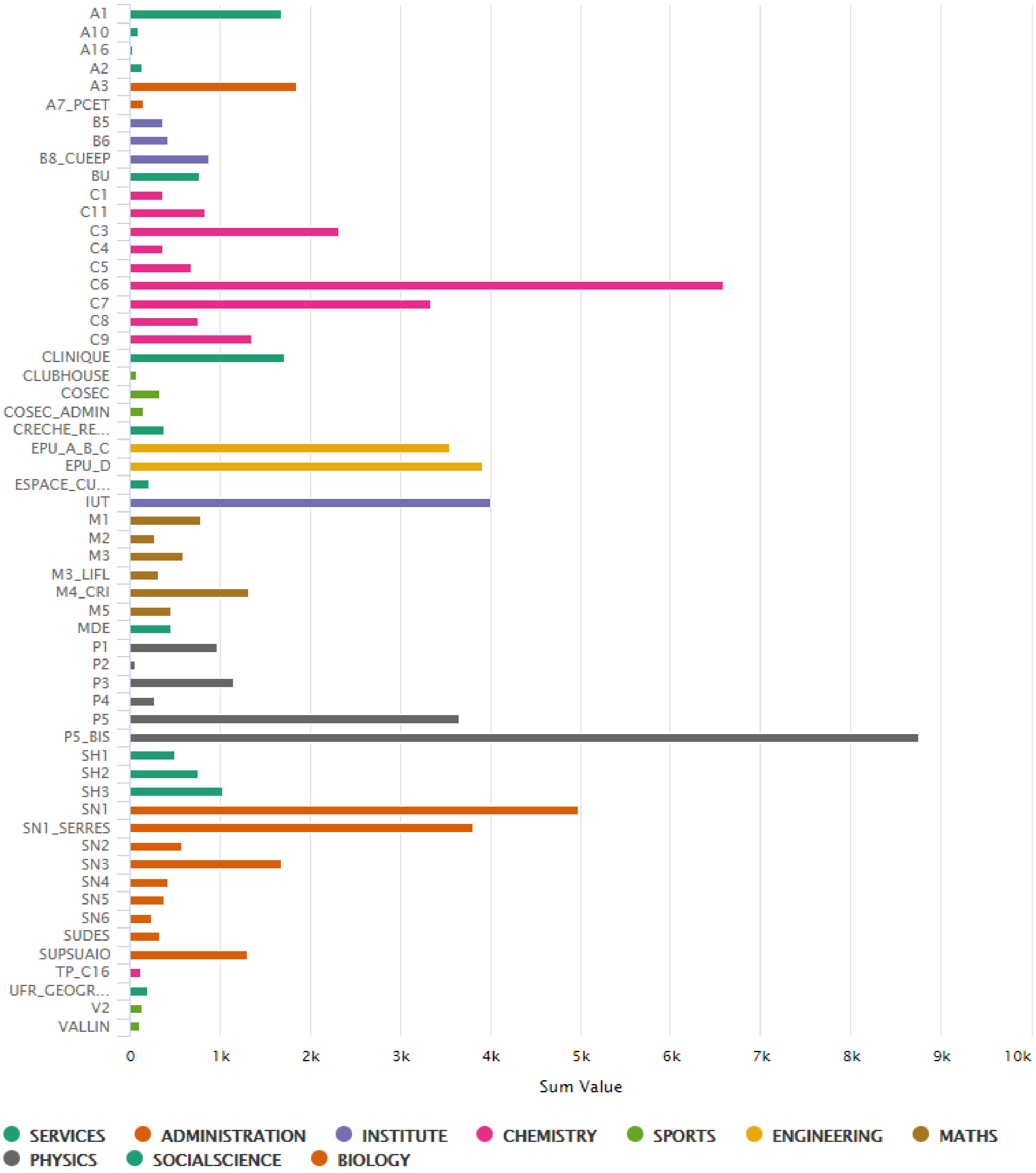



Figure 4.43: Consumption of LILLE1 buildings in 2016

The distribution of the water consumption of LILLE1 buildings is shown in Figure 4.44. The three sectors: CHEMISTRY (16 645 m3), PHYSICS (14 885 m3) and BIOLOGY (12 091 m3) consume 60% of this domain. This is due to the presence of research facilities, which have high water consumption.

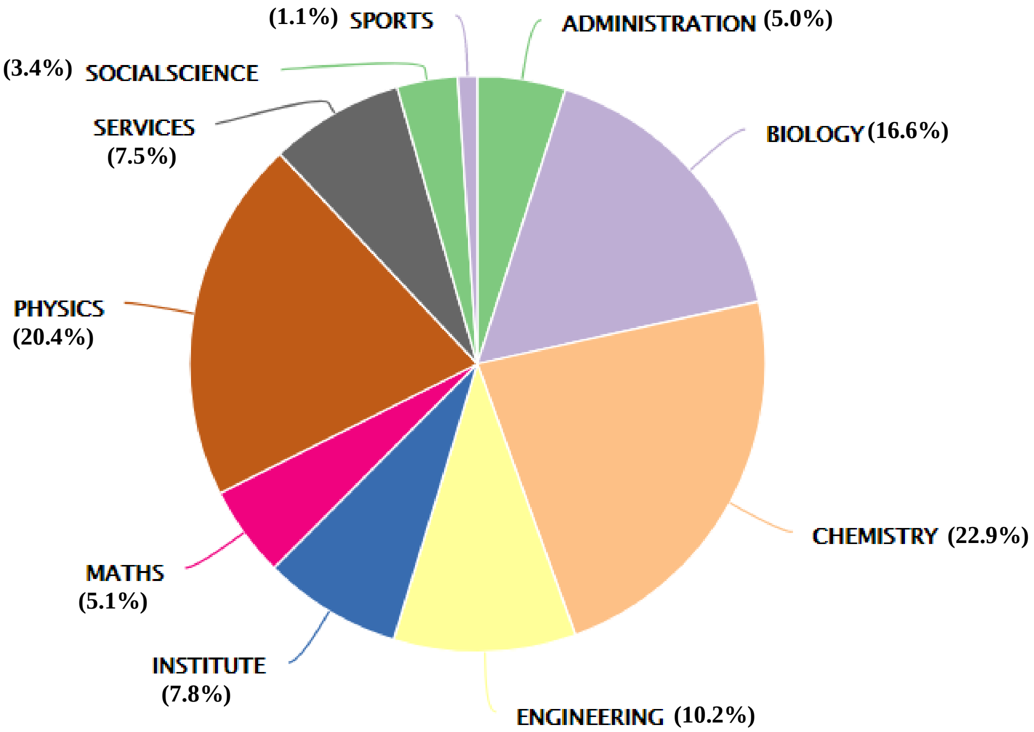



Figure 4.44: Distribution of the water consumption by sections

ODS provides a powerful tool for building interactive maps to facilitate data analysis. Figures 4.45 (a)-(c) illustrate examples of the distribution of water consumption.


Figure 4.45 (a): Distribution of water consumption over the MATHMATICS section


Figure 4.45(b): Distribution of water consumption over the PHYSICS section


Figure 4.45(c): Distribution of water consumption over the CHEMISTRY section

### 4.5.7 Implementing of TWCP using ODS tools

ODS processors and functions have been used to separate the water consumption in 2016 into four categories (Saturdays, Sundays, Wok days, and Holidays). Figure 4.46 shows the water consumption in workdays and holidays.

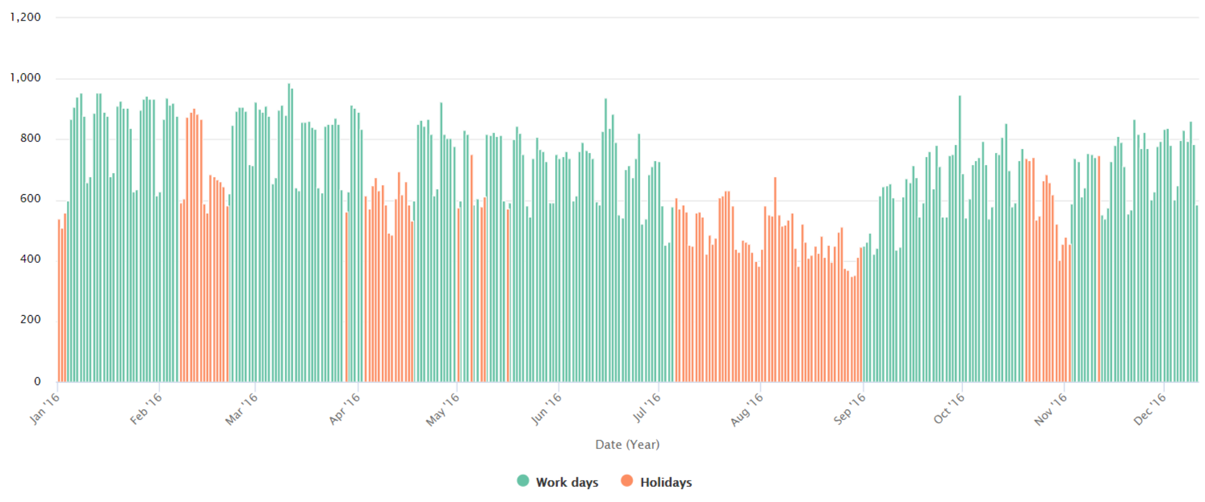



Figure 4.46: The water consumption during workdays and holidays of the year 2016

Figure 4.47 shows the water consumption in Saturdays and Sundays

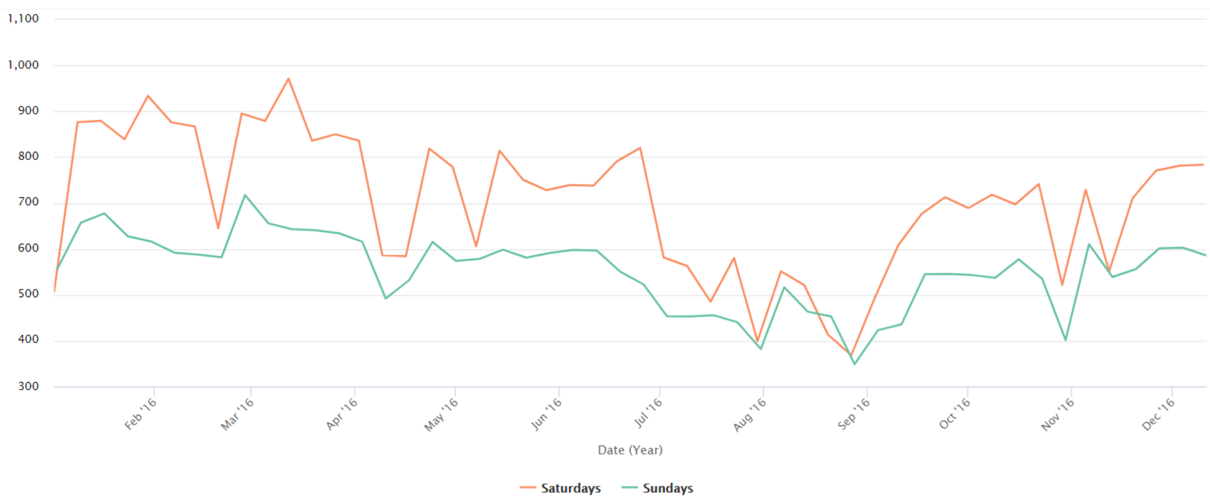



Figure 4.47: The water consumption in Saturdays and Sundays of the year 2016

Then the mean value M and the standard deviation SD are evaluated for each category. Table 4.8 shows the results with $\alpha = 1$, while Table 4.9 shows results with $\alpha = 2$.



