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by

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GIS-based Urban Information System for Sustainable and Smart Cities: Application to "SunRise – Smart City" demonstrator

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Résumé

La thèse porte sur l'utilisation du système d'information géographique (SIG) pour la construction du système d'information urbaine pour les villes durables et intelligentes. Le travail comprend à la fois le développement d'une méthodologie pour la construction du système d'information urbain basé sur le SIG et son application sur un démonstrateur à grande échelle de la ville intelligente et durable (projet SunRise Smart City).

La thèse comporte quatre parties :

La première partie comporte une analyse bibliographique des travaux réalisés sur les thèmes relatifs à ce travail de thèse à savoir : l'émergence de la ville, les concepts de Ville Durable et de Ville Intelligent, le système d'information géographique (SIG) et son application sur l'environnement urbain.

Le deuxième chapitre présente l'application du SIG pour la construction du système d'information urbaine du campus scientifique de l'Université de Lille, qui est utilisé comme site de démonstration pour le projet « SunRise Smart City ». Le système d'informations urbaines comprend des informations sur les bâtiments du campus, ainsi que les réseaux urbains.

Le troisième chapitre présente l'utilisation du SIG pour la visualisation des données dynamiques des réseaux urbains, qui sont collectées par des capteurs intelligents. Le chapitre présente la méthodologie suivie pour la visualisation dynamique de ces données, ainsi que l'application de cette méthode sur les données de consommation d'eau.

Le dernier chapitre présente l'utilisation du BIM dans le système d'information urbain SunRise. La méthodologie est d'abord présentée, puis elle est appliquée sur un bâtiment du campus.

Mots clés : Réseaux intelligentes, Réseaux d'infrastructure, System d'information géographique, Système d'information urbain, Ville intelligente, Building information modelling, Télédétection, Consommations

Abstract

The thesis concerns the use of the Geographic information system (GIS) for the construction of urban information system for Sustainable and Smart Cities. The work includes both the development of a methodology for the construction of the GIS-based urban information system and its application on to the large-scale demonstrator of the Smart and Sustainable City (SunRise Smart City).

The thesis is composed of four parts.

The first part includes a state of the art on the emergence of the Smart City Concept and the achievements in this area. It also presents the Geographic Information System (GIS) and its use in both environmental and urban areas.

The second chapter presents the application of the GIS for the construction of the Urban Information System of the Scientific Campus of the University of Lille, which is used as a demonstration site for the project SunRise Smart City. The urban information system includes information about the campus buildings as well as the urban networks.

The third chapter presents the use of the GIS for the visualization of dynamic data concerning urban networks, which is collected by smart sensors. The chapter presents the methodology followed for the dynamic data visualization as well as the application of this methodology on the water consumption data.

The last chapter presents the use of the BIM in the SunRise urban information system for the management of buildings. The methodology is first presented then it is applied to a building of the Campus.

Keywords: Smart City, Geographic information system, urban information system, urban infrastructure networks, Remote Sensing, Building information modeling.

Table of Contents

List of Figures

List of Tables

General Introduction

Today, more than 50% of the world population live in cities; for developed countries, the urbanization rate is about 80%. In 1950, 30% of the world's population were urban and by 2050, this urban concentration could reach 70%. The size and the spatial distribution of the population will change in the coming decades. In the global world, the number of mega-cities has nearly tripled since 1990.

There is great diversity in the characteristics of the world's urban environments. About a half of urban dwellers resides in relatively small settlements of less than 500,000 inhabitants, while nearly one in eight lives in the 28 mega-cities of 10 million inhabitants or more. However, several decades ago, most of the world's largest urban agglomerations were found in the more developed regions, today's large cities are concentrated in the South, and the fastest-growing agglomerations are medium sized cities and cities with 500,000 to 1 million inhabitants are located in Asia and Africa.

Cities are important drivers of development and poverty reduction. They concentrate an important part of the national economic activity, government, commerce, and transportation. Urban life is often associated with higher levels of literacy and education, better health, greater access to social services, and enhanced opportunities for cultural and political participation.

As urbanization becomes a major issue of modern cities, we need to develop innovative solutions to host more people in eco- and socio- friendly conditions in a context of the environmental and economic crisis. The Smart City concept is an innovative solution, which is based on both the digital technology and collective intelligence. It offers a large opportunity for the optimal and safe management of cities as well as the involvement of all the stakeholders in the city development.

The Smart City concept aims in particular to an optimal management of urban infrastructures. This management requires the construction of a powerful urban information system that includes geo-localized information on the infrastructures components as well as their operating data. The system should also offer the possibility to conduct a geostatic analysis of urban infrastructures as well as their interaction. The Geographic Information system (GIS) offers the large possibility for the construction of this Urban Information System.

This work was conducted within the SunRise project[1], which aims at the construction of a large-scale demonstrator of the Smart City. The project is conducted at the Scientific Campus of the University of Lille in the North of France.

[1] http://sunrise-smartcity.com/fr/accueil/[Retrieved: 31 Aug. 2016].

The first step of SunRise concerned the construction of a GIS-based urban information system, which includes the asset and operating data of the Campus urban infrastructures. This work concerned the preparation of the GIS platform and the coordination and integration of data into SunRise GIS information system.

The thesis is composed of four parts. The first part presents a literature review of the Smart City concept as well as the Geographic Information system. The second part describes the construction of the SunRise GIS platform concerning urban networks as well as buildings. The third part deals with the visualization of dynamic data, that obtained by smart monitoring. The final part concerns the use of the Building Information modeling (BIM) in SunRise urban information system.

Chapter 1 : Smart City and GIS - Literature Review

This chapter presents a literature review of works conducted on topics related to the development of a GIS – based urban information system for Sustainable and Smart Cities. It deals with the emergence of the Smart City Concept, the Geographic Information System (GIS) and its use in Smart Cities.

1.1 Smart City Concept

The Smart City concept aims at improving the management of cities and mitigates the "unplanned" urbanization problems (Mahavir & Pabh, 2014). Literature indicates that the current trends in Smart City concern two areas: (i) transformation of existing infrastructures into smart infrastructures, (ii) the creation of smart cities from the scratch. In both cases, the Information and Communication Technology (ICT) is used as a core of the Smart City. Some researchers argue that the concept of the Smart City is related to digital city (Vinod, 2014). In the literature, we find general studies on Smart Cites as well as researchers on particular components of the Smart City. In his book, Vinod (2014) discusses the smart district, smart building, and smart networks.

The digital city appears as connected communities that gather the broadband and service-oriented communication to meet the government needs. The spatial situation of the digital city extends from neighborhood to a city, then to a multi-metropolis. An intelligent city has always combined multi-dimensions and features, depending on the individuals living and working in the city. The Smart City deals with sustainability, socio-cultural, socioeconomic, and environmental issues. They all play an important role in adapting or creating a Smart City, living healthy, smart green energy, green buildings, and walkable friendly land use. The involvement of citizens in the city governance is also an important objective of the Smart City. "The City could be defined as smart if it's developed in one city at a time" (Vinod, 2014).

There are several convergent definitions of the Smart City concept. According to IBM, "A city is an interconnected system of systems, a dynamic work in progress, with progress as its watchword, a tripod [Infrastructure, operations, people] that relies on strong support for and among each of its pillars, to become a smarter city for all" (Doran & Daniel, 2014).

MIT focuses on the fact that "[...] cities are systems of systems, and that there are emerging opportunities to introduce digital nervous systems, intelligent responsiveness, and optimization at every level of system integration – from that of individual devices and appliances to that of buildings, and ultimately to that of complete cities and urban regions" (Doran & Daniel, 2014).

According to the Forrester Research Institute, "the use of smart computing technologies to make the critical infrastructure components and services of a city more intelligent, interconnected, and efficient" (Doran & Daniel, 2014). Figure 1-1 shows the IBM and MIT conceptions of the Smart City or Smart Community as a system of systems interconnected by ICTs.

Furthermore, some researchers have developed a Smart City Model describing the three main components of the Smart City:

- **Economic factor** includes public administration and economic actors. It covers governance models, urban regeneration, open data and big data

- **Environmental factor** includes resources and managerial infrastructures. It covers water, air, energy and waste management, public and alternative transportation, geographical information, green buildings and green spaces

- **Social factor** includes the citizens. It covers community life, urban mediation, participatory democracy, social innovation, human-scale cities and civic participation.

Figure 1-1: Smart City model (Source: http://dx.doi.org/10.3233/IP-140330)

The proposed model corresponds to the sustainable development model. It aims at creating an advanced, wealthy, civic and resilient city. In this regard, we define the Smart City as a knowledge-based city that operates 24/7, connects in real time to help end-users to achieve good life quality.

Smartness should be one of the main terms in the implementation of the Smart City concept. From another perspective, "smartness" is the incorporation of different components that are working together, taking quick actions and making efficient decisions. Each component has its own capability of monitoring certain situations; generate data, work autonomously or collaboratively. Thanks to the ICT revolution, the social media has become a hub for agglomeration of the collective intelligence, a collaboration that supported by the internet and different forms of participation opportunities (Mitchell, 2007). The question is how smartness associates the city? A century ago, there were less than 20 cities around the world with a population of more than 1 million people. In the 18th century, less than 5% of the global population lived in a city.

The 2009 annual report of IBM mentioned that: "The 19th century was a century of empires, the 20th century was a century of nation states and the 21st century will be a century of cities" (IBM, 2009). Cities are gaining more economic power, developing greater political influence and increasingly employing more advanced technological capabilities to enhance their performances:

Table 1-1 summarizes the system wich constitute the core of the City . It shows that the city is a system of material and immaterial systems, which should work in harmony.

Table 1-1: City's core systems (Source: the University of Technology of Vienna 2007)

System	Definition	Content
People Systems	Focus on citizens and social groups	Public safety, disaster affairs, health care, education
Business Systems	Covers regulations and policies related to trade and business life	Legislative and administrative regulations about national and international trade,
Operational Systems	Involve transport system	Administration, legislative and financial provisions
Communication Systems	Telecommunication infrastructures	Mobile Systems, SMS, web-based applications,

Water System	Water systems, reserves, refinement, storage and sanitation	Capacity management, Water basin management, quality control, and regulations.
Energy System	Power supply and transmission networks.	Grid systems, Energy efficiency, smart power meters

The Smart City concerns the transformation of a wide range of urban activities such as industry, education, health, arts, culture, transport, etc. The Smart industry concerns the use of ICT in the production process. The Smart City concerns also important issues such as public safety, security, environmental protection, environmental sustainability and energy.

Table 1-2 summarizes the main areas of the Smart City as proposed by the University of Technology of Vienna. They concern Smart Economy, Smart Governance, Smart Environment, the Smart People, Smart Mobility and Smart Living.

Table 1-2: Core domains of a Smart City (Source: Vienna University of Technology, Centre of Regional Science 2007, 12)

Smart Economy	Smart People
Smart Governance	Smart Mobility
Smart Environment	Smart Living

1.2 Geographic Information System (GIS) and Smart Cities

1.2.1 History of GIS

The Geographic Information System (GIS) is a modern extension of the traditional cartography with one fundamental similarity and two main differences (Dempsey, 2012). The similarity of these tools lies in the fact that they contain examples of a base map to which additional data can be added. The differences are (i) there is no limit to the amount of data that can be added to a GIS map and (ii) the GIS uses analysis and statistics to present data in support of particular arguments, which a cartographic map cannot offer.

Table 1-3 summarizes the phases of the development of the GIS.

Table 1-3: GIS timeline (Source: Vienna University of Technology 2007)

The early 1960s and mid-1970s	The mid-1970s to early 1980s	1982 until the late 1980s	Since the late 1980s
Saw as a new discipline has been dominated by a few key individuals in order to shape the direction of future research and development	Saw the adoption of technologies by national agencies that led to a focus on the development of best practice	Saw the development and exploitation of the commercial marketplace surrounding GIS	Focus on ways of improving the usability of technology by making facilities more users centric

In recent years, the expansion in the computer technology significantly contributed to the extension of GIS applications. Today's GIS is easier and more cooperative for the user community. GIS is a technological tool for understanding geography and making intelligent decisions. GIS allows Multiple Criteria Evaluation (MCE). It may be also a computerized system to store, record, analyze, and produce maps and geographic products based on spatial data.