Table 4.8: TWCP with (α = 1) (values are given in m³)

| | $M_B$ | $SD_B$ | $L_1 = M_B + SD_B$ | Events exceeding L1 |
|---|---|---|---|---|
| **Working Days** | 740 | 133 | 873 | 43 |
| **Saturdays** | 701 | 135 | 837 | 9 |
| **Sundays** | 552 | 74 | 627 | 7 |
| **Holidays** | 556 | 95 | 651 | 21 |

Table 4.9: TWCP with (α = 2) (values are given in m³)

| | $M_B$ | $SD_B$ | $L_2 = M_B + 2\ SD_B$ | Events exceeding L2 |
|---|---|---|---|---|
| **WD** | 740 | 133 | 1006 | 0 |
| **Saturdays** | 701 | 135 | 972 | 0 |
| **Sundays** | 552 | 74 | 701 | 1 |
| **Holidays** | 556 | 95 | 746 | 5 |

We observe some values exceeding the threshold. Since these values could be related to leaks, they are eliminated then analyses are conducted with the new values. Results of these new analyses are summarized in Tables 4.10 and 4.11 as well as in figures 4.48 and 4.49.

Figure 4.49 shows a high probability of leak during the holidays between February 9 and 13, 2016. The water consumption exceeds the threshold during this period. The onset of this leak is detected clearly on February 9. An abnormal consumption is also observed between October 20 and 22 2016. Two abnormal consumptions are also reported May 5, and November 11



Table 4.10: TWCP after eliminating with (α = 1)

| | $M_A$ | $SD_A$ | $L_1 = M_A + SD_A$ | Events exceeding L1 |
|---|---|---|---|---|
| **WD** | 740 | 133 | 873 | 43 |
| **Saturdays** | 701 | 135 | 837 | 9 |
| **Sundays** | 549 | 71 | 621 | 7 |
| **Holidays** | 536 | 74 | 610 | 29 |

Table 4.11: TWCP after eliminating with (α = 2)

| | $M_A$ | $SD_A$ | $L_2 = M_A + 2\ SD_A$ | Events exceeding L2 |
|---|---|---|---|---|
| **WD** | 740 | 133 | 1006 | 0 |
| **Saturdays** | 701 | 135 | 972 | 0 |
| **Sundays** | 549 | 71 | 692 | 0 |
| **Holidays** | 536 | 74 | 684 | 11 |




Figure 4.48: Daily consumption in Holidays in the year 2016 before eliminating values


Figure 4.49: High probability of leakage detection during the holidays

ODS provides powerful visualization tools for creating web applications, any created map, chart, analysis and table can be inserted as a widget to the web application. This helps users to interact easily with existing data. Figure 4.50 illustrates an example of a web application created with ODS tools. This application contains in the left a map of the CITE SCIENTIFIQUE with both buildings and water network; the sensors of the network are colored depending on its category. By clicking on a sensor, information about this sensor appears on the right, it contains:

- Analysis table with dynamic data (minimum, maximum, average, standard deviation and total)
- Static information: such as category, serial number, meter number, and label.
- Chart about the consumption of this sensor with a dynamic filter.



This web application allows to analyze and compare the consumption of two sensors or more. Information could be managed through the ODS dashboard.

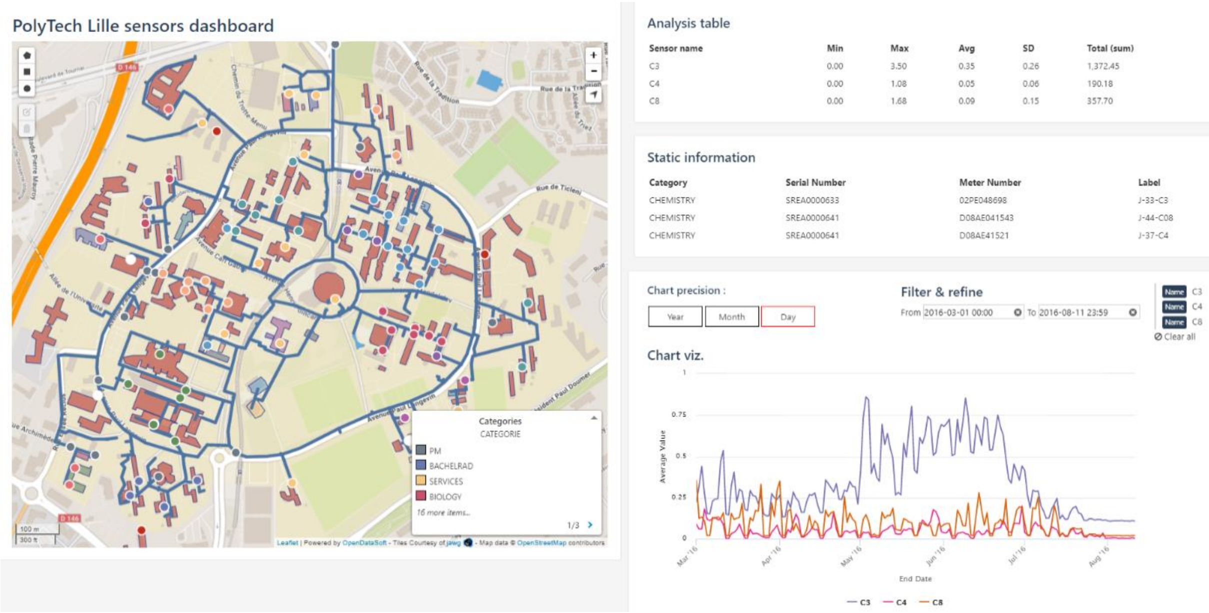



Figure 4.50: A web application created with ODS tools

## 4.6 Conclusion

In this chapter, we have described the use of two professional platforms for management of SunRise Smart City project.

We have presented the PI System and its components then we have described its implementation for the management of SunRise demonstrator. PI system tools have been used to implement two methods for water leakage detection : (i) the Global Balance method that allow the determination of the volume of water lost, and (ii) the Threshold Water Consumption Profile method that determines water leak by deviation from expected consumption. PI System contains interesting requirements to manage the Smart City, in particular its ability to connect and get data from different sources, to analyze real time and historical data and to visualize data in a friendly environment.

We have also presented the platform OpenDataSoft and its implementation for the management of SunRise demonstrator. ODS is used for data visualization more than data analysis. This platform offers also interesting facilities for the management of the Smart City, in particular the ability to process large-scale, real-time data from IoT objects and to transform these data into interactive visualizations like maps and charts as well as an Application Programming Interface (API)-centered design.

In the next chapter, we will present the development of a new platform for the management of SunRise demonstrator.



# Chapter 5
# Development of the Platform SunRise

# Chapter 5 – Development of the Platform SunRise

This chapter describes the development of SunRise platform for the management of SunRise Smart City project. It takes into consideration the requirements presented in Chapter 2. In the first section, we present the platform architecture, while the second section describes the platform development stages and the tools that have been used. Finally, we describe the implementation of the platform in the SunRise project.

## 5.1 Introduction

The development of the SunRise platform is a part of SunRise project. It aims at the construction of a flexible and open platform that meets SunRise requirements and which could easily extended to include additional functionalities. This platform is adapted to small scale urban entities such as the Campus.

## 5.2 Architecture of SunRise Platform

Figure 5.1 illustrates the overall architecture of the SunRise platform, which is the middle layer between data sources and smart city applications. It consists in 5 layers: data collection, data storage, data analysis, data visualization and Users' interface.

How is the SunRise platform works at the high level? First, data with different formats are collected via the data collection layer from multiple data sources, then they are processed and aggregated by a set of pre-defined processing tasks. These processors transform data into new formats or creating new structured tables to index data, they perform complex and intensive processing tasks as well, such as aggregating or mining data via advances data analytics. Then the processed data are forwarded to the storage layer. Some modules are developed in the analysis layer to perform required analysis by fetching data from storage layer for its input and display the results in the data display layer as its output. Users' interface has been developed to facilitate users' interaction using some tools such as interactive maps. The development details are discussed in the following section.