The user profile of GIS may vary, from a tourist who is seeking a destination by using navigation systems in a city to an expert working on the urban planning of leading a mega city. The current practice of the systems shows that GIS is highly ranked in the top list of decision makers. A vast amount of literature argues the role of GIS in the local development of cities, "many local governments are adding GIS technology as part of their regular administrative management system" (Kamal, 2008).

However, research indicates that GIS layers are the key components as well as the established features of urban and regional planning policy. GIS is one of the most powerful tool for land use analysis (Jianhua & Hui, 2012).

Since the arrival of the GIS tools and the Computer Aided Design (CAD), researchers have progressively advanced throughout the different sectors of architectural projects.

Today, GIS provides various tools to assist in the integration of building data in Geo context. GIS uses the geographic (spatial) location for collection, storage, analysis, and presentation of information in digital form (National Research Earth, 2003).

Figure 1-2 shows the strong relation between GIS and CAD (Maguire, 1991)

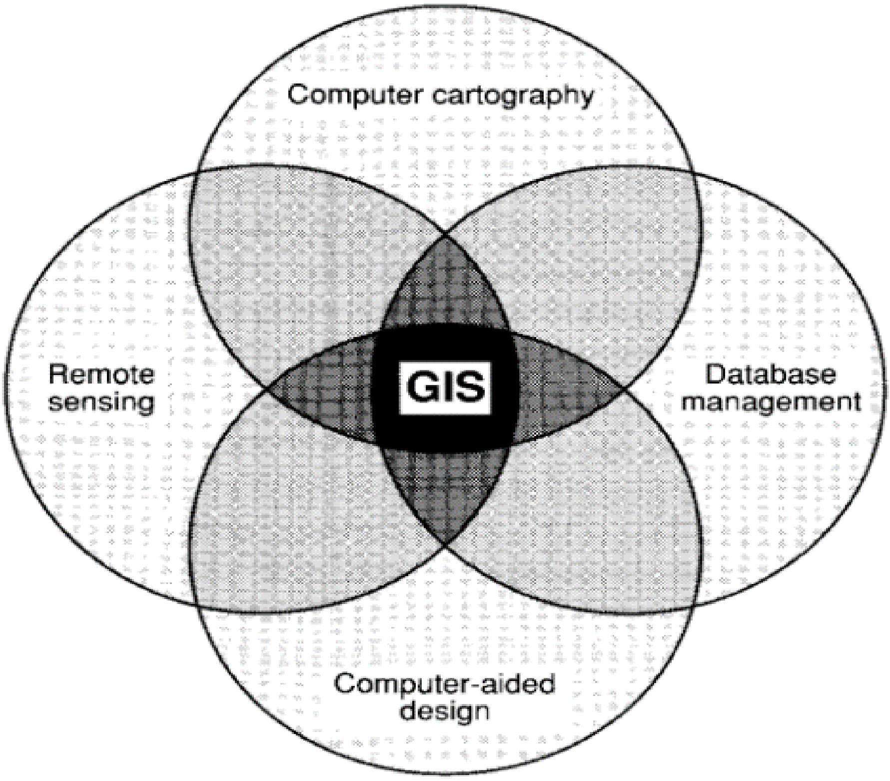

Figure 1-2: The relationship between GIS and computer-aided design

(Source: (Maguire, 1991)**)**

1.2.2 Data visualization using GIS remote sensing (RS)

GIS can store, manipulate, and analyze physical, social, and economic data of a city by using the spatial query and mapping functions of GIS. It can support the identification of areas of conflict and of land development with the environment by overlaying existing land development on land suitability maps. Areas of environmental sensitivity can be identified using remote sensing and other environmental information. Geographical information, when integrated with remote sensing, can save time in collecting land use and environmental information. Urban sustainable development is becoming a major issue; urban open space system takes increasing attention (Zang, 2004).

The spatial information technology solves more problems based on the enhanced information. Spatial information technology has a wide application in the prevention of disasters, land-use planning, urban planning, and engineering management (Shao et al., 2009).

Information and information technology has a great influence on the modern economy, society, culture, and life. Spatial Information technology includes Remote Sensing, (RS), GIS, and Global Positioning System (GPS).

The use of GIS in smart urban planning plays a key role for planners to create livable "smart" communities improving the overall quality of life while protecting the environment and promoting economic development. GIS can provide an efficient platform for modeling, analysis, and visualization of urban systems.

According to (Yeh, 1999), GIS provides efficient tools for urban planning (Figures 1-3 and 1-4) such as improved mapping, improved map currency, more effective thematic mapping, and reduced storage cost; greater efficiency in retrieval of information; faster and more extensive access to the types of geographical information important to planning and the ability to explore a wider range of 'what if' scenarios; improved analysis; better communication to the public and staff; improved quality of services.

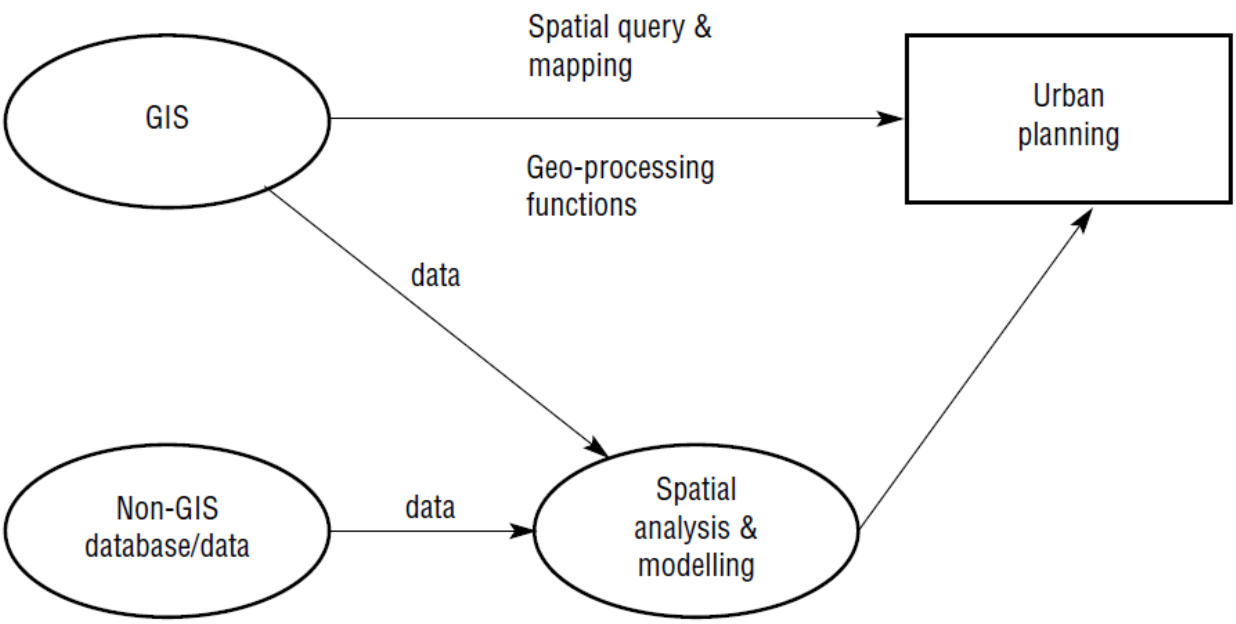

Figure 1-3: GIS and urban planning (Source: (Yeh, 1999))

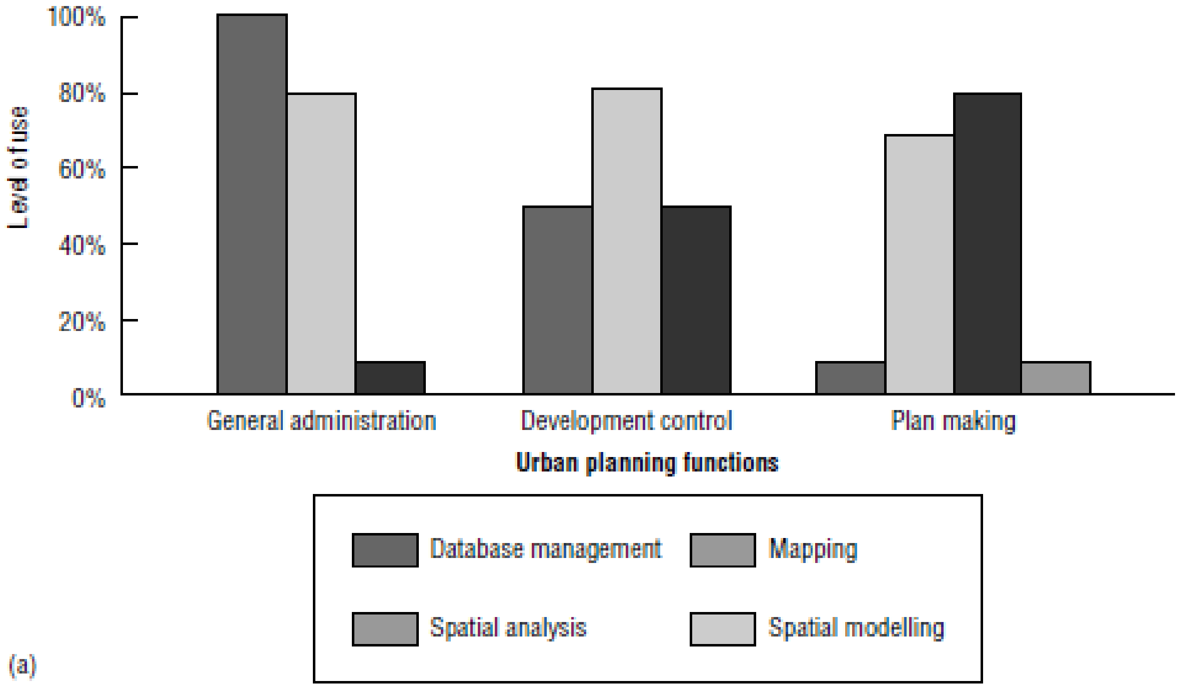

Figure1-4: Use of GIS in urban planning (Source: (Yeh, 1999))

Remote sensing technology allows obtaining real-time information using remote monitoring. With the help of GIS, people can acquire, store, manage, analyze, display, and make use of the spatial data.

Spatial information technology is no longer limited to data collection but emphasizes on earth spatial data and information from the acquisition, processing, and measurement. GIS, when integrated with remote sensing, saves time in collecting land use and environmental information.

The innovations of information, data, and technology have been increasingly developed. Urban remote sensing applications have rapidly gained popularity across a wide variety of communities; they concern the urban planner, researchers, and geographers.

The definition of RS has been presented by (Jensen et al., 1989) "as the measurement or acquisition of information of some property of an object or phenomenon, by a recording device that is not in physical or intimate contact with the object or phenomenon under study".

1.2.3 Geo-Database and GIS implementation

There are three sets of conditions for an effective implementation of GIS (Yeh, 1999):

- An information management strategy that identifies the needs of users and takes account of the resources at the disposal of the organization.
- Commitment to and participation in the implementation of any form of information technology by individuals at all levels of the organization;
- A high degree of organizational and environmental stability. GIS that is most likely to be used by those that can deal with identified problems.

GIS is an essential tool in the smart supervision of growing cities and has a vast scope. In the digital world, geospatial databases and digital maps are being integrated into workflows for instance, in land management, urban planning and transportation in government sectors. Many organizations have developed successful applications by using GIS as a platform for data integration, to create models for better decision-making and visualization. On the technical side, web applications give the framework and environment for GIS related to photogrammetry and computer vision, so it will manage big data sets collected by smart meters and implement professional GIS functions in an e-computing.

1.2.4 Geo-Database (GDB): Modeling and managing spatial data

A database is a collection of information that exists over a long period of time. In common practice, the term database refers to a collection of data that is managed by a Database Management System (DBMS). The DBMS is the software that manages the creation, maintenance and the storage of data. It allows users and other soft wares to store and retrieve data in a structured way.

Database management systems are usually categorized according to the database model that they support, such as the network, relational or object model. The model tends to determine the query languages that are available to access the database (Bureau US Census, 2003). By the mid-1960s, businesses and governments used simple databases for storing and retrieving information on rudimentary storage systems (Silberschatz et al., 2004).

In the 1970s, the relationship database model was developed, and much of the language used in modern database programming was developed during this time period. SQL databases have dominated the field. Computers are capable of storing a tremendous amount of information, and the amount of data. Databases are at the forefront of making this information available to programs and to computers.

Data in various different formulas can be saved into GDB; which refers to the geographic database. Data are organized in layers and spatial representations. The GDB contains various information such as location and some other characteristics. Digital or computerized data can also be exported into GIS. Figure 1-5 shows an example of the use of GIS for data collected by satellites including land use, the location of farms, towns, or forests.

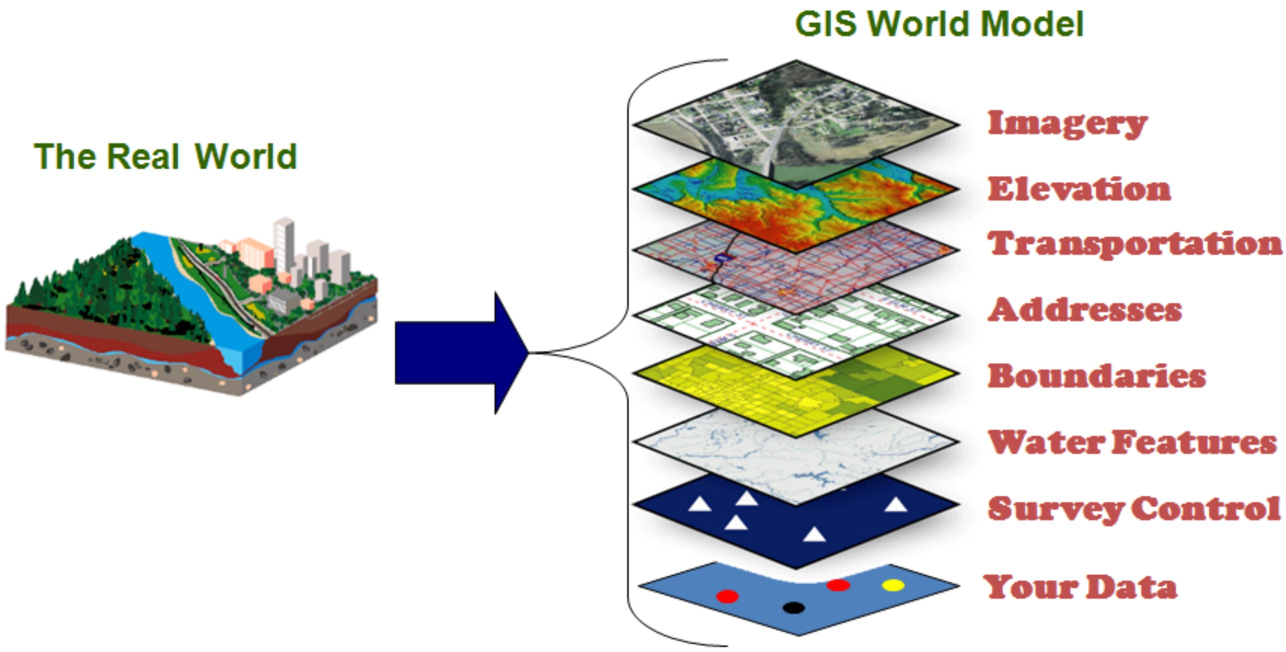

Figure 1-5: GIS data layers (Source: (Esri, 2008))

GIS provides graphical tools, statistical treatment, and interfaces with several modeling software of the urban networks. The different types of the Geo-Database GDB established within the project were created by the integration of the urban information system database, analysis tools.

The geolocation database on heritage elements (buildings, infrastructure, etc.) includes relevant attribute tables relates to the geometric and physical characteristics of these elements (Esri, 2008).

The GDB is the common data storage and management framework for ArcGIS; it contains spatial and attributes data. It combines geo (referring to spatial) with database—specifically, a relational database management system (RDBMS).

It promotes the idea of having all GIS data stored uniformly in a central location for easy access and management.

Table 1-4: Several highlights of the GDB

GDB highlights
The Geodatabase helps maintain integrity of spatial data
Users can apply sophisticated business rules and relationships to data
The Geodatabase supports concurrent, multi-user editing

1.3 GIS for Smart City

The Smart City concept is based on the collection of data concerning urban systems and services, the share and analysis of data for an optimal and safe management of the city and the visualization of data for both a good understanding of the urban system as well as for the communication with the city stakeholders.

The management of urban infrastructures constitutes the core of the city management. It concerns urban networks such as drinking water, sanitation, storm water, district heating, public lighting and electricity as well as transport infrastructures (Allen, 2009). The management of these infrastructures requires geo-localized data concerning the infrastructure asset as well as the operating data collected via sensors networks as well as data transmitted by end-users or technical staff.

The GIS offers powerful tools for the management of data concerning the infrastructure asset. The Smart City platform could use these tools for the construction of multi-layer GIS system. Each layer concerns an urban infrastructure and its attributes or an urban object.

The GIS system offers then the possibility to cross the data, to share it with other users, to analyze the data and to visualize. The GIS system can also integrate data related to the maintenance of urban infrastructures and then to conduct analysis concerning the maintenance of this infrastructure in order to understand the state of these infrastructures and to set up investment strategy for their renovation and upgrading (Al-Hader & Rodzi, 2009).

The GIS offers also the possibility to integrate dynamic data concerning the operating state of the infrastructures and to visualize these data at different scale. It can be used to send alerts concerning any operating fault (Dempsey, 2012).

1.4 Conclusion

This chapter included three parts.

The first part presented the development of the Smart City concept. This concept aims at the use of the digital technology for an optimal and safe management of the City. It concerns the urban infrastructures (water, energy, transport, and municipal waste), urban services, education, health, culture, administration, tourism, the concept is based on the collection, share, and analysis of urban data for a collective optimal management of the City.

The second part presented the Geographic Information System, which offers powerful tools for the integration and analysis of geo-localized data concerning physical objects. The GIS is largely used in the field of the environment as well as urban infrastructures and services.

The third part presented the use of GIS in Smart City projects. It offers powerful tools for the construction of the Urban Information system including both static and dynamic data as well as for geospatial data analysis and visualization.

The GIS is already largely used for urban issues. It presents large opportunities for the implementation of the implementation of the Smart City projects. In the following, we present its use for the SunRise Smart City project, which concerns the construction of a large-scale demonstrator of the Smart City.

Chapter 2 : Construction of A GIS –based urban information system for the Smart City – Application on SunRise demonstrator

This chapter presents the construction of the GIS –based urban information system for the Smart Cities and its application to the SunRise Smart City demonstrator. It presents successively (i) the SunRise Smart City project, which concerns the construction of a large-scale demonstrator of the Smart City, (ii) the Scientific Campus of the University of Lille, which is used for the implementation of the SunRise demonstrator, (iii) the methodology followed for the construction of the GIS-based urban information system for SunRise (iv) the GIS layers concerning the Campus infrastructures.

2.1 Presentation of SunRise Smart City demonstrator

SunRise Smart City demonstrator was initiated in 2010 by a consortium of academic, industrial and local government partners, which aimed 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 from 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,
- It is supported by a large local government, industry, and academic partnership,
- It is used as a living lab for both research, education and Ph.D. programs and it is conducted within an international environment.

2.2 Presentation of the scientific campus, support of SunRise demonstrator

The Scientific campus of the University of Lille is located nearby the city of Lille in the north of France. The campus is a small town of 110 Hectares and 25,000 users (Students, academic administrative and technical staffs) (Shahrour et al., 2014). It was built between 1964 and 1966. Later, some of the buildings have been renovated; and several buildings have been constructed.

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

Figure 2-1: A conceptual model for SunRise project "Geo Canvas"

2.2.1 Presentation of the campus buildings

The campus buildings are classified according to their usage in the following categories:

- Administration and services (15.4%),
- Research (17.5%),
- Education (26.2%),
- Education & Research (22%),
- Student residence (14, 7%)
- University restaurants (4.2%).

The following sections provide details about these categories.

2.2.1.1 Administration and Services sector

The administration and service sector includes 14 buildings, which are used for the administration of the university, the library, the cultural space and the heating center. Table 2-1 summarizes the information about each building such as the year of construction, the surface area, the number of floors and basement.

The total surface area of this sector is equal to 34 716 m^2. Five buildings were constructed in 1966, two of them were renovated in 1992 and 1998, three were constructed in 1988 and the others were constructed between 1995 and 2004.

Table 2-1: Sector of the administration and services

Building Name	Use	Construction Year	Surface Area [m^2]	N. floors	Basement
A1	Heating centre	1966	1 401	2	0
A3	Administration	1966/1992	5 450	3	-1
A7	Administration	1996	538	3	-2
SUDES	Administration	1996	1 660	3	0
SUP/SUAIO	Administration & Teaching	2004	6 680	1	-1
A2	Technical Service	1966	923	1	0
A6	Technical Service	1995	497	2	0
A9	Sport	1988	254	2	0
A 11	Culture	2001/2003	1 408	1	0
Library	Library	1966	9 747	2	-2
A 10	Health Centre	1966/1998	570	2	0
A4	Administration	1988	1 095	1	0
A5	Administration	1988	1 095	1	0
DESS	Teaching	1995	3 398	2	0
TOTAL					**34 716**

2.2.1.2 Chemistry department sector

The sector of chemistry includes 11 buildings, which are used for both research and teaching. Table 2-2 summarizes the use of these buildings as well as their year of construction, surface area and a number of floors. Five buildings were constructed in 1966, then three of them were renovated latter, two were constructed between 1992 and 1996. The total area of this sector is equal to 18 836 m^2.

Table 2-2: Sector of chemistry

Name	Use	Construction Year	Surface Area [m^2]	N. floors	Basement
C1	Teaching	1966	4602	3	-1
C4	Research	1966/2003	2675	3	-1
C5	Teaching & Research	1966	3862	4	-1
C9	Research	1966/1995	4561	3	-1
C11	Research	1966/2000	1027	3	-1
C15	Teaching	1992	1348	3	0
C16	Teaching	1996	761	3	0
Total					**18836**

2.2.1.3 Institute of Technology (IUT)

The institute of technology is hosted in a large building (around 19 287 m^2), which was constructed in 2006. This building is used for teaching.

2.2.1.4 Sector of mathematics and computer science

The sector of mathematics and computer science sector contains six buildings. Table 2-3 summarizes the use of these buildings as well as their year of construction, surface area and a number of floors.

Four buildings were constructed in 1966, then two of them were renovated latter, two were constructed between 1993 and 1994. The total area of this sector is equal to 14 168 m^2.

Table 2-3: Sector of mathematics and computer science

Name	Use	Construction Year	Surface Area [m²]	N. floors	Basement
M3	Teaching & Research	1966/2002	7437	4	-1
M4	Computer Center	1966	1898	1	0
M5	Teaching	1993	3001	2	0
M1	Teaching	1966		3	-2
M2	Research	1966/1992		4	0
M6	Research	1994	1832		0
Total					**14168**

2.2.1.5 Sector of natural science

The sector of natural science sector includes six buildings, covering an area of 12 872 m^2. The buildings of this sector are used for research and teaching (Table 2-4). They were constructed in 1966.

Table 2-4: Sector of natural science

Name	Use	Construction Year	Surface Area [m²]	N. floors	Basement
SN2	Research	1966	4829	4	-1
SN3	Research	1966	5584	4	-1
SN4	Research	1966	2459	4	-1
SN6	Teaching & Research	1966	9 390	4	-1
Serre	Teaching	1966	4 048	4	-1
Total					**12872**

2.2.1.6 Sector of physics

The sector of physics includes seven buildings, which are used for research and teaching (Table 2-5).

Five buildings were constructed in 1966; two were constructed later (1992 and 1998). The total area of the buildings of this sector is equal to 34 139 m^2.