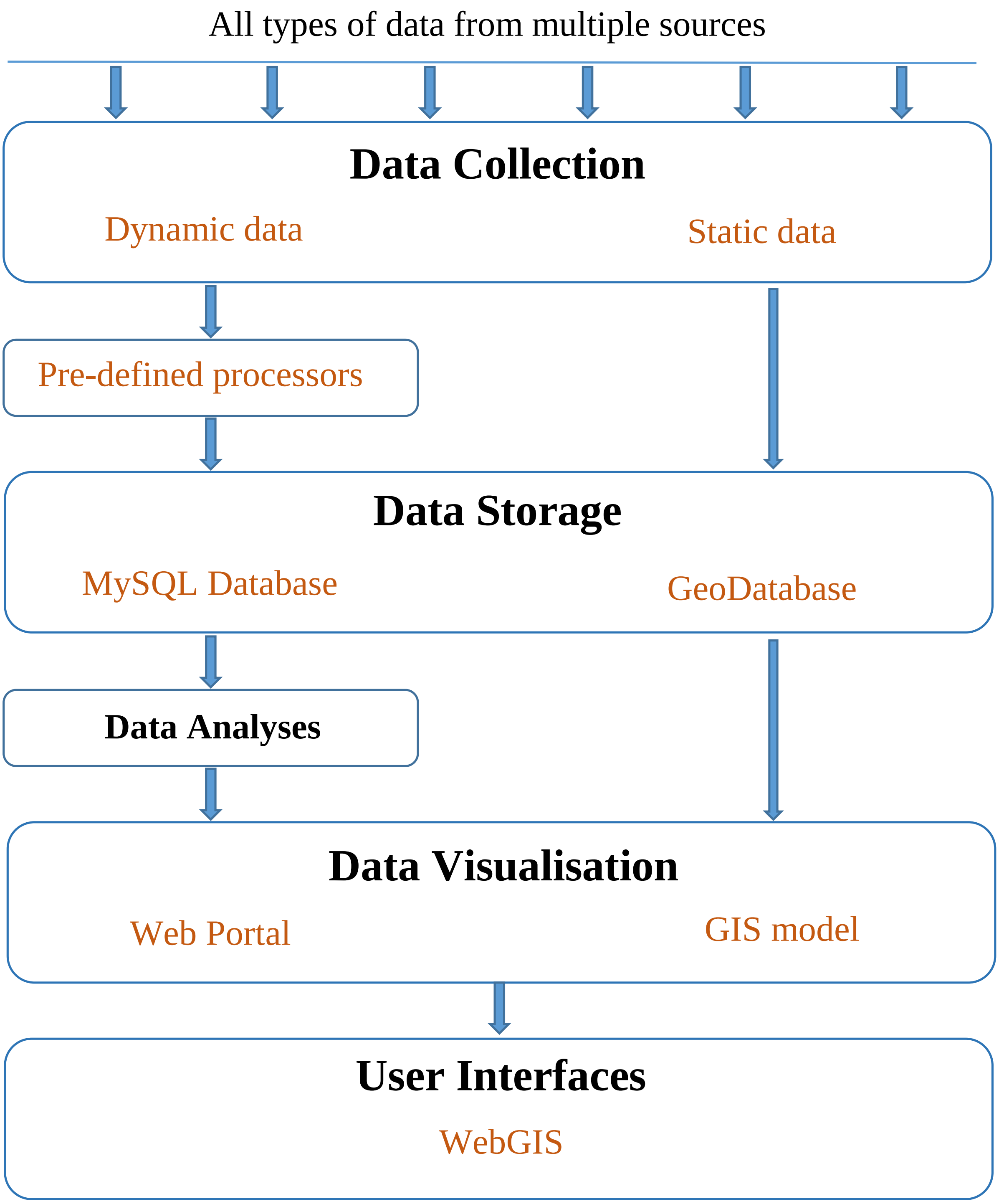



Figure 5.1: The architecture of SunRise platform

## 5.3 SunRise platform development

### 5.3.1 Data collection

Data can be collected from various sources such as urban networks, buildings, transportation, weather conditions, economic activity, and social media. The biggest challenge in data collection is to deal with the diversity of data formats data. Since we do not own the sensors, which are installed in the campus, data is collected from web servers of the sensors' managers. Data is divided into two parts: static and dynamic data. Static data concerns the characteristics of sensors, buildings, pipes etc. of the campus. It contains XY coordinates, serial numbers, installation dates, etc. so it is saved directly in Geodatabase (GDB) in the storage layer, which will be discussed later. The dynamic data contains consumption values, start and end dates, counters indexes, etc. In order to provide a unified interface for the dynamic data an open source software has been used called KNIME. It has pre-defined processors as blocks, which can read different types of files, treat and forward them directly to the data storage layer using writer processors.

### 5.3.2 Data storage

All data and information collected from various sources are saved in a Structured Query language (SQL) database as tables, including the historical and latest real-time data. The decision to go to MySQL database was made regarding the structure of collected data. It provides a built-in HTTP REST API, which allows other components of the platform to read and write directly. This provides convenient and flexible interfaces for external processing modules to conduct data analytics outside of the storage layer. MySQL is able to notify external components whenever there is a change into the database.

The structure of the database is designed to be as simple as possible. Each network in the campus is represented by a table in the database. This table has three columns date time, sensor name, and the value. Historical data from 2012 to the end of 2016 are converted from excel sheets and stored in the database. The number of records (rows) depends on the number of sensors and the time of sending data, for example we have 93 sensors in the water network, they send their data each hour. It means:

- 93 * 24 = 2 232 records per day.
- 2 232 * 365 = **814 680** records per year.
- 814 680 * 4 = **3 258 720** records from 2012 to 2016.

Whereas the heating network has 42 sensors and they send data each hour as well after that means **367 620** records per year and **1 471 680** records from 2012 to 2016.

### 5.3.3 Data analysis

Data analyses in SunRise platform is divided into two types: internal analysis and external analysis. Internal analysis is conducted by the MySQL database, while external analysis is executed out of the MySQL database.

➢ **Internal analysis**

Internal analysis operates data aggregation and it must be triggered by a query, PHP programming language is used to build queries. It can fetch data directly from MySQL database, performs simple analysis, and then forward the results of a query to the visualization layer. In the following some examples of created queries:

- Get the list of existing sensors in the database grouped by networks or sections.
- Get statistics about a sensor consumption such ad MIN, MAX, AVG, and Total consumption, the sensor name must be passed to the query as a parameter.
- Filter a sensor’s data in date and time scale monthly, weekly, daily and custom range of time.
- Compare two or more sensors statistics.
- Get statistics per section.
- Get sensors values in specific time.
- Add, Delete, and Update information.

➢ **External analysis**

External analysis is more flexible and less limited than internal one in terms of computation resource and programming language. An external analysis task fetches data from MySQL, perform some analysis and then transmits output results back to MySQL database. It can be implemented in any language such as MATLAB, as long as it can communicate with MySQL database. For instance complex and intensive data analyses such as data mining, clustering, and classification are operated externally.

### 5.3.4 Data display and visualization

Data display and visualization constitute an important component of the Smart City Platform. They aim at presenting huge and complex data and information in an easily, understandable and attractive way. In the SunRise platform, a GIS model of all the campus networks has been created to present the static data. A GIS is a computer-based tool that contains all type of information based on geographic location (William 2016). Each network in the campus is presented as a layer or a set of layers. For example, buildings are represented by a layer of polygons, while the water network is represented by a set of layers, a layer of lines corresponding to pipes, a layer of nodes matching either the water supply points or the connection between the pipelines, and a layer of points corresponding the water meters (Figure 5.2). Each layer has an attribute table, which contains the static geographic information about the layer such as (meters names, serial numbers, surfaces of buildings, shapes, XY coordinates, etc.), the collection of the attribute tables of all layers constitutes the geo-database.

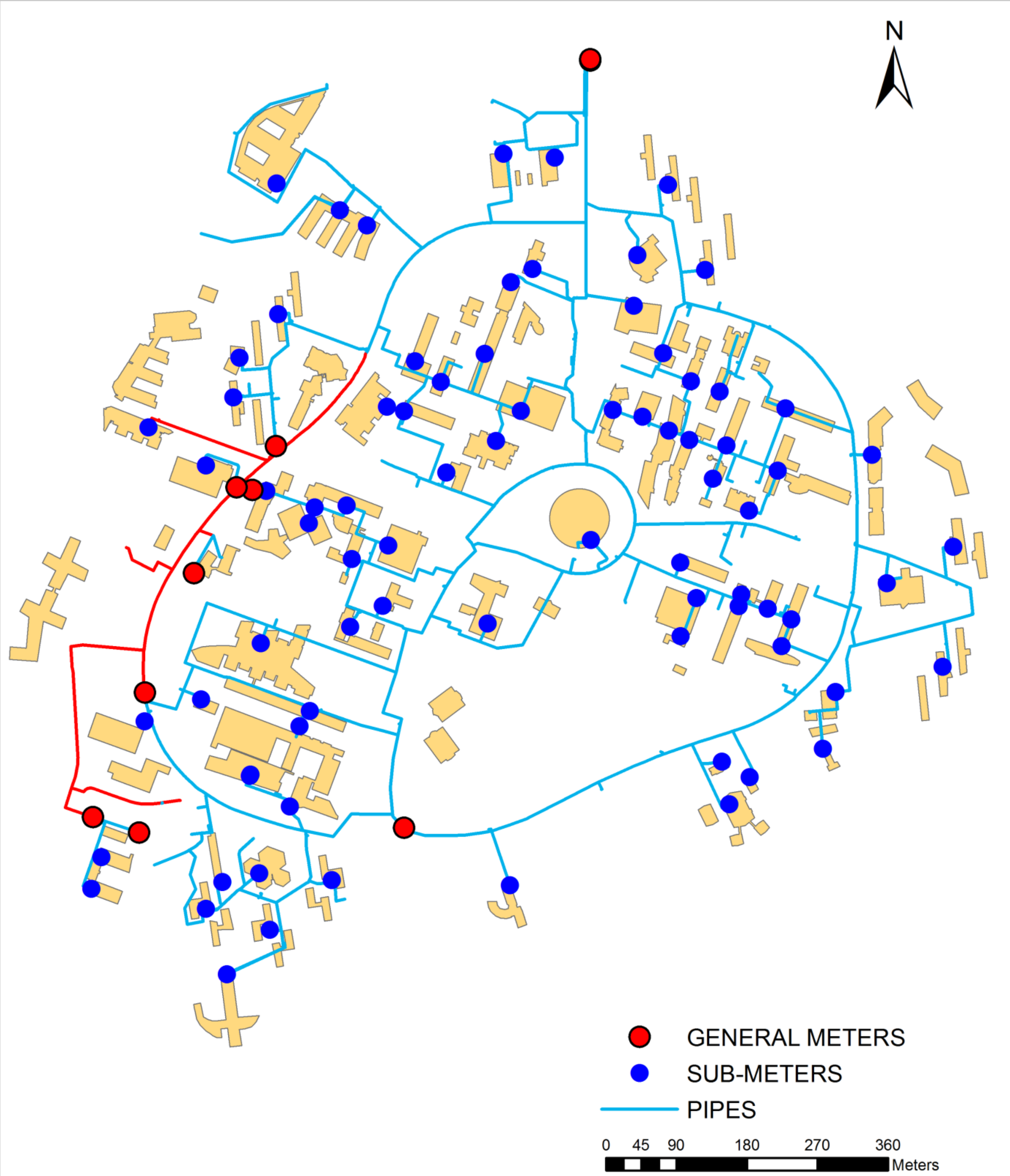



Figure 5.2: GIS Model of the water network

A web portal has been developed for visualizing the dynamic data; it is connected to the GIS model, which contains the static data. In the following two sections, we give a brief presentation of the architecture of the portal and the used tools; then we describe the methodology used to create a connection between GIS model and the web portal.

#### 5.3.4.1 Web portal Architecture

Hierarchical Model View Controller (HMVC) architecture pattern is used in the development of the web portal, which is a direct extension to the MVC pattern. The Model-View-Controller (MVC) architectural pattern separates an application into three main groups of components: Models, Views, and Controllers. Each one is in charge of the following tasks.

- Contoller: it manages the user HTTP requests triggered when a user clicks on GUI elements to perform actions. The Controller chooses the View to display to the user, and provides it with any Model data it requires.
- Model: it is a set of classes, each class contains many functions, which communicate and retrive data directly from the database.
- View: it provides different ways to present the data received from the model.

The Model View Controller pattern is illustrated in Figure 5.3.

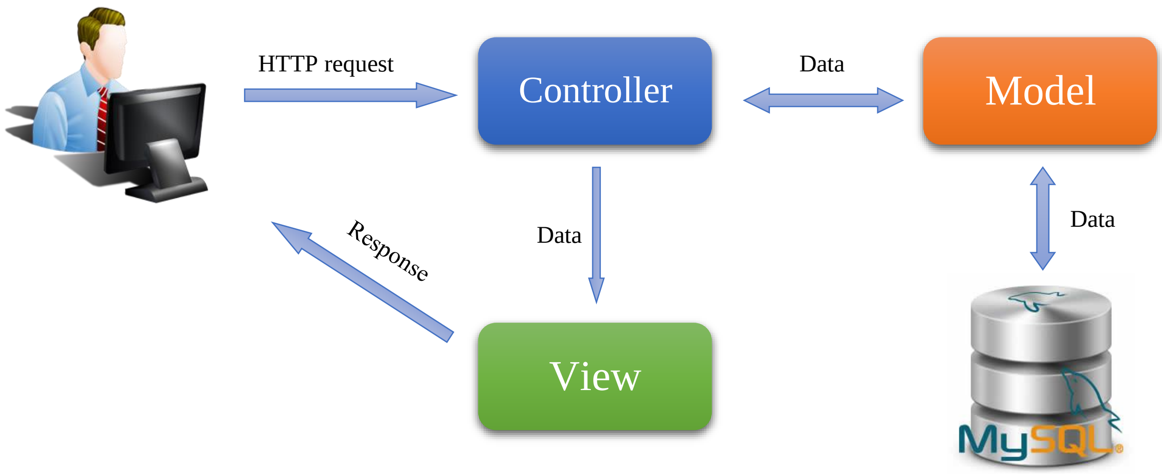



Figure 5.3 : Model-View-Controller pattern

The HMVC pattern is used to provide more scalability to the portal, it is a chain of MVC traids where a controller may pull in various different models and have a single view to compose the results, implementing this pattern has several advantages:

- **Modularization:** Reduction of dependencies between the disparate parts of the application.
- **Organization:** Having a folder for each of the relevant triads makes for a lighter work load.
- **Reusability:** By nature of the design it is easy to reuse nearly every piece of code.