Table 2-5: Sector of physics

Name	Use	Construction Year	Surface Area [m²]	N. floors	Basement
P1	Teaching	1966	10197	4	-1
P2	Teaching & Research	1966	4829	4	-1
P3	Research	1966	4655	4	-1
P4	Teaching & Research	1966	3090	4	-1
P5 Building	Research	1966/1999	9373	**4**	-1
P7 Building	Admin. & Teaching	1992	584	4	-1
Cerla	Research	1998	1411	4	-1
Total					**34139**

2.2.1.7 Sector of social science

The sector of social science is composed of four buildings (Table 2-6). The first building was constructed in 1988, while the most recent building was built in 2003. The total area of the buildings of this sector is equal to 14 022 m².

Table 2-6: Sector of social science

Name	Use	Construction Year	Surface Area [m²]	N. floors	Basement
SH1	Teaching	1988	2437	2	0
SH2	Teaching	1996	4077	3	-1
SH3	Teaching	2003	7508	4	-1
GEO	Teaching	1996	2 020	3	0
Total					**14022**

2.2.1.8 Sector of engineering

The sector of engineering sector is composed of three buildings (Table 2-7), which are used for teaching and research.

Two buildings were constructed in 1966, while the third one was constructed in 1997. The total area of the buildings of this sector is equal to 39 851 m².

Table 2-7: Sector of engineering

Name	Use	Year of construction	Surface Area [m²]	Basement	N. floors
Polytech'Lille Building : D	Teaching and research	1966	7 000	-1	5
Polytech'Lille Buildings : A/B/C/E/F	Teaching and research	1997	16 209	-1	5
Ecole Centrale de Lille	Teaching and research	1966	16 642	-1	1 - 5
Total					**39 851**

2.2.1.9 Student residences

The sector of students' residence is the largest sector: it covers an area of 79 629 m^2. It includes four large residences built in 1966 and a residence built in 1996 (Table 2-8).

Table 2-8: Sector of students residences

Name	Use	Construction Year	Surface Area [m²]	Basement	N. floors
Bachelard	Residences	1966	15 417	0	5
Camus	Residences	1966	19 065	0	5
Boucher	Residences	1966	13 650	0	5
Galois	Residences	1966	13 675	0	5
L. Vinci	Residences	1966	17 822	0	4
Total					**79 629**

2.2.1.10 Sector of restaurants

The sector of restaurants is composed of three buildings (Table 2-9). Two buildings were constructed in 1966, while the third one was built in 2000. The total surface area is equal to 9 108 m^2.

Table 2-9: Sector of restaurants

Name	Use	Construction Year	Surface Area [m²]	Basement	N. floors
Sully	Catering	1966	3497	0	2
Pariselle	Catering	1966	3784	0	2
Barrois	Catering	2000	1827	0	5
Total					**9108**

2.2.1.11 Sector of sports

The sector of sport is composed of three sports hall and one building (Table 2-10). The first building was constructed in 1966; the second one was built in 1975, while two buildings were constructed in 1994. The total surface area of this sector is equal to 7529 m^2.

Table 2-10: Sports sector

Name	Use	Construction Year	Surface Area [m^2]
Hall Vallin	Sports	1996	2500
Hall Pilote	Sports	1994	395
Hall Gremeaux	Sports	1994	2415
Cosec Building	Sports	1975	2219
Total			7529

2.3 Construction of the GIS – based urban information system

2.3.1 Georeferencing: Assigning map coordinates and spatial location

All the features in a map layer have a specific geographic location that enables them to be located on or near the earth's surface. The accuracy of the geographic location is critical in both mapping and GIS. This process is called Georeferencing. GIS must extract the information from the various maps and sources align, so they fit together because maps have different scales.

A scale is a relationship between the distance on a map and the real distance on the Earth. GIS combines the information from different sources such as satellite maps, images, google maps in such a way that all information have the same scale.

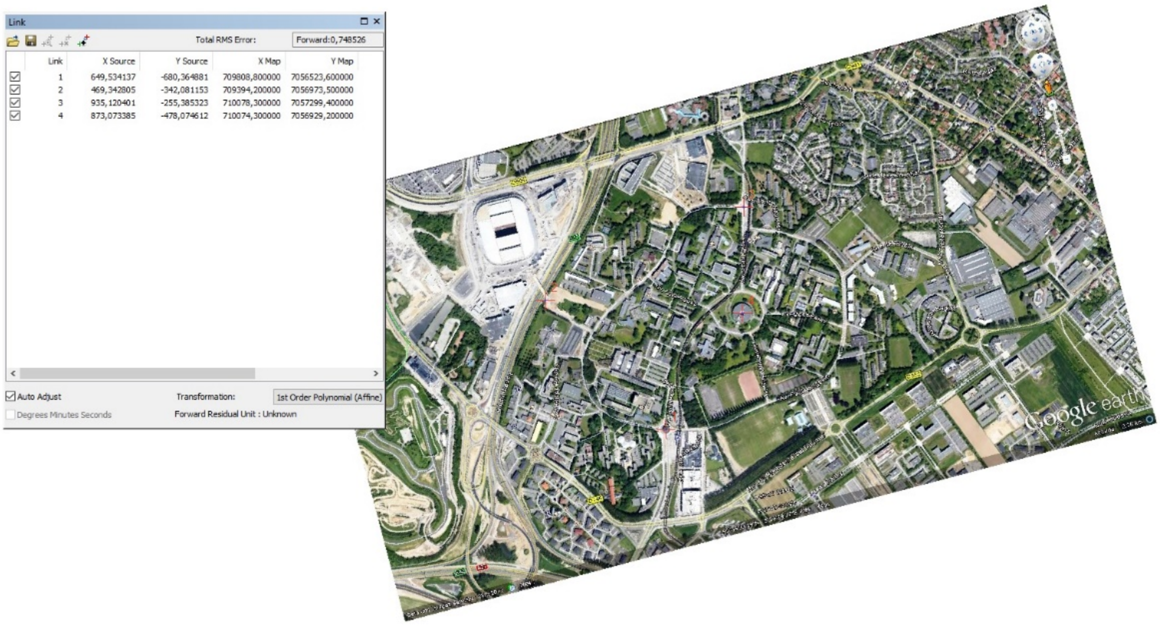

Figure 2-2: Geo-referencing for the campus map as displayed in ArcMap

To obtain the best result for the geo-referencing process, each (X, Y) point coordinates should have at least six characters after the comma either in altitude or in longitude. The spatial reference system Lambert 93 is used in our project. It is a global system, which is used to locate geographical entities.

A spatial reference system defines a specific map projection, as well as transformations between different spatial reference systems. The spatial reference system describes as a projected CRS (coordinate system) last revised on 04/22/2008.

France - onshore and offshore, mainland and Corsica. RGF93 / Lambert-93 use the RGF93 geographic 2D CRS as its base CRS and the Lambert-93 (Lambert Conic Conformal (2SP)) as its projection. RGF93 / Lambert-93 are a CRS for Large and medium scale topographic mapping and engineering survey.

2.3.2 Data preparing for ArcGIS

The ArcGIS system is used for the construction of the GIS- based urban information system. The CAD files were prepared for the master plan of the campus and export of outcomes data into ArcMap.

The transformation and the integration process were carried according to the following steps:

- Preparation of CAD files for the master plan for the campus

- Importation the file and its transformation into compatible extensions as .shp using the program Features Manipulating Engine (FME).

- Exportation of the outcomes from AutoCAD and their importation into ArcMap.

Figure 2-3 shows the campus master plan and layers "AutoCAD File".

Figure 2-3: Campus master plan and layers "AutoCAD File"

Feature Manipulation Engine (FME) helps to transform data in limitless ways. It converts data between formats as well as processes data geometry and attributes.

The set of tools includes:

- FME Workbench, the main graphical user interface for designing data transformation workflows
- FME Data Inspector
- FME Quick Translator

In addition to Map Guide and AutoCAD data, FME works with more than 200 other GIS, CAD, raster, and database formats. Safe Software, founded in 1993, took its name from a data format called the Spatial Archive and Interchange Format (SAIF), which was primarily used in Canada and is similar to today's universal model, Geography Markup Language (GML).

FME supports a broad range of spatial and non-spatial data types. The transformation process was conducted using the Feature Manipulating Engine (FME) Workbench.

FME workbench includes different types of implantation such the Reader file (in our case was Campus Lille 1.dwg) and the writer file (in our Esri Shape for GIS, ArcGIS). Figure 2-4 shows the transformation process from CAD files to Esri Shapefiles "FME".

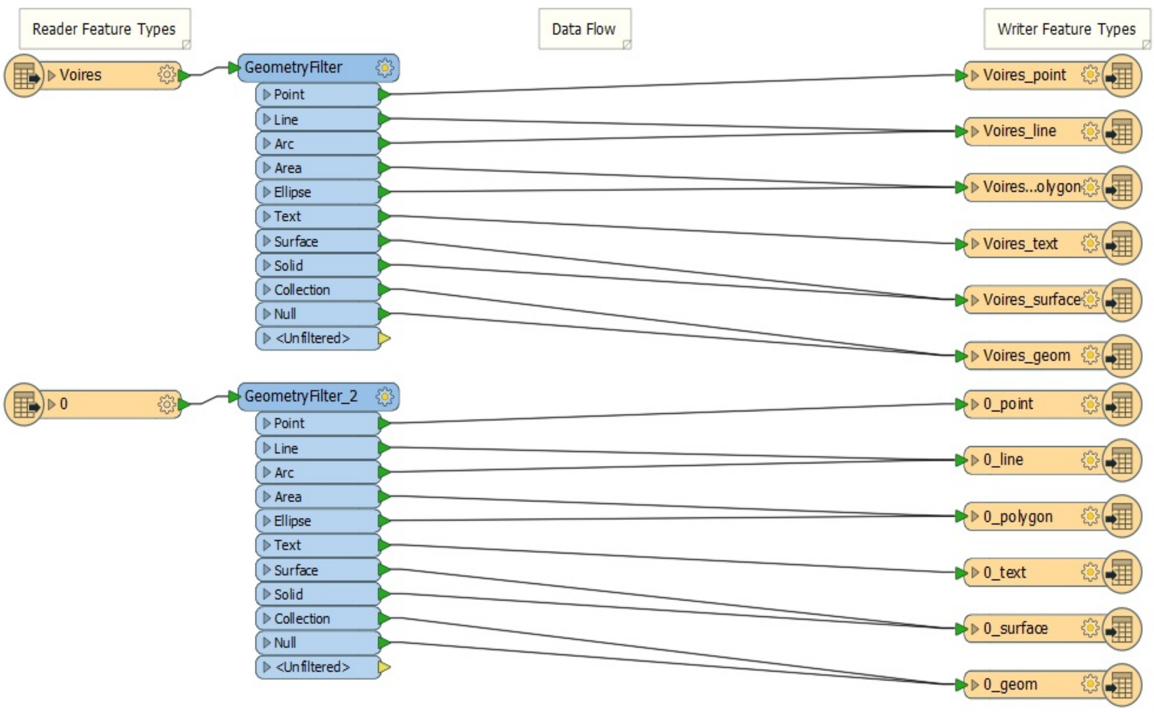

Figure 2-4: Transformation process from CAD files to Esri Shapefiles "FME"

The database concerning the GIS urban information system contains static and dynamic data. The static data concern the characteristics of the different buildings and layers of the Campus.

For example, the attributes tables in ArcMap includes name, function, XY coordinates, total area, etc. For the integration of these data into SunRise platform, the data should be transformed into ArcGIS files with extensions presented earlier (.shp, .gdb, etc.). The FME workbench has several transformers such as "create vertex", which appends coordinates to null, point, text, line, and arc geometry or replaces existing geometry with point geometry. If the feature turns into a closed polygon because of adding the point, it will be tagged as an area feature.

Otherwise, it will be tagged as a line or a path ending in a line for arcs. Figure 2-5 shows the transformation from xls sheets to Esri database files "Attributes Tables" "FME".

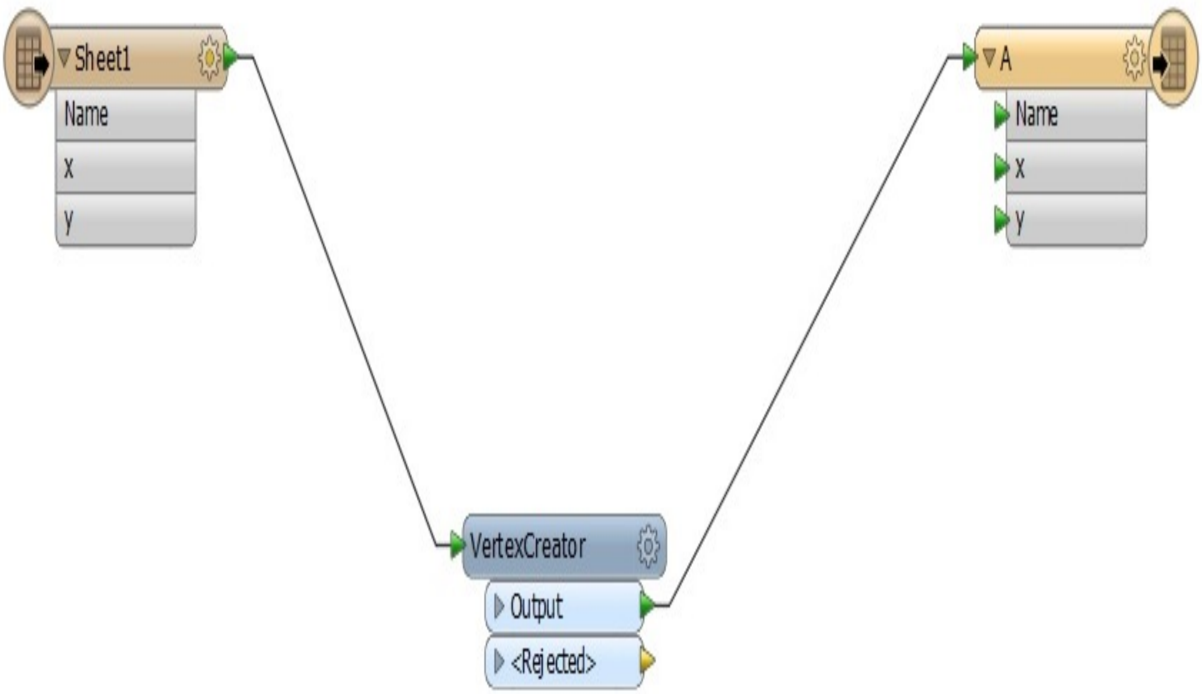

Figure 2-5: Transformation from xls sheets to Esri database files "Attributes Tables" "FME

The results will be presented in ArcMap software as attributes tables. Each layer has a specific attribute table. Table 2-11 shows the attributes of the campus building layer as displayed in ArcMap.

Table 2-11: Attributes table for the campus buildings in ArcMap

Object ID	Name	Function	Area (m^2)	Construction Year	Number Floor
1	Polytech	Teaching & Research	46392	2000	4
2	Bibliothèque	Library	9747	1966	4
6	UFR de Géo	Research	2373	1996	4
7	SN5	Research	5945	1966	4
8	SN4	Research	2459	1966	4
9	SN4 Ann_SN6	Research	577	1996	4
10	SN2	Research	4829	1966	4
11	SN1	Teaching	10205	1966	4
12	SN3	Research	5584	1966	4

Figure 2-6 shows the main components and structures of the campus master plan layer, which includes multi-functions buildings as well as the university restaurants and residences.

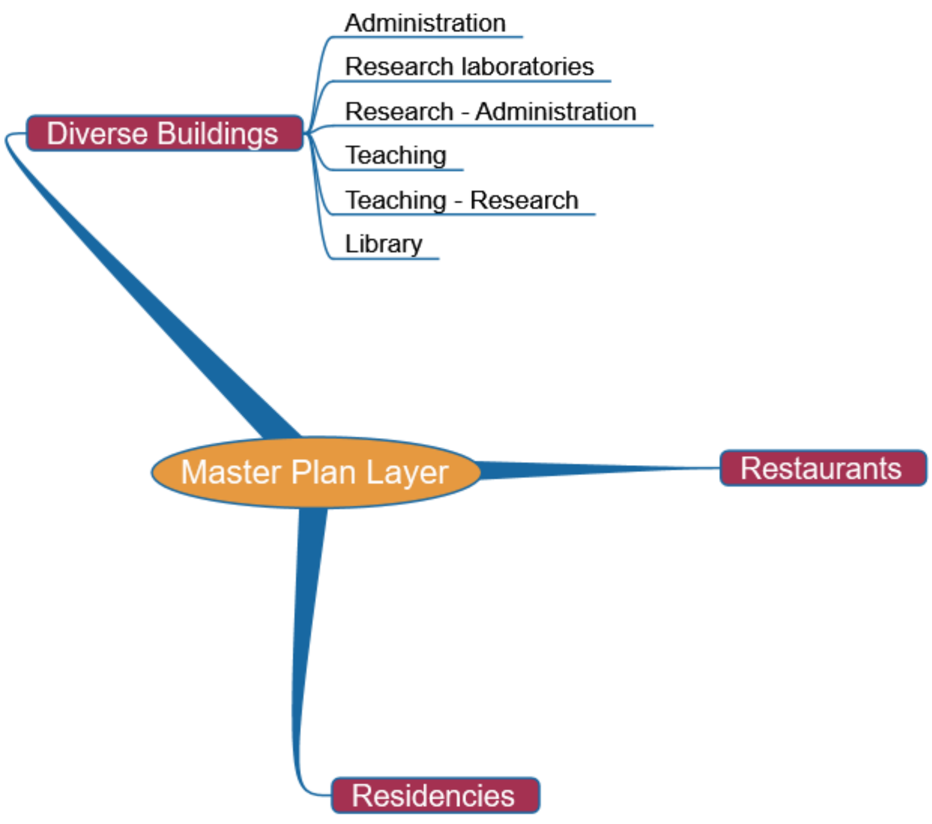

Figure 2-6: Campus buildings layer components and structures

2.3.3 Implementation of SunRise master plans using ArcMap

The visualization process in ArcMap is constructed in several steps. Figure 2-7 shows the integration steps for the Master Plan using ArcGIS. In ArcMap, the master plan of the campus is displayed as a layer in the projection system "Lambert 90"and inside the created SunRise GDB.

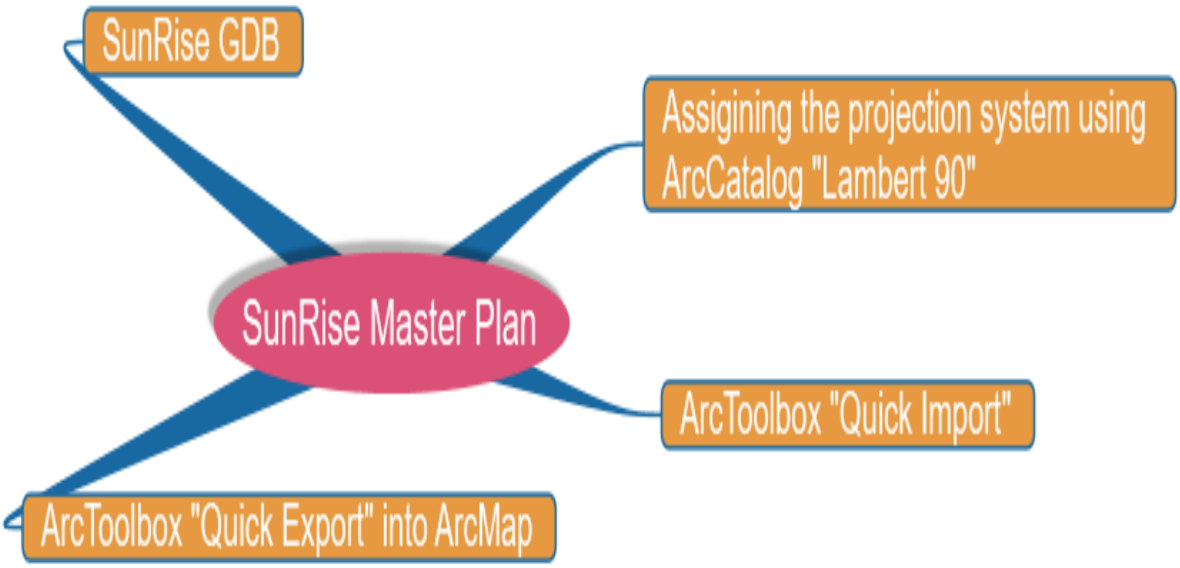

Figure 2-7: The integration steps for the master plan using ArcGIS (Source: Author)

2.4 SunRise urban infrastructures

Layers are logical collections of geographic data. Layers include how geographic data is organized and combined to create maps and scenes; they are the basis of geographic analysis. There are many types of layers.

They can represent geographic features (points, lines, and polygons), imagery, surface elevation, cell-based grids, or virtually any data feed that has a location (weather, gauges, traffic conditions, security cameras, tweets, etc.) (Harder, 2015).

Figure 2-8 shows the different layers and features created using the ArcGIS software and tools. The SunRise GDB contains layers and sublayer. The main layers (orange color) cover the whole campus.

They have different types Points, Lines, and Polygons. The layers include different components such as the name of the facility, its usage, and Geo-Database.

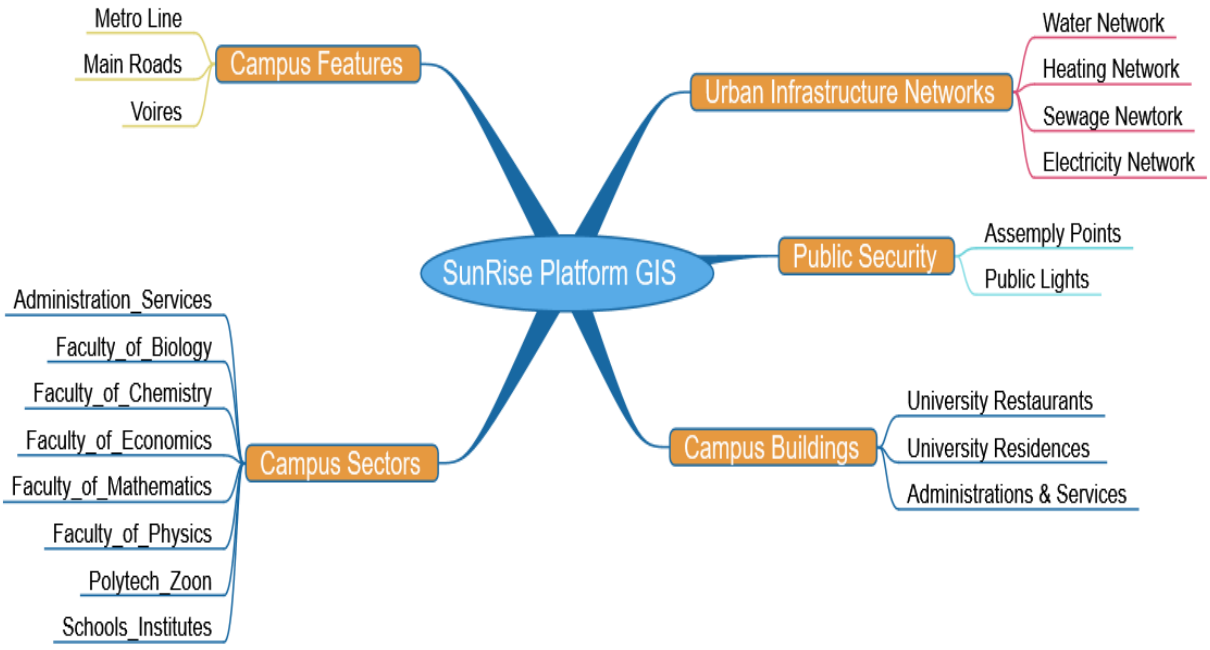

Figure 2-8: SunRise GDB, main features, and layers

Figure 2-9 shows the master plan for the campus.