- **Extendibility:** Makes the application more extensible without sacrificing ease of maintenance.

HMVC pattern is illustrated in Figure 5.4.

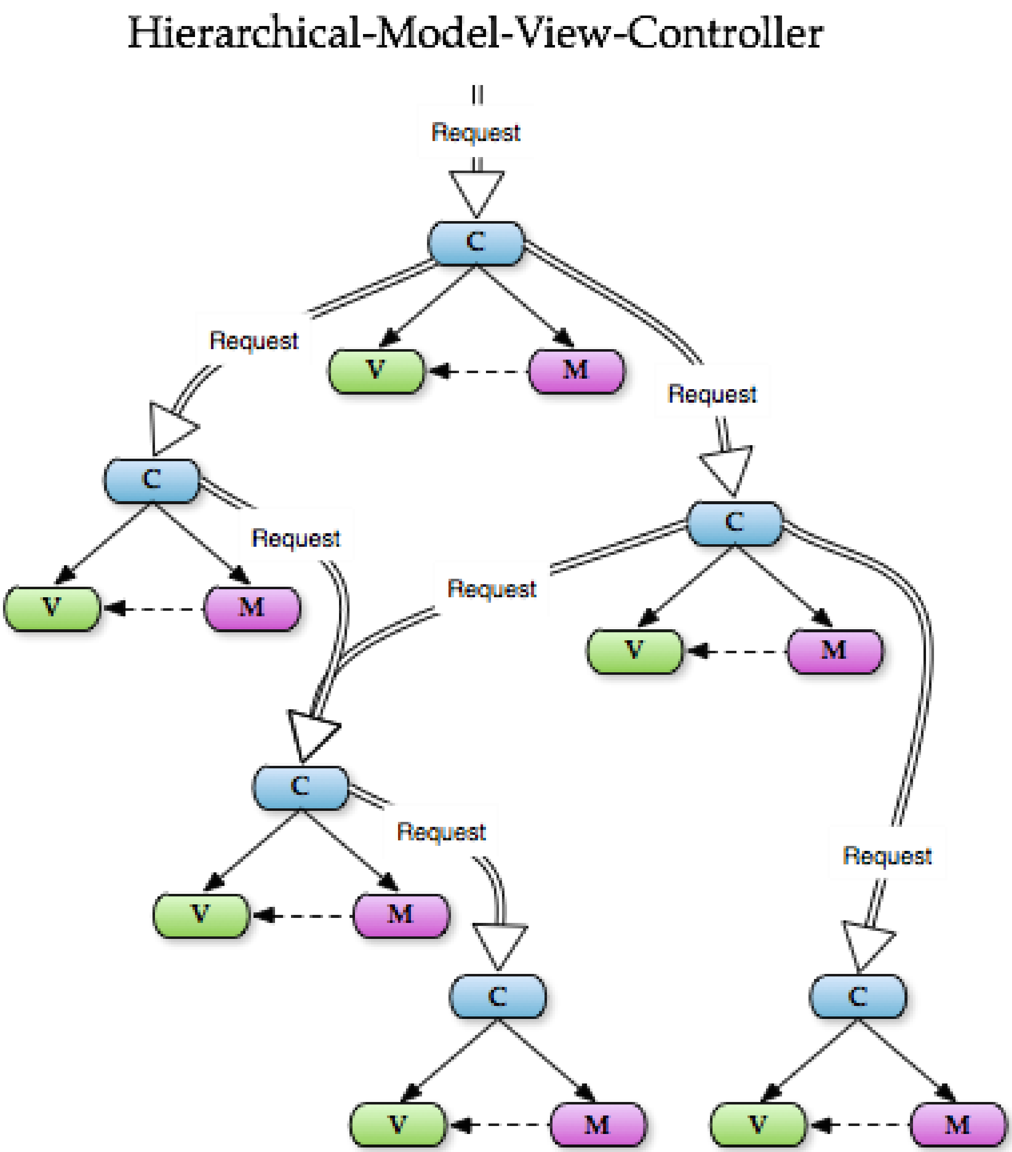



Figure 5.4: Hierarchical-Model-View-Controller pattern (Source: inviqa.com)

Many open source tools and models are used in the development. Open source tools provide the entire instrument necessary to build-up web solutions. Any open source software according to (Wheeler 2015) must grants the following freedoms:

- To run the program for any purpose.
- To access to the source code and study how the program works.
- To redistribute copies for helping others.
- To make it available for public.



In the following, we give a brief presentation of the tools used in the web portal development:

a) **HTML**

It stands for Hypertext Markup Language, is the standard markup language for creating the structure of web pages. It includes a set of markup tags, each tag describes different document content. Browsers use these tags to render the content of the page ("HTML Tutorial"). It works with:

- Cascading Style Sheets **(CSS)**, which is a language for styling the rendering of HTML documents such as font size, background colors, etc.
- **JavaScript,** which is a cross-platform, object oriented client side scripting language used to make HTML pages interactive such as complex animations, clickable buttons, etc.

**b) PHP**

It stands for Hypertext Preprocessor, it is a server scripting language, it is used for making the web pages dynamic and interactive. It communicates directly with the MySQL database to fetch required data depending on a query ("PHP: Hypertext Preprocessor").

**c) CodeIgniter**

It is an open-source software rapid development web framework, for use in building dynamic web sites with PHP. It is loosely based on the popular model–view–controller (MVC) development pattern. It can be also modified to use Hierarchical Model View Controller (HMVC), which allows developers to maintain modular grouping of Controller, Models and View arranged in a sub-directory format ("CodeIgniter Web Framework").

**d) Apache**

It is an open source web server, it receives HTTP requests from the client-side and sends back HTTP response, which renders web pages (" The Apache HTTP Server Project").

**e) Highcharts**

It is a charting library written in pure JavaScript, it offers an easy way to add interactive chart to web applications. I provides a wide variety of charts, such as spline, area ,bar charts, etc. ("Interactive JavaScript Charts for Your Webpage | Highcharts").



Figures 5.5 and 5.6 show an example of integrating the dynamic data of the water network in the campus with the developed web portal.

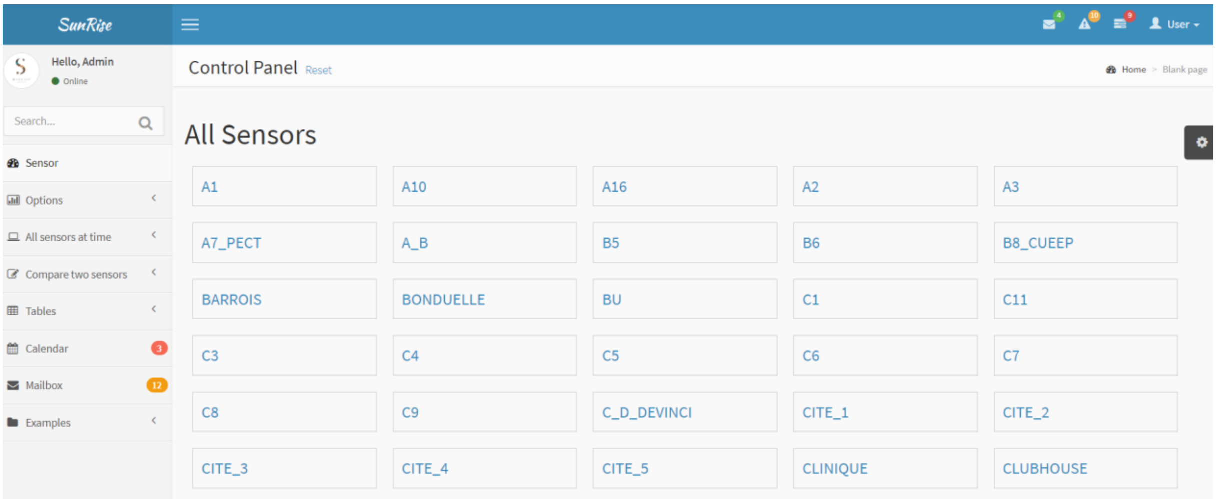



Figure 5.5: The list of the some existing sensors in the water network

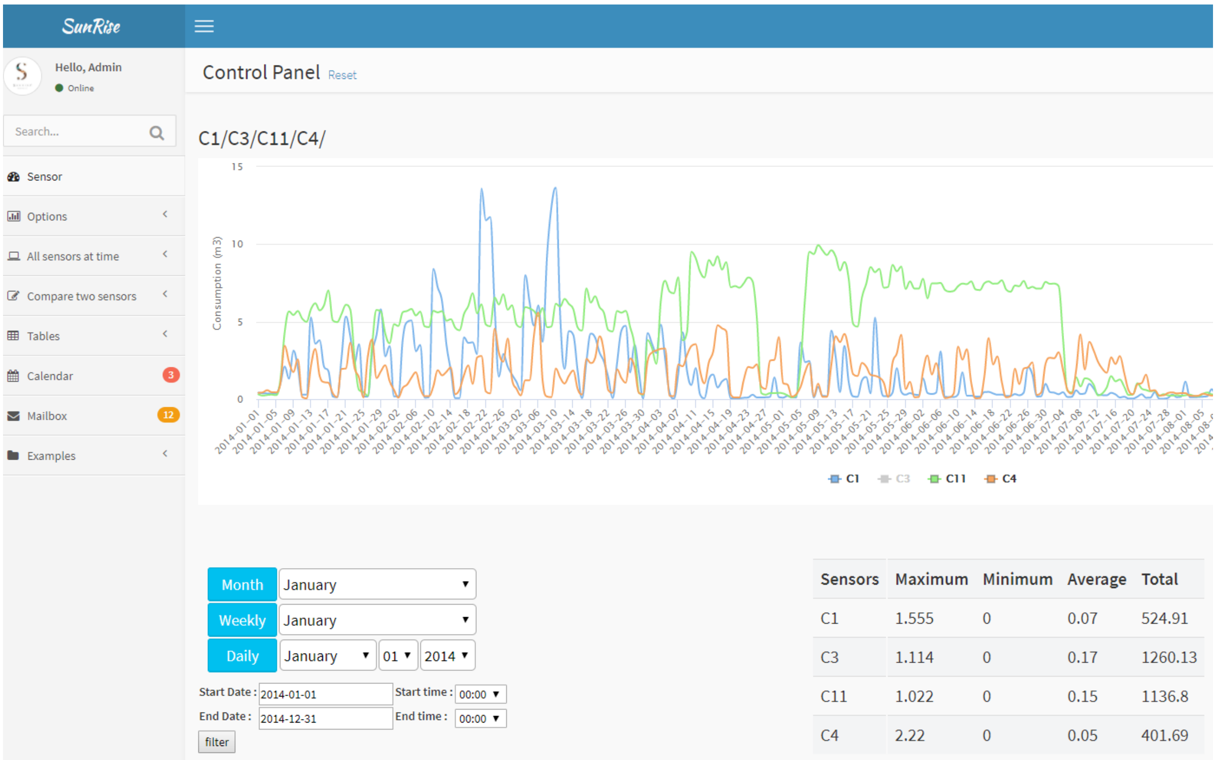



Figure 5.6: Comparison the water consumption between the buildings of Chemistry sector in a period of time

### 5.3.4.2 Connecting dynamic and static data

The drinking water system in the Campus is used as an example for connecting the static and dynamic data to create a dynamic visualization. The water system is represented as layers in ArcGIS software. The HTML pop-up feature is used to create the connection between the GIS model and the web portal. Pop-up HTML enables users access to formatted content such as XML and HTML web pages for each feature by clicking on the feature. It can be customized directly from ArcGIS as shown in Figure 5.7.



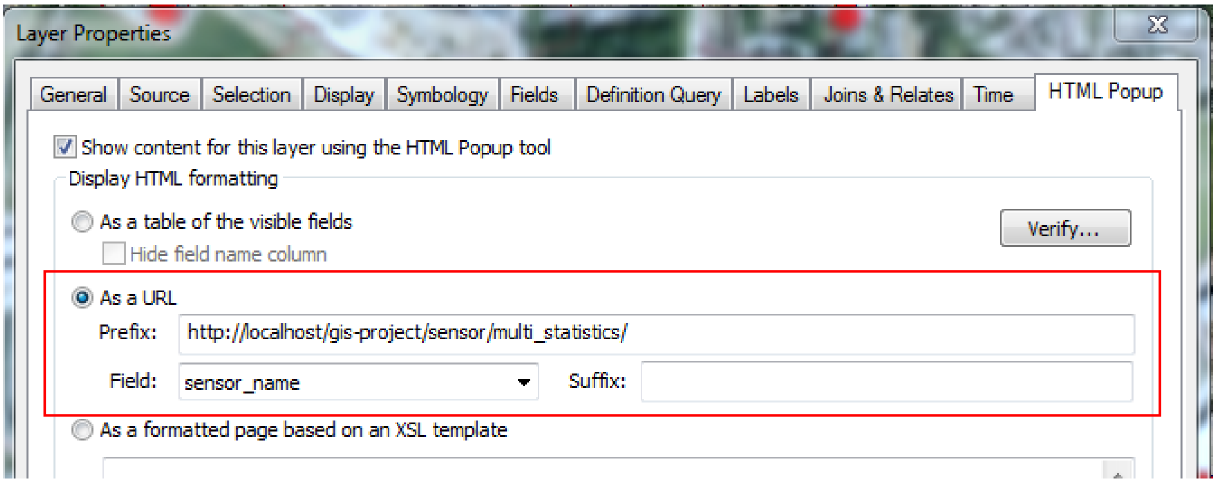



Figure 5.7 : Pop-up HTML configuration

The popup HTML needs a URL for the HTML page, which will be displayed by clicking on the feature. The web portal is hosted on the server of the University of LILLE1, so it can be accessed by the link (http://sunrise.univ-lille1.fr/gis-project), sensor word in the link refers to the sensor module, and the multi_statistics refers to a function in the sensor controller. The clicked feature in determined in (Field:) field, sensor_name is a column of the attribute table for sensors layer. It contains all sensor's names. When a user clicks on a feature, the ArcGIS recognizes which one is clicked and joins its name with the provided URL. For example if the sensor C1 has been clicked, the URL will be like: (http://sunrise.univ-lille.fr/sensor/multi_statistics/C1). This will create an HTTP request and will send it to the server. This request triggers the function multi_statistics in the sensor controller to get statistics about the sensor C1 and they will be displayed in the popup HTML. The following chart describes how the mutli_statistics function works when a user clicks on a feature (Figure 5.8).



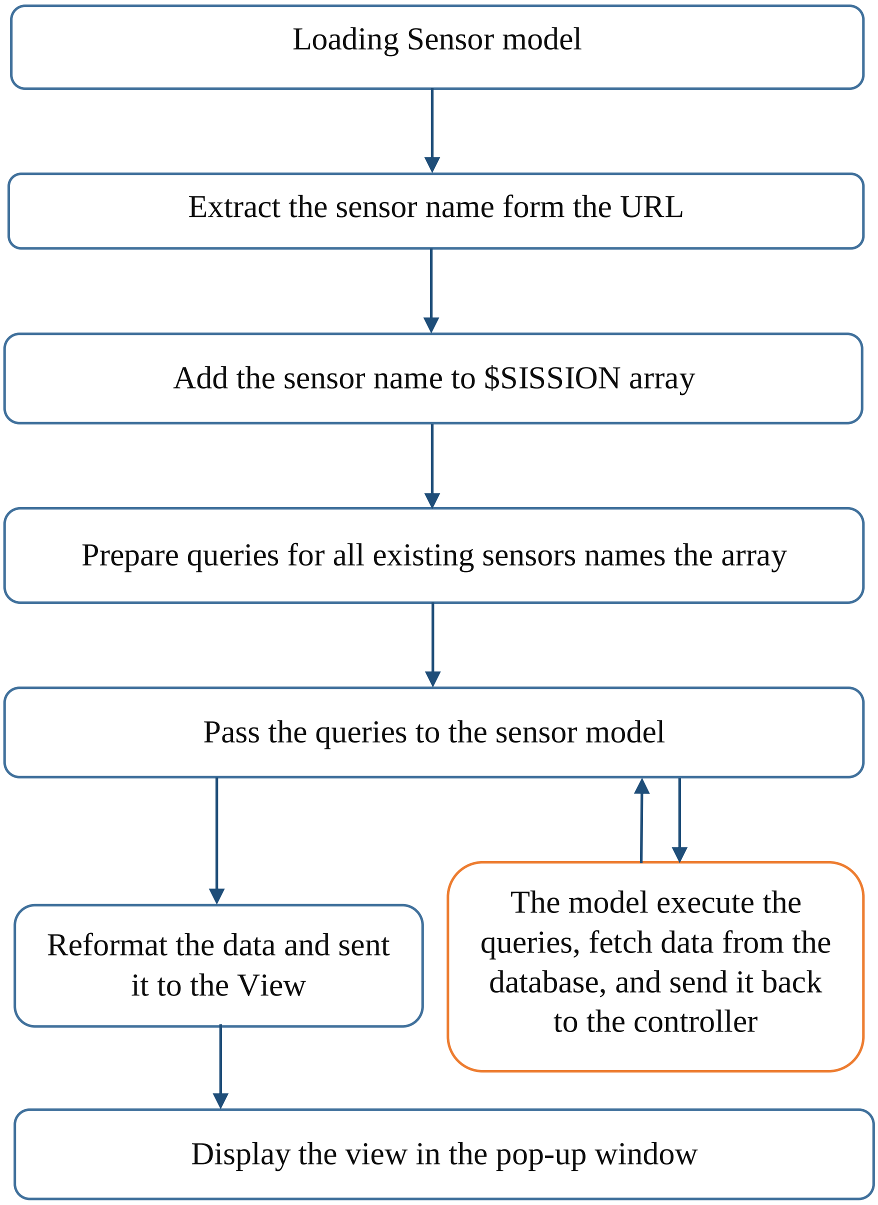



Figure 5.8: A flow chart for multi_statistics function

Figure 5.9 shows the result when more than one feature is clicked. The function multi_statistics, which has been used in this example is a simple function, performs internal analyses such as MIN, MAX, AVG, and Total for each clicked feature. It displays interactive curves, and provides an effective filter. With this filter, a user can control the curves to be displayed in Monthly, Weekly, Daily scales or in custom range of time. This function is useful for comparing the water consumption between different sensors. Other functions have been developed for performing more complex analyses.

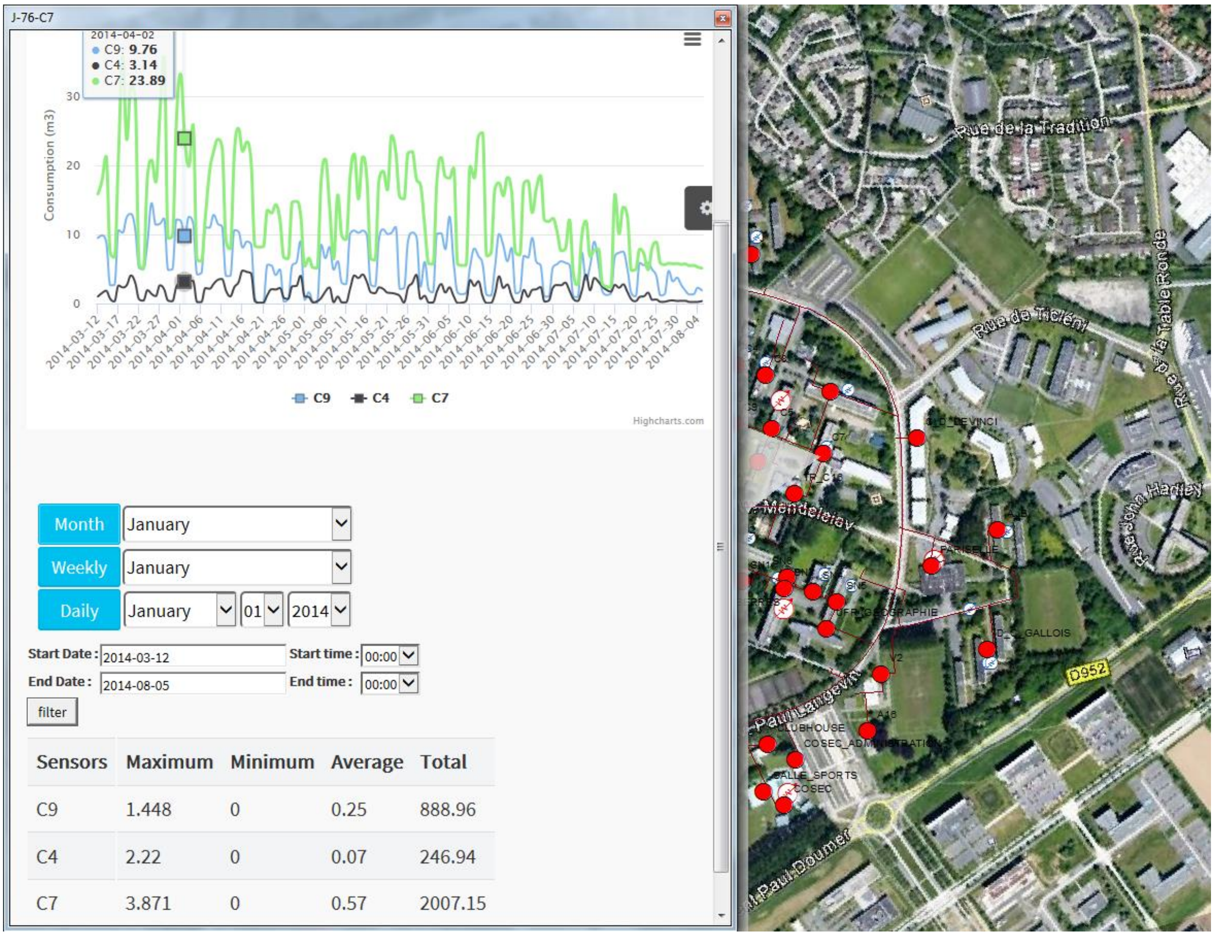



Figure 5.9: A compression between the water consumption of three sensors in CHIMESTRY sector

The MySQL database could be connected directly to the different data sources in the campus to save data in real-time. The same methodology could be implemented for each network and layer in the GIS model such as buildings, electric stations, etc. This helps the city managers to analyze data more quickly and keep everything under the control.