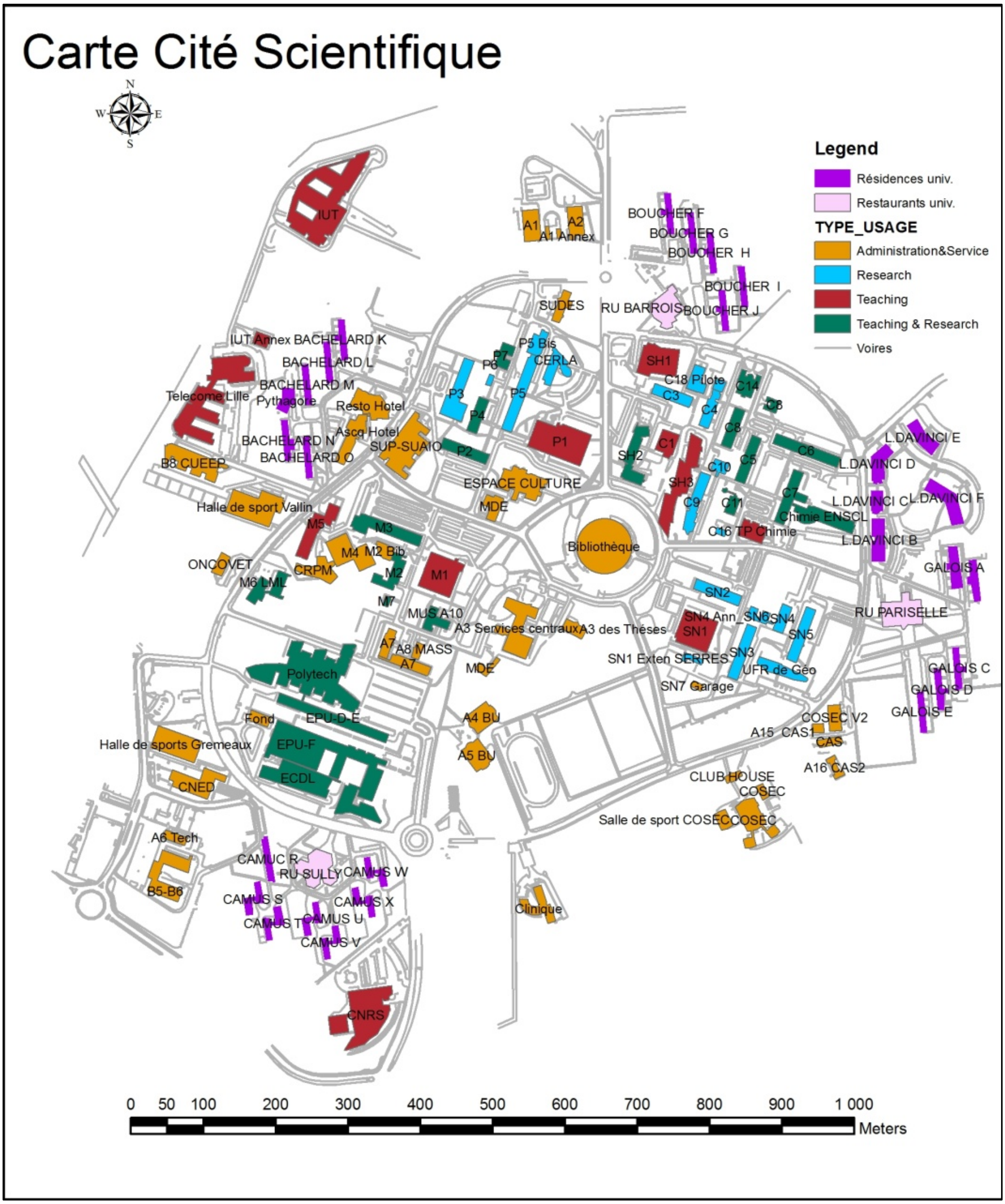

Figure 2-9: University campus buildings by sector

In the following, we present the integration of the campus networks in the GIS system.

2.4.1 Drinking water network (Farah, 2016)

The drinking water network was constructed in 1964. The pipes are in majority gray cast iron with a diameter varying from 20 to 300 mm. The length of the water network is equal to 15 km. It includes 49 hydrants designed according to the fire frightening standards, 250 valves and a set of stabilizers and purges. Figure 2-10 shows the water network. It can be observed that it is highly meshed.

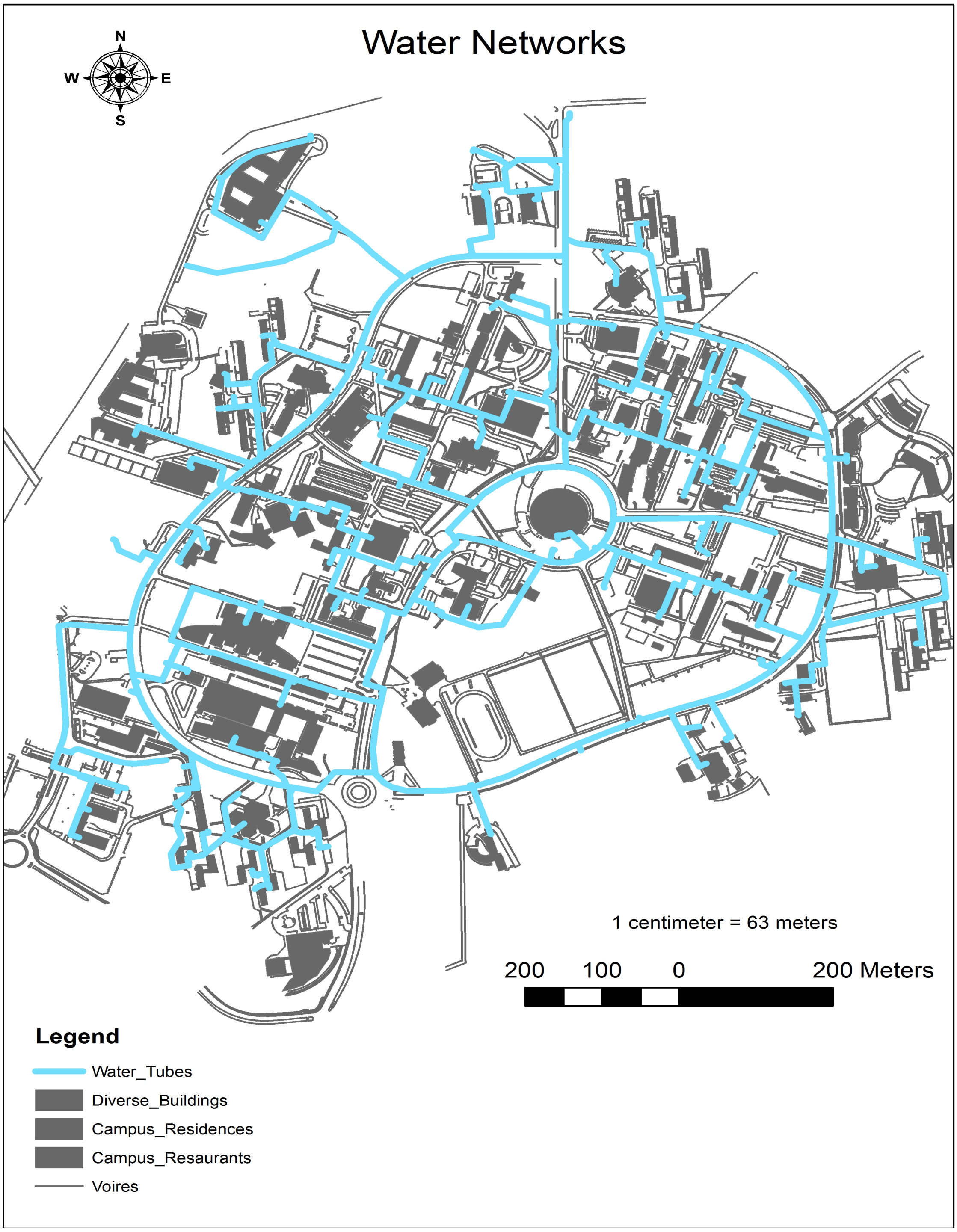

Figure 2-10: Campus drinking water network

The campus is supplied through the five connections with the public water network:

- Cite Scientifique in the North of the campus
- 4 Cantons in the south of the campus
- ECL in the southwest of the campus
- Bachelard in the west of the campus
- M5 in the west of the campus

2.4.1.1 Smart Monitoring

2.4.1.1.1 Automatic Meters Readers (AMRs)

Around 90 Automatic Meters Readings (AMRs), which measure at one-hour time lag the water supply, as well as the buildings consumption, monitor the water network. The data transfer is conducted using a local radio network, which is connected via GPRS to the central server.

The collected data are accessible from a web portal through an internet connection. The Table 2-12 shows an example of the different used AMRs.

Table 2-12: The different AMRs used in instrumentation process

Object ID	Shape	Elevation	Label
1	Point	37	J-8-A1CHAUFFERIE
2	Point	37	J-10-A2ATELIERS
3	Point	38	J-16-RUBARROIS
4	Point	38	J-19-BOUCHERG
5	Point	39	J-21-BOUCHERJ
6	Point	39	J-24-SH1
7	Point	38	J-27-SUDES
8	Point	38	J-28-P5BISCERLA
9	Point	40	J-33-C3
10	Point	39	J-37-C4
11	Point	39	J-44-C08
12	Point	39	J-46-P3
13	Point	38	J-48-C06

The total consumption of the buildings is computed from 13 principal meters regrouped as follows:

- The first group includes four AMRs entitled 4CANTONS, ECL, BACHELARD, M5 and the regrouping of 5 AMRs CITE SCIENTIFIQUE: looped network.
- The second group comprises four AMRs entitled CUEEP, DELTEC_ICARE, HALL_VALLIN, and LML: branched network (disconnected part).
- 'Bonduelle' company and the Clinic '4Cantons' (2)

2.4.1.1.2 Pressure sensors

In addition to the water meters, a set of five pressure sensors are installed in the following buildings: BARROIS restaurant, C1 chemistry building, SN5 biology building, and Polytech'Lille and BACHELARD L residence.

Each sensor is connected to a data logger, which stores the water pressure at one-hour time lag and sends the via SMS at user-definable periods (every 8 hours in our case). Tables 2-13 summarize the structure of the pressure sensor layer as well as the attributes of each component.

Table 2-13: The structure of the pressure sensor layer

Object ID	Shape	Elevation	Label	Sensor ID
1	Point	40	PR_BACHELARD	1419
2	Point	38	PR_BARROIS	1422
3	Point	39	PR_C1	1425
4	Point	40	PR_POLYTECH	1416
5	Point	34	PR_SN5	1428

2.4.1.1.3 Telemetry System

The Automatic Meters Readings consist of two parts:

- Meter reading devices (transmitters)
- Base stations (collectors)

Each meter has an impulse sensor and a VHF radio transmitter. The impulse sensor that converts it to an electronic index reads the index of the water consumption. The impulse counter is connected to a microcontroller unit to store the cumulative readings for transmission. The readings are transmitted via a radio frequency of 169 MHz to the base station. The radio receivers are installed on the roofs of buildings and gathering all indexes transmitted within a maximum range of 300 meters for an urban area.

The base stations then sent the collected data through the mobile network to a central information system with four signals per day of 1/10th of a second.

2.4.1.1.4 Acoustic logger – EAR system

EAR (Early Alarm Recording) is a listening system enabling a permanent and reliable monitoring system to increase the water network performance.

The system is composed of:

- Hydrophone positioned into the fluid vein and allows direct acquisition of noises carried out by the water and
- SEBA LOG HYDRO transmitter enabling the transmission of the data recorded.

The EAR system is installed on a 100 mm gray cast iron pipe that passes in a technical gallery and supplied the buildings in the Biology sector of the campus. The system is programmed to turn on automatically at night between 2 a.m. and 4 a.m. to monitor system noise and transform the acoustic vibrations caused by pipe leaks into actionable information on the location of leaks.

These units collect noise data during the night in order to minimize the interference from other noise sources, such as roads traffic or high daytime water consumption sound.

2.4.2 District Heating Network (Ayari, 2014)

The heating system was built in 1967. Originally, it was high pressure / high temperature (180 ° - 120/60 ° and 16 bars). The heating network was converted into low-pressure / temperature (BP / BT) and 105 ° max 4 bar pressure in 2002.

The other rehabilitation was performed in 2011 to upgrade the mechanical meters into ultrasonic meters. The heating center has a total thermal power 31Mw provided by three boilers whose main characteristics are shown in the Table 2-14.