### 5.3.5 User interface and stockholders' interaction

The stakeholders' interaction is in the heart of the Smart City concept. The platform should integrate specific tools for the stakeholders' interaction (citizen, administrative, services providers, professional, and visitors). To achieve this goal, a WebGIS pattern is used for building user interfaces. WebGIS is the process of designing, implementing, generating and delivering maps, geospatial data, and geographic information system on the World Wide Web (Mathiyalagan et al. 2005). It uses web technologies especially open source solutions such as GeoServer, OpenLayers, etc. The decision to use WebGIS pattern was made regarding to two important points. The first point concerns accessibility; users can access, consult, and retrieve spatial data and participate in the decision making without geographic limitations. The second point aims at centralizing the system; all administration and can share, update, and get their spatial data in one place.



The following section presents tools used in the development of user interfaces and the implementation methodology.

**a) Apache and HTML**

Explained in section 5.3.4.1

**b) GeoServer**

An open source platform supports the Open Geospatial Consortium (OGC) standards like Web Map Service (WMS), Web Feature Service (WFS) and Web Coverage Service (WCS). Geoserver provides an admin panel that allows great flexibility for map creation and data sharing. It works with large range of data formats such as Shapefiles (.shp), GeoJson, MySQL, etc. ("GeoServer").

**c) OpenLayers**

An open source client-side JavaScript library, it facilitates creating interactive maps in web pages. It can display map tiles, vector data, and markers loaded from any source ("OpenLayers - Welcome").

### 5.3.5.1 Architecture of WebGIS

The simplest form of WebGIS should have at least a sever (web server) and a client (browser). Figure 5.10 gives an overview of the various components. The client-side is the user interface, which contains the interactive. It provides a user with functions, which allow them to interact with the map. The server-side includes the web and map servers, it performs the processing tasks and response the user's requests. The third component is the data-side, which is a GIS software to create the geospatial database and a GIS model. Then then GIS model is exported as shapefiles, and imported to the map server.

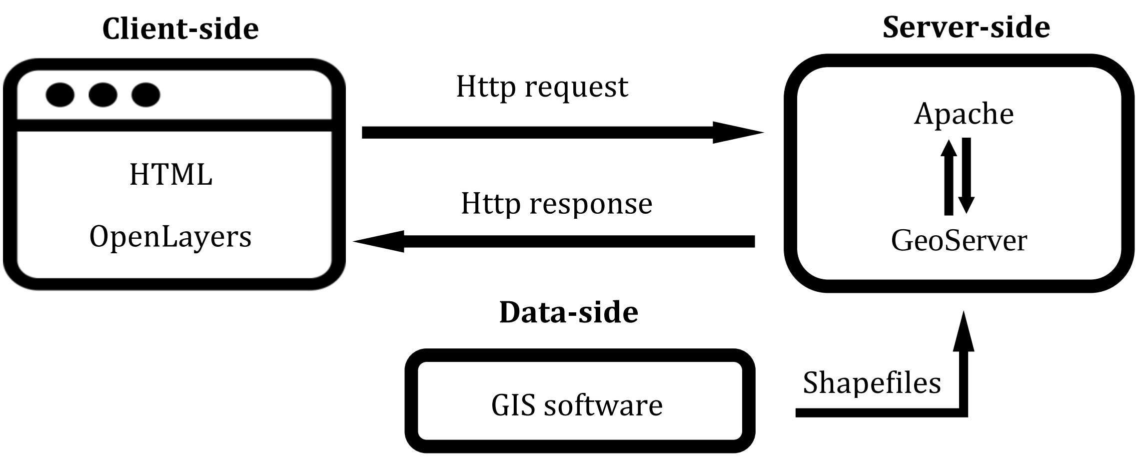



Figure 5.10 : WebGIS architecture

When a user request data from the web server using a web browser, Apache establishes a connection with Geoserver and pass the HTTP request to it. Geoserver receives the request, perform the required processes, and sends back the result to the web server, which sends the results to the client-side. Openlayers process the results and transform them into shapes, tables, images, etc. for the user on the browser.

#### 5.3.5.2 Implementation and results

The implementation of server-side is conducted as follows: (i) Geoserver and Apache web server have been installed on the server of the university; (ii) the GIS model that has been created previously (layers and attribute tables) is exported as shapefiles (.shp) and compressed in zip files; (iii) the compressed files have been uploaded to the data folder, which is created by Geoserver in this path: (../Geoserver/data_dir/); (iv) each shapefile is customized using the Geoserver admin panel.

Figure 5.11 shows an example of Geoserver admin panel. In the red rectangle we can see the layers, which have been customized. The number EPSG:2154 is the projected coordinate system in France.

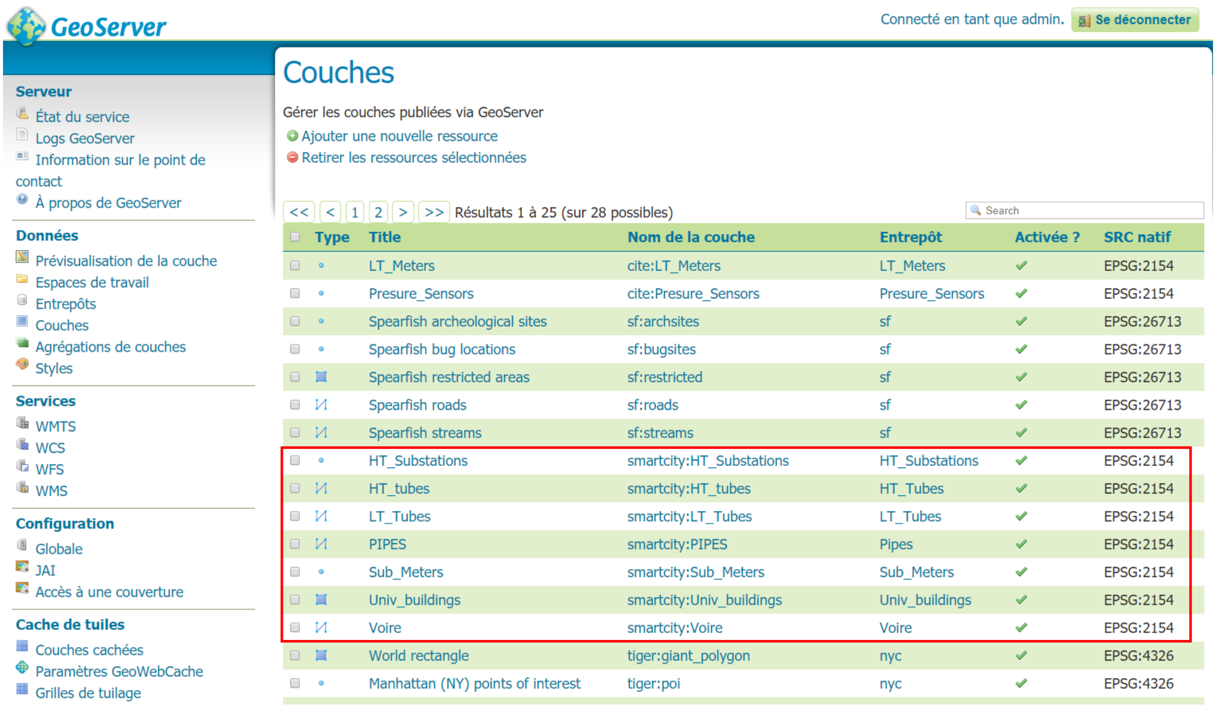



Figure 5.11 : Geoserver admin panel

For the client-side, an HTML page has been created to display the map. This page contains the script, which has been written using OpneLayers JavaScript library. This script has different functionalities, such as:

1. Initialize the layers, which will be displayed of the map. Figure 5.12 shows an example of initializing sub meters layer of the water network. In the first block in the code a layer has been created, the data source has been set in the URL, which refers to the uploaded layer on Geoserver, and the format of data has been set to GeoJson, which is

a format for encoding a variety of geographic data structures. The second block in the code specify a style for this layer such as image, colors, etc.

```
//Initialize SUB METERS Layer
var meters = new ol.layer.Vector({
    source: new ol.source.Vector({
    url:'http://sunrise.unive-lille1.fr/geoserver/smartcity/ows?service=WFS
         &version=1.0.0&request=GetFeature&typeName=smartcity:Sub_Meters
         &outputFormat=application/json' ,
        format: new ol.format.GeoJSON({
            defaultDataProjection :'EPSG:2154',
            projection: 'EPSG:3857'
        })
    }),
    style: new ol.style.Style({
        image: new ol.style.Circle({
            fill: new ol.style.Fill({ color: [255,0,0,1] }),
            stroke: new ol.style.Stroke({ color: [0,0,0,1] }),
            radius: 8
        })
    }),
    name: 'Meters'
});
```

Figure 5.12: Initializing SUB METERS layer

2. Initialize the map and add layers. Figure 5.13 shows simple settings for the map, OpenStreetMap (OSM) has been selected as the base map, it is a free wiki world map.

```
var map = new ol.Map({
    layers: [
    new ol.layer.Tile({
        source: new ol.source.OSM()
    }),
    voires,

    //Buldings
    univ_buildings,
    res,
    //Heating network
    lt_tubes,
    ht_tubes,
    lt_meters,

    //Electric network
    ht_substaions,
    fiber_obtic,

    //Water network
    pipes,
    presure_sensors,
    meters
    ],
    overlays: [overlay],
    target: selector,
    view: new ol.View({
        center: ol.proj.transform([710074.61,7056933.63], 'EPSG:2154', 'EPSG:3857'),
        //center: ol.proj.fromLonLat([3.1398773,50.6092764]),
        zoom: 15.6
    })
});
```

Figure 5.13 : Map initialization



The layers of each network have been added to the map. The center of the map is set to be the center of the campus.

3. Customize the popup window to contain the static data for the clicked feature and a link to its the dynamic data.
4. Drag box function, which allows displaying the dynamic data for a set of selected features.

A user can access to this interface by a web browser and the following link: (http://sunrise.univ-lille1.fr/Campus). Figure 5.14 shows the developed user interface. It is divided to two parts, the first part on the left contains a list of existing networks, and the second part on the right contains the interactive map of the campus. The water network, electric fiber optic, and the buildings are presented in this map.

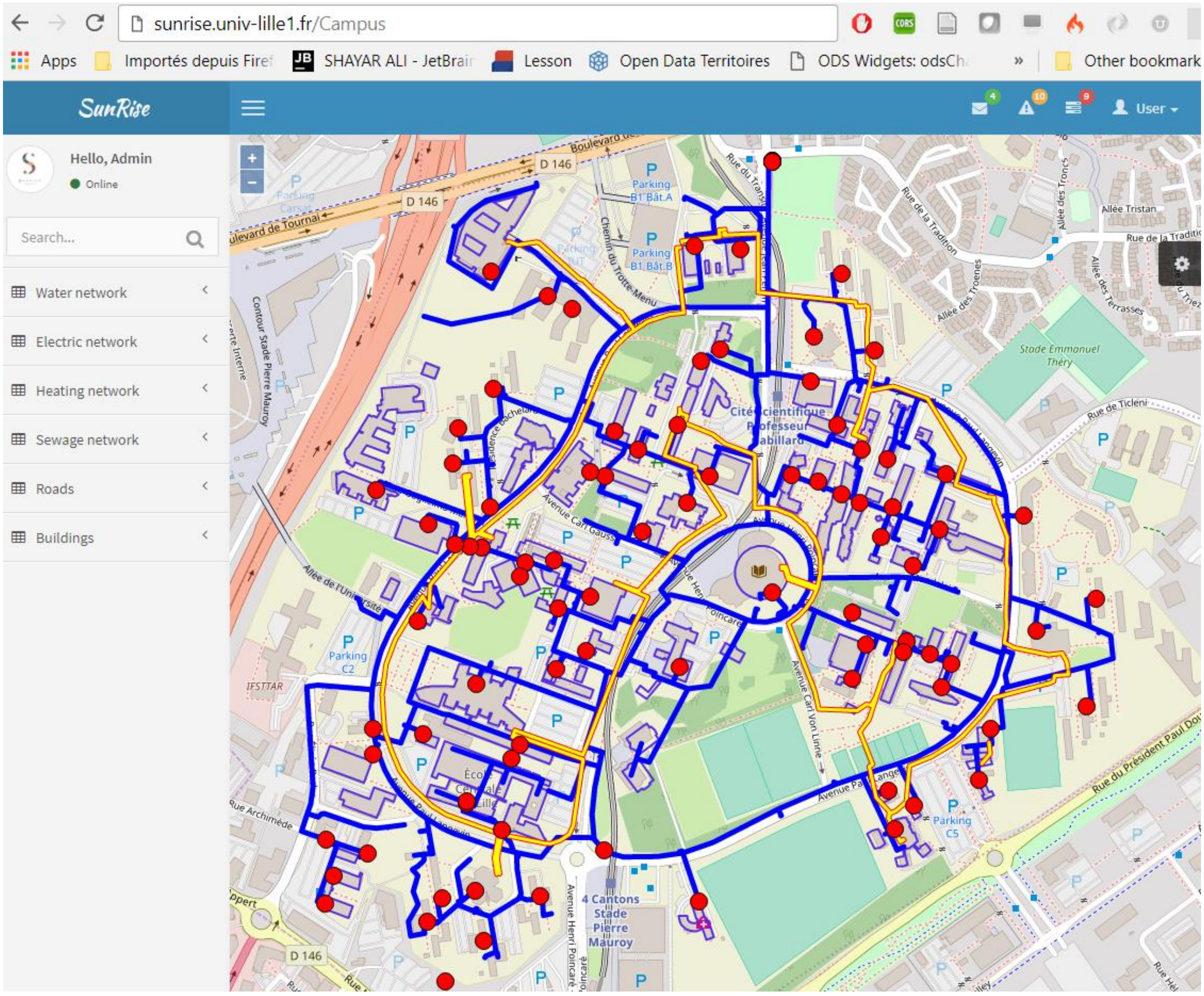



Figure 5.14: The users interface

All layers on the map are clickable, a popup window has been customized to display related data about the feature. Figure 5.15 shows an example of the popup window when a user clicks on the sensor A3. Information about the sensor are displayed in the popup window. The sensor name is customized to be linked with the web portal created previously. Its color changes to blue to be recognized.



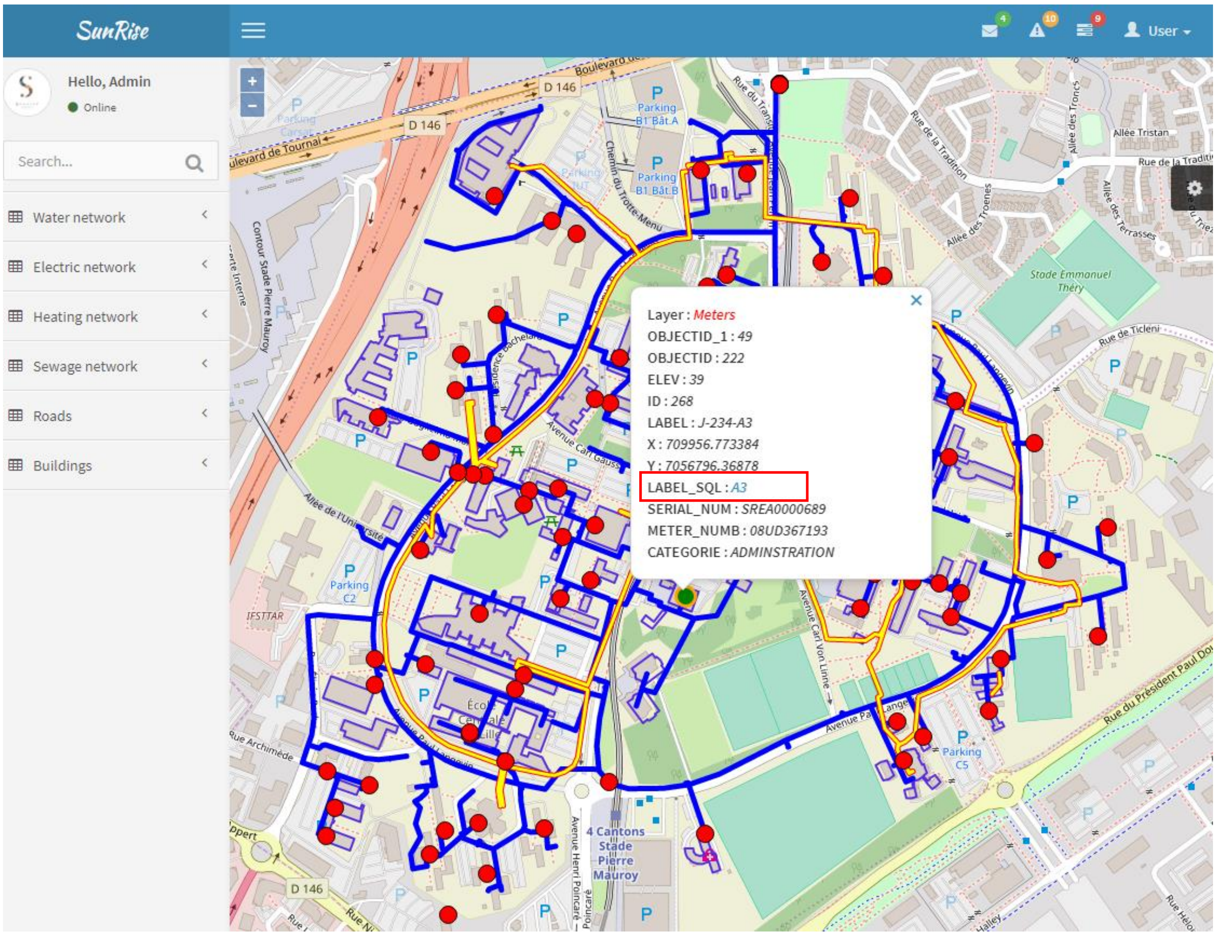



Figure 5.15: An example of popup window

When a user clicks on the name of the sensor, another page opens and display the dynamic data for the sensor Figure 5.16.

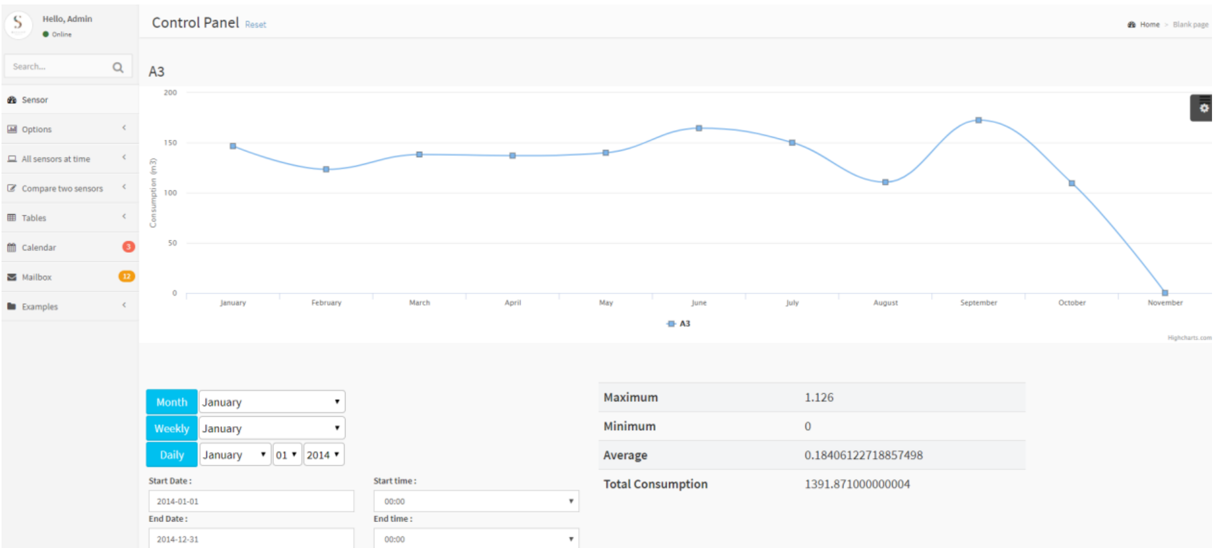



Figure 5.16: Dynamic data for the clicked sensor



Another important feature has been developed for the users' interface, which is the ability to select and compare more than one feature in the same layer. Figure 5.17 and 5.18 show examples of comparing sensors in the buildings of Chemistry sector.