Table 2-14: Heating boilers characteristics

Name	Boiler 1	Boiler 2	Boiler 3
Brand- Mark	BRAND SOCOMAS ROBOBLOC	BRAND ALSTOM F3626	BRAND REMEHA DANSKOTER TVB17
Installation Year	1995	1998	2003
Energy		Natural Gas	
Power	6 MW	10 MW	15 MW

The heating system includes pipes and necessary equipment to transfer the heat from the heating center to heating sub-stations and then to buildings.

The network heats the majority of the campus buildings. Some buildings are not connected to the district heating (SN6, Vallin Halle, Halle Grémaux, F6, Mass, and T10). The heating system provides also the hot water.

2.4.2.1 Primary Network

The primary network is about 5 km long. It is composed of two tubes (go & Return). The pipe diameter varies between 26 and 350 mm. Figure 2-11 shows the architecture of the primary network.

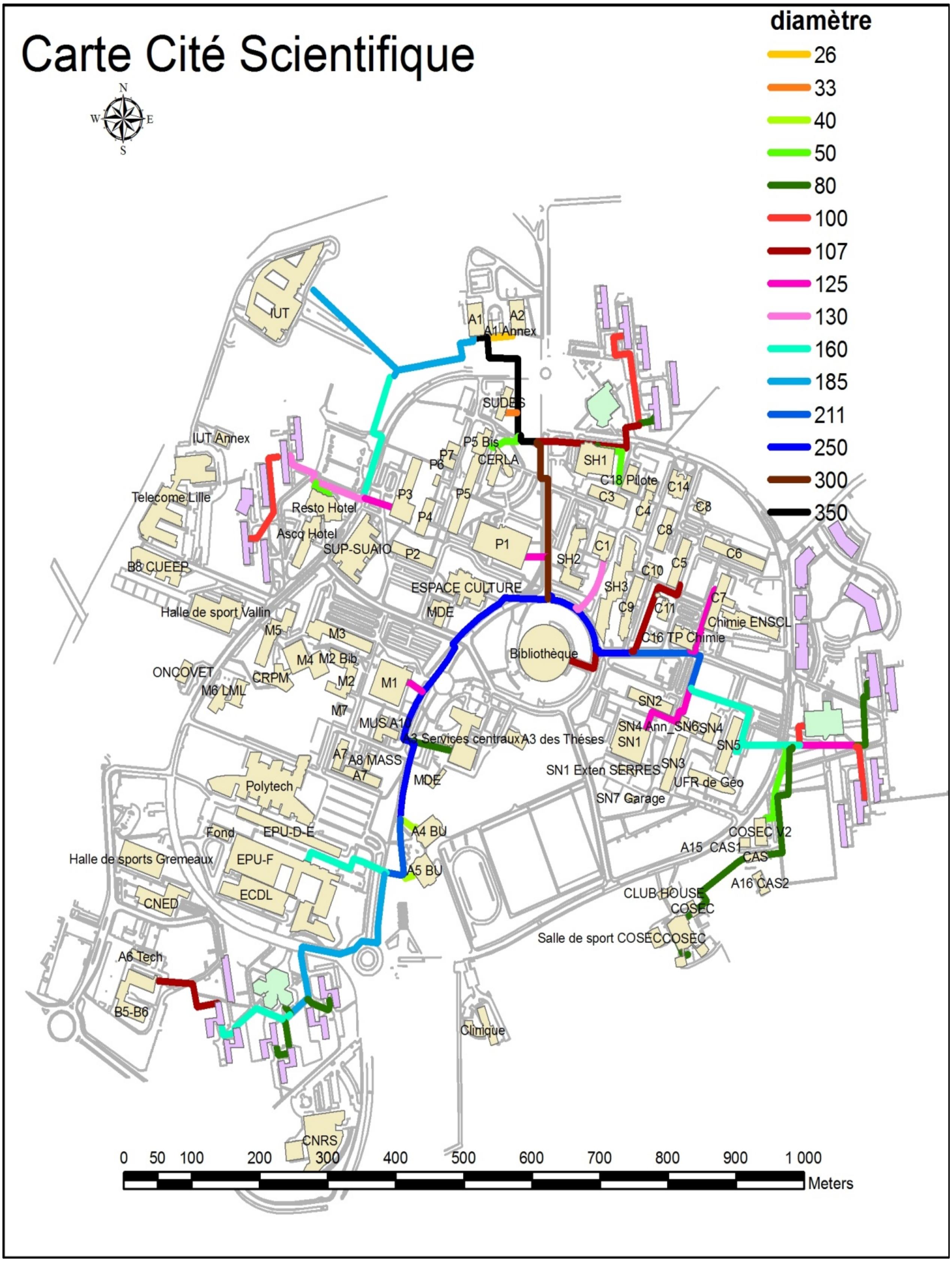

Figure 2-11: Architecture and sections of the pipes of the primary network

2.4.2.2 The Secondary Network

The secondary network is about 3.7 km in length. These pipes have the same characteristics as the primary network. The majority of pipes were installed at the construction of the Campus in 1966. Other pipes were installed for the heat supply of buildings constructed latter.

Figure 2-12 shows the secondary network (violet color).

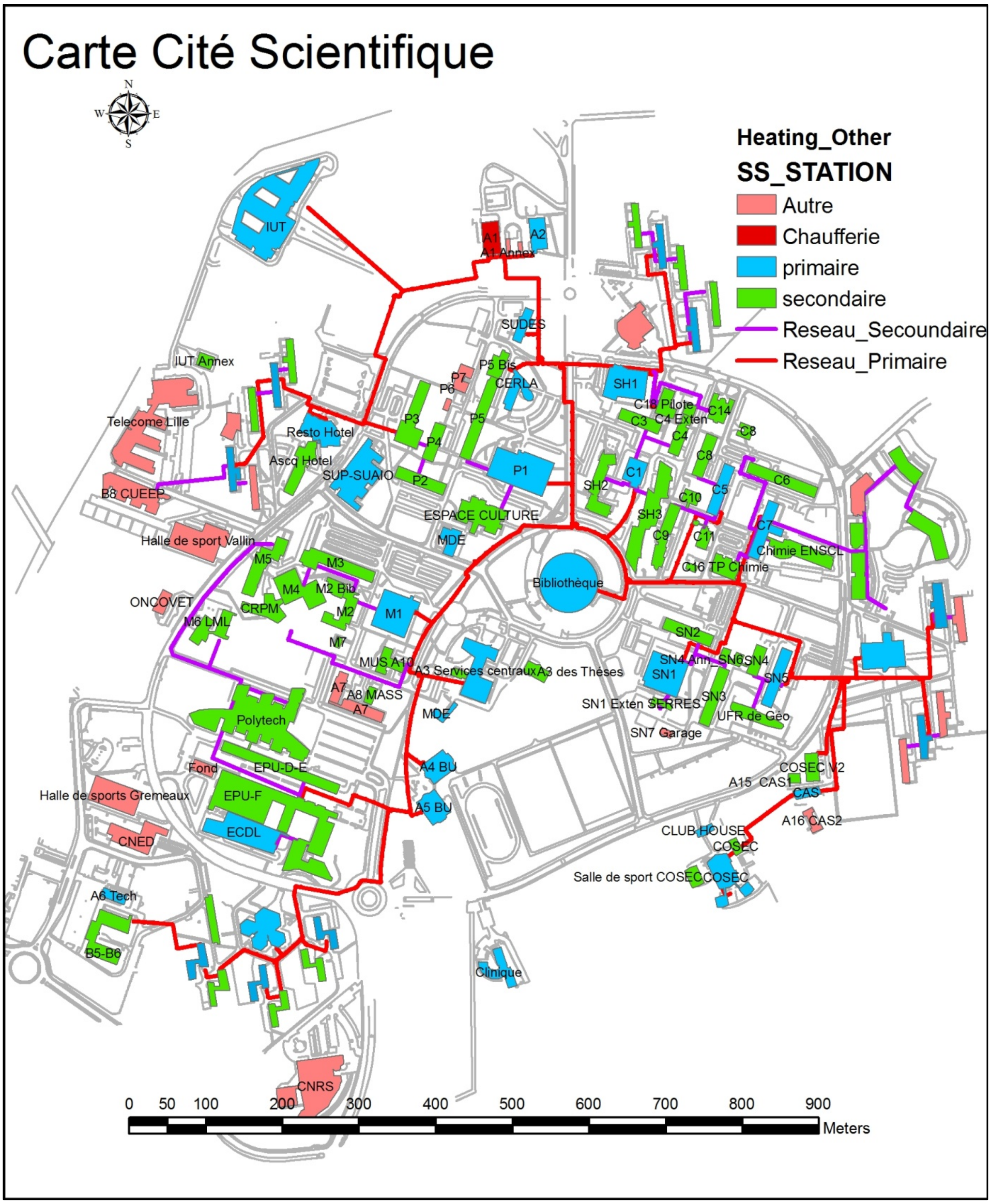

Figure 2-12: Heating network "Primary & Secondary"

2.4.2.3 Substations

Primary sub-stations are used to transfer heat from the primary network to the secondary network through plate exchangers. Each primary sub-station can heat one building or several buildings. In the latter case, secondary substations are used to heat the buildings, which are not directly connected to the primary sub-station.

Figure 2-13 shows the year of installation of the regulation system of the sub-stations. For example, the IUT is heated with one primary sub-station, while the primary substation P1 heats the buildings P1, P5, P5 Bis and the “Space culture”.

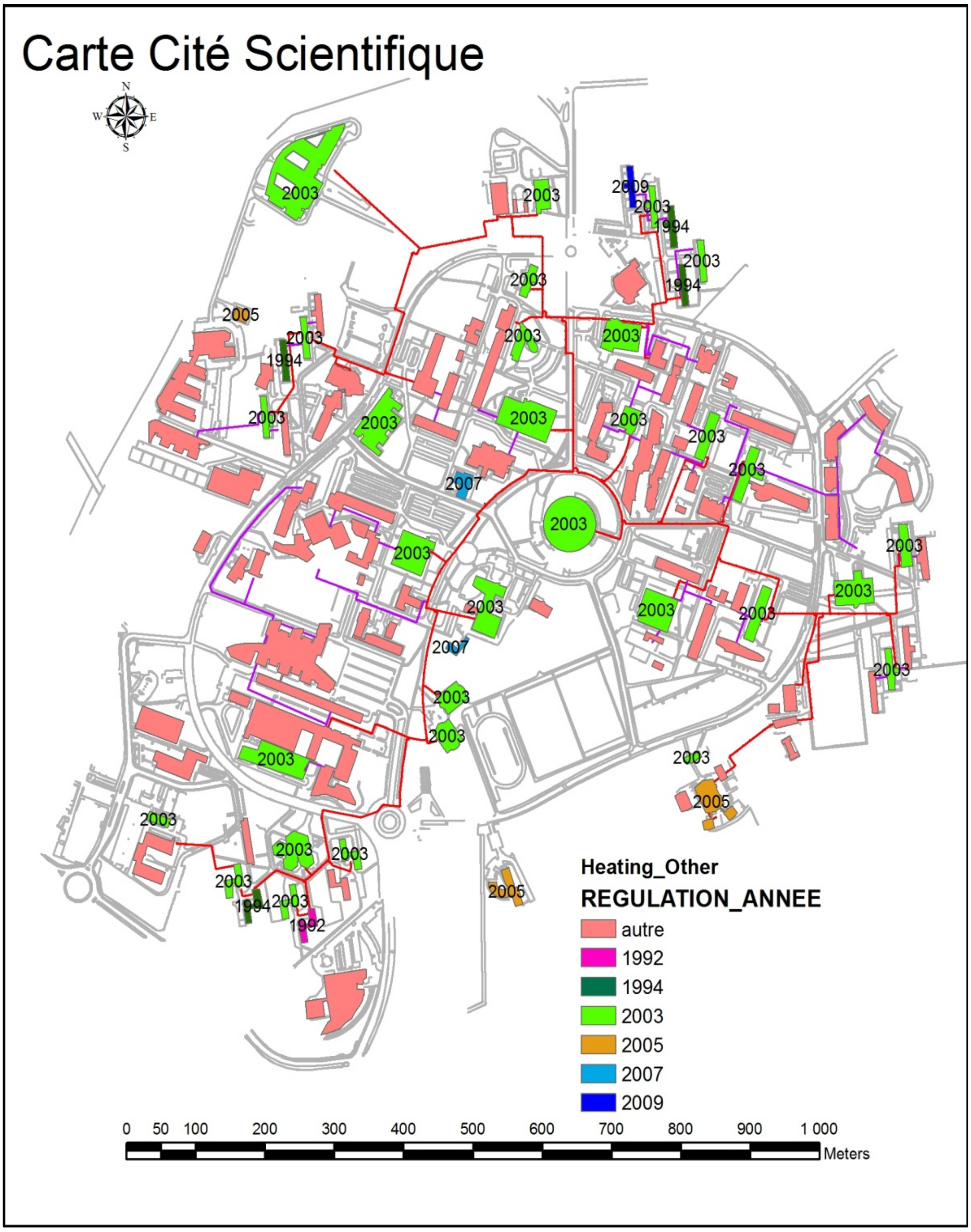

Figure 2-13: Year of installations of the sub-station regulation system

Sub-stations measure and transmit the heating consumption and other control parameters (temperature, debit, pressure, valves states). They are also used for the local regulation. Figure 2-14 shows the substations powers in the entire campus. We observe that the majority of the building are equipped with old regulation systems, which were installed in 2003 or prior to this date.