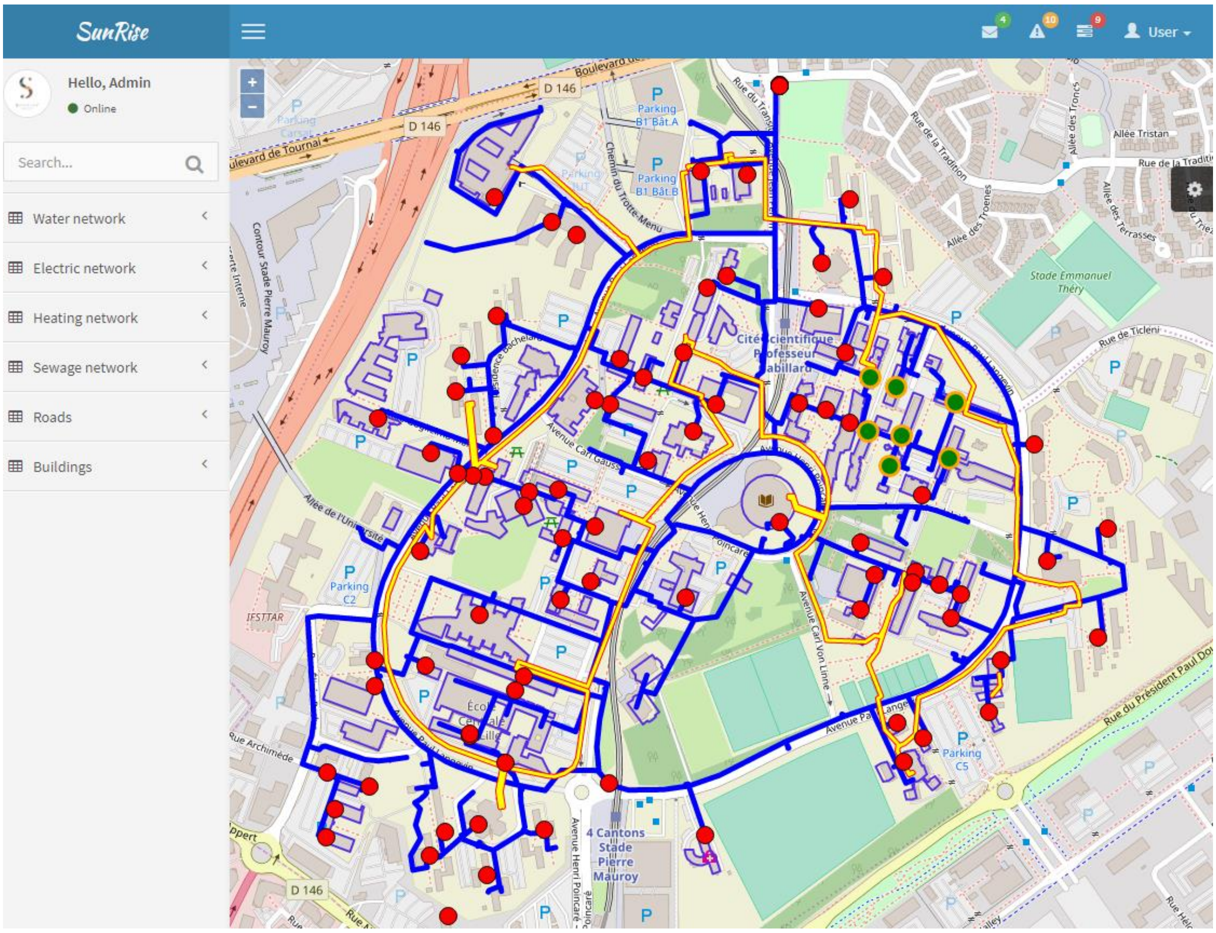
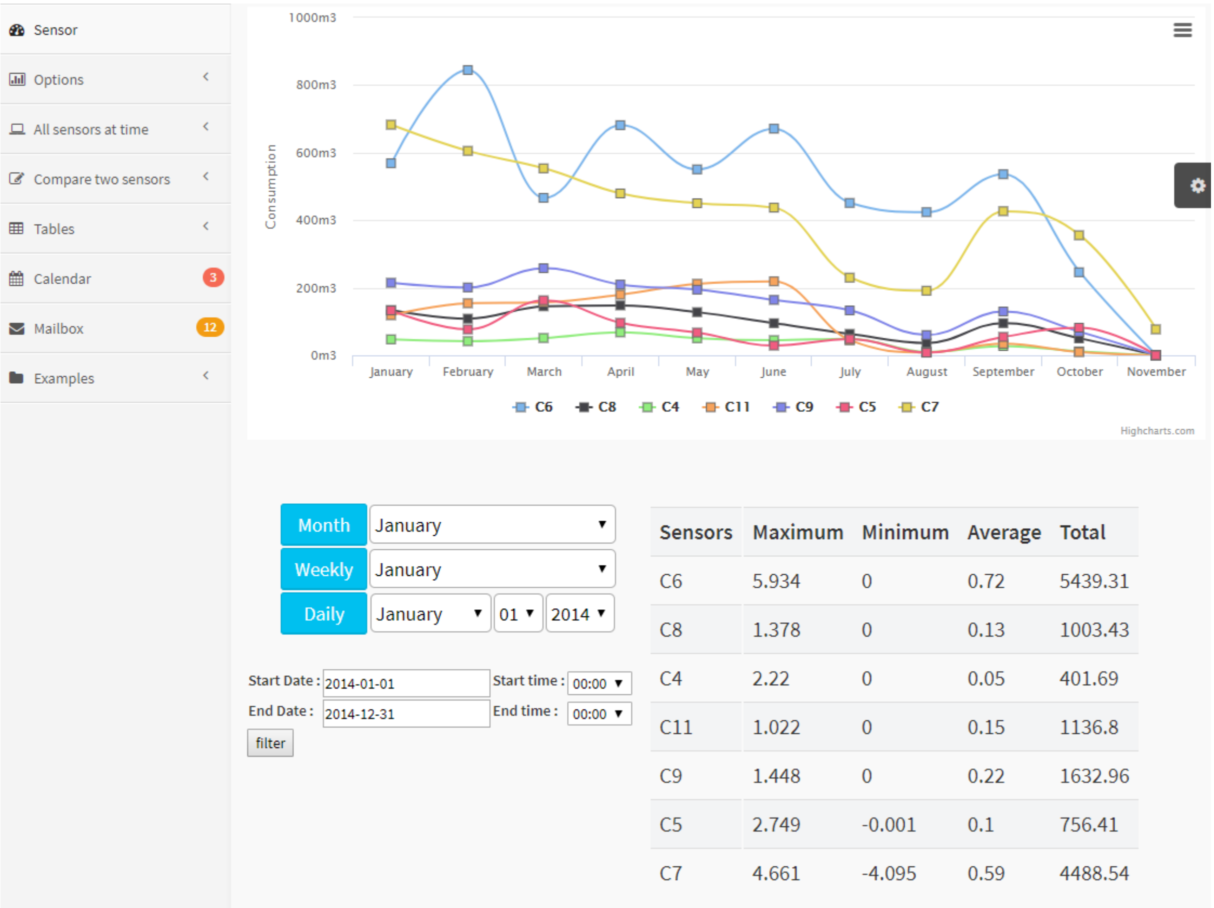



Figure 5.17: Compression between multiple sensors in CHEMISTRY sector

The user's interface is totally customizable. Data could be controlled from the admin panel, authentication is added to prevent anonymous users to access data.




| Sensors | Maximum | Minimum | Average | Total |
|---|---|---|---|---|
| C6 | 5.934 | 0 | 0.72 | 5439.31 |
| C8 | 1.378 | 0 | 0.13 | 1003.43 |
| C4 | 2.22 | 0 | 0.05 | 401.69 |
| C11 | 1.022 | 0 | 0.15 | 1136.8 |
| C9 | 1.448 | 0 | 0.22 | 1632.96 |
| C5 | 2.749 | -0.001 | 0.1 | 756.41 |
| C7 | 4.661 | -4.095 | 0.59 | 4488.54 |

Figure 5.18: Statistics for the sensors of the CHEMISTRY sector

## 5.4 Conclusion

This chapter presented the architecture and the construction of a platform for the management of SunRise Smart City project. This platform meets the project requirements concerning simplicity, flexibility and ease in extension and integration of additional functions. The platform is designed to small scale urban entities, such as the Campus.

The platform includes both asset data for of the campus urban networks as well as sensors of these networks. Tools were created for an ease transfer of data towards the platform.

The platform offers a friendly interactive environment concerning the visualization of both static (asset) and dynamic data (sensors). It offers the possibility to compare sensors records by geographic area. WebGIS pattern is used for the user's interface; it allows users to access data without location limitations.

This platform works well. It could be easily used or/and extended by PhD and Master Degree students.



# General conclusion

This research was conducted within SunRise Smart City project, which aims at turning the Science campus of University of Lille1 into a large scale demonstrator of the Smart and Sustainable city. It concerns the use and construction of platforms for the management of smart cities. These platforms play a crucial role in Smart Cities. They act as the brain of the Smart City, which ensure the coordination of the city functions such sensing, analysis, decision-making, control and evaluation.

The literature review confirmed the importance of platforms in the management of smart cities. However, since the issue of Smart City is new, we do not have enough feed-back about the development of inclusive Smart Cities' platforms. Based on this analysis, we developed in the 2nd chapter the functional and non-functional requirements for building smart cities platforms. The functional requirements concern WSN management, data management, data processing, real-time monitoring, external data access, and service management. The non-functional requirements include interoperability, scalability, security, privacy, flexibility and Extensibility, configurability, simplicity and social aspects.

In order to explore and develop the use of platforms in smart cities, we explored first the use of existing professional performs (PI System and OpenDataSoft) for the management of SunRise project (Chapter 4). Then, based on this experience and the requirements presented in chapter 2, we developed a specific platform for SunRise Smart City (Chapter 5).

The use of PI System for the management of SunRise project showed that this System contains interesting requirements to manage the Smart City, in particular its ability to connect and get data from different sources, to analyze real time and historical data and to visualize data in a friendly environment. The use of OpenDataSoft showed that this platform offers also interesting facilities for the management of the Smart City, in particular the ability to process large-scale, real-time data from IoT objects and to transform these data into interactive visualizations like maps and charts as well as an Application Programming Interface (API)-centered design.

The development of the new "SunRise – Smart City" platform aimed at meeting specific requirements concerning simplicity, flexibility and ease in extension and integration of additional functions for the management of small-scale urban entities, such as the Campus. The platform includes both asset data for of the campus urban networks as well as sensors of these networks. Tools were created for an ease transfer of data towards the platform. It offers a friendly interactive environment concerning the visualization of both static (asset) and dynamic data (sensors). It offers also the possibility to compare sensors records by geographic area. The use of WebGIS pattern for the user's interface; allows users to access data without location limitations. This platform could be easily used by users without any informatics background. PhD and Master Degree students could extend this platform easily by adding more functions to perform complex analyses, alerting system, etc.

Finally, the choice of a platform for the management of the Smart City project is crucial for the successful implementation and use of the Smart Technology and services. A deep analysis of the requirement of the smart city project is needed as well the exploration of exiting professional platforms capacities and economic model. Based on this analysis, 2 strategies could be used : (1) Implementation of existing platform, which allows time and development savings as well as professional support and share of innovation; (II) the development of a new platform, which could match better with the project requirement, but needs important human and material resources for the platform design, construction, maintenance, extension and exploitation.

The SunRise platform developed within this work present a good step to have an operational research tool, its transformation in a professional tool and the integration of new capacities such Artificial Intelligence, Virtual and Augmented Reality and Social Media constitute a good perspective for this platform.



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