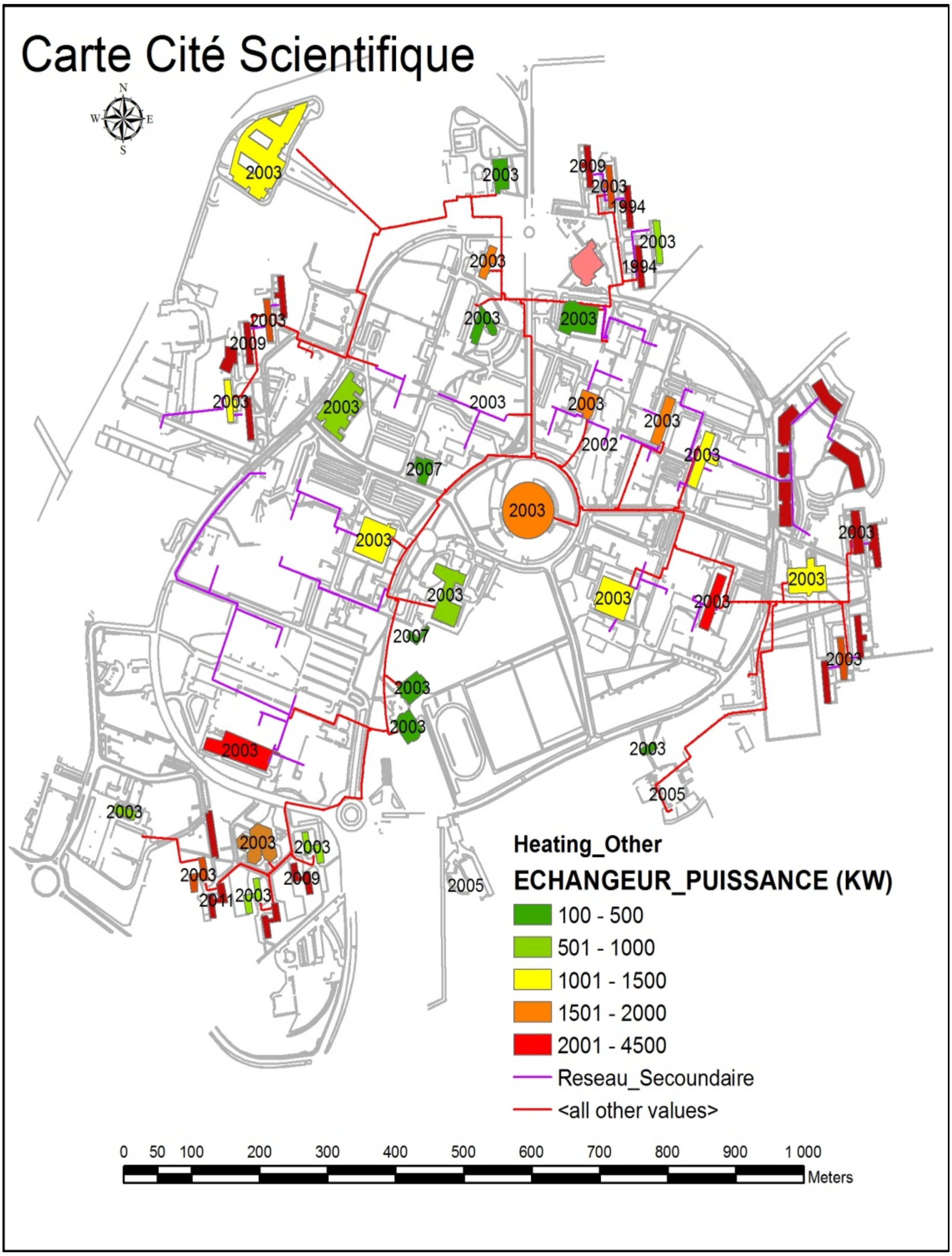

Figure 2-14: Substations powers

Table 2-15 presents the different structures for the substations layer components. We observe a large variation of the sub-stations' power, which varies between 100 and 4 500 kW.

Table 2-15: Sub Stations layer components attributes

Building	Sub Station	PLATE EXCHANGER - BRAND	PLATE EXCHANGER - POWER	PLATE EXCHANGER - YEAR	REGULATION - BRAND	REGULATION - POWER
IUT	Primary	Barriq	1500 KW	2003	Sauter	NOVA 230
BOUCHEZ PAVILLON F, G, H	Primary	Barriq	1700 KW	2003	Sauter	NOVA 230
BOUCHEZ PAVILLON I,J	Primary	Barriq	900 KW	2003	Sauter	NOVA 230
SUDES	Primary	Barriq	170 KW	2003	Sauter	NOVA 230
CERLA P5 BIS	Primary	Barriq	350 KW	2003	Sauter	NOVA 230
SH1	Primary	Barriq	200 KW	2003	Sauter	NOVA 230
P1	Primary	Barriq	1500 +1500 KW	2003	Sauter	NOVA 230
DEUG-SUIAO	Primary	Barriq	600 KW	2003	Sauter	NOVA 230

2.4.3 Sewage Network

The campus uses a separate sewage system. A sanitation network is used for the wastewater and a storm water network for rainwater.

2.4.3.1 Sanitation network (Abbas, 2015)

Figure 2-15 shows the sanitation network. It is composed of:

- A primary network (red color), which is around 4 km in length and managed by Lille Metropolis. This network transports the wastewater from the campus to the public sewage network.

- A secondary network (green color), which is around 12 km in length. This network is managed by the university. It transports wastewater from buildings to the primary network. Table 2-16 and Table 2-17 shows the structure of this layer.

Table 2-16: Sanitation network layer structure and attributes table 1

OBJECTID	Entity	Diameter	GE start	GE end	Upstream
1	Line	200	40,78	40,95	37,16
2	Line	200	39,63	39,54	36,03
3	Line	150	41,16	40,96	39,86
4	Line	200	41,26	39,63	39,63
5	Line	200	39,22	39,67	37,76
6	Line	200	41	41,05	39,06
7	Line	200	40,76	40,69	39,74
8	Line	150	40,44	40,39	39,09
9	Line	150	39,31	39,22	37,99
10	Line	200	41,73	41,53	40,95
11	Line	200	41,53	41,45	40,22

Table 2-14: Sanitation network layer structure and attributes table 2

Downstream	Slope	Slope Gr
36,1	0,070746	-0,011346
36,2	-0,007927	0,004197
39,66	0,03799	0,03799
38,9	0,01559	-0,004872
38,59	0,070748	0,004306
38,72	0,013126	0,001774
40,22	0,107793	0,029532
39,17	0,038348	0,002922
38,36	0,009232	0,002872

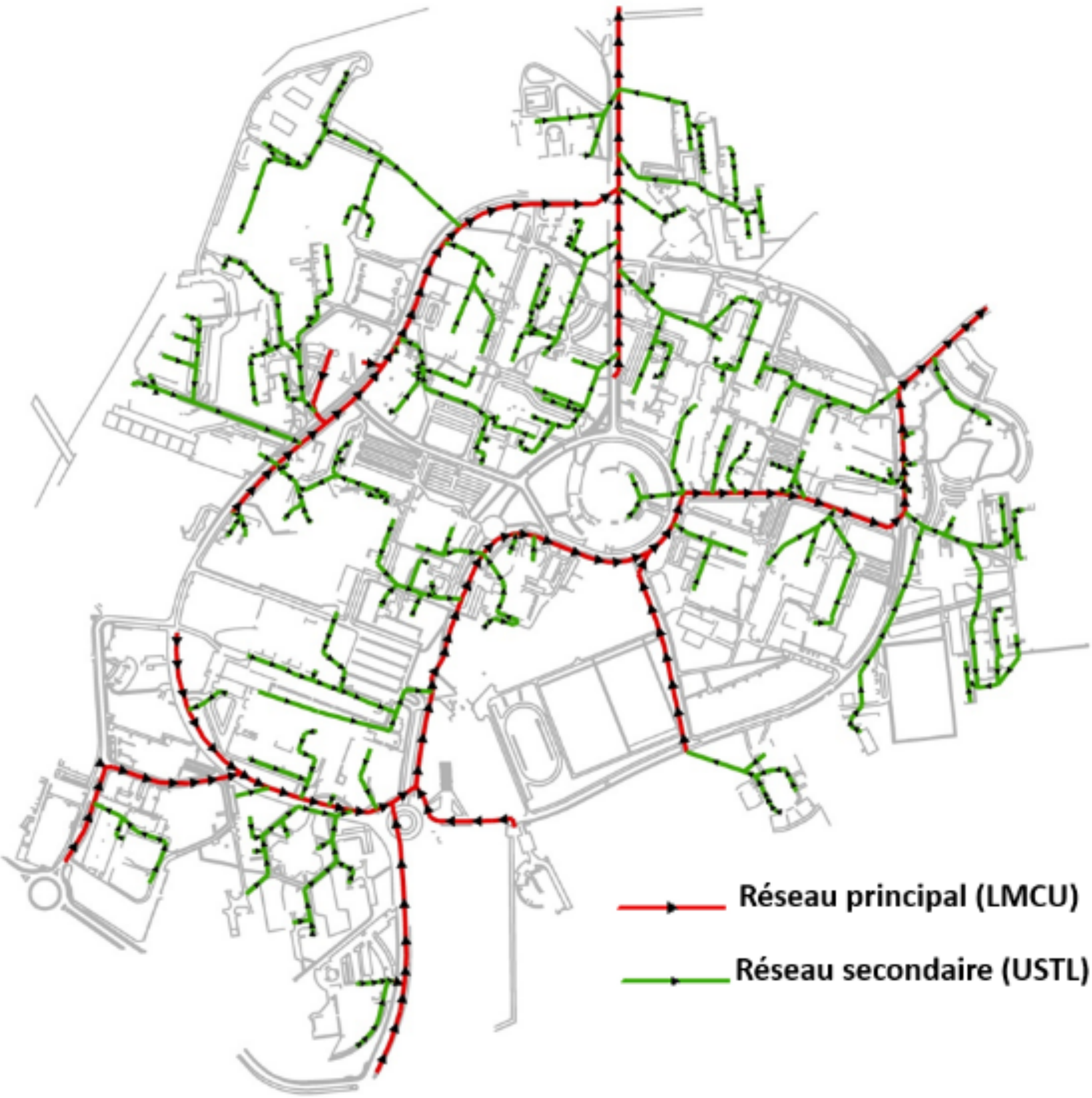

Figure 2-15: Wastewater network

2.4.3.2 Stormwater network (Abou Rjeily, 2016).

Figure 2-16 shows the stormwater network. It is composed of:

- A primary network (red color), which is around 7 km in length and managed by Lille Metropolis. This network transports the rainwater from the campus to the public network.

- A secondary network (blue color), which is around 24 km in length. This network is managed by the university. It transports rainwater to the primary network.

The pipes' diameter varies between 150 and 1200mm.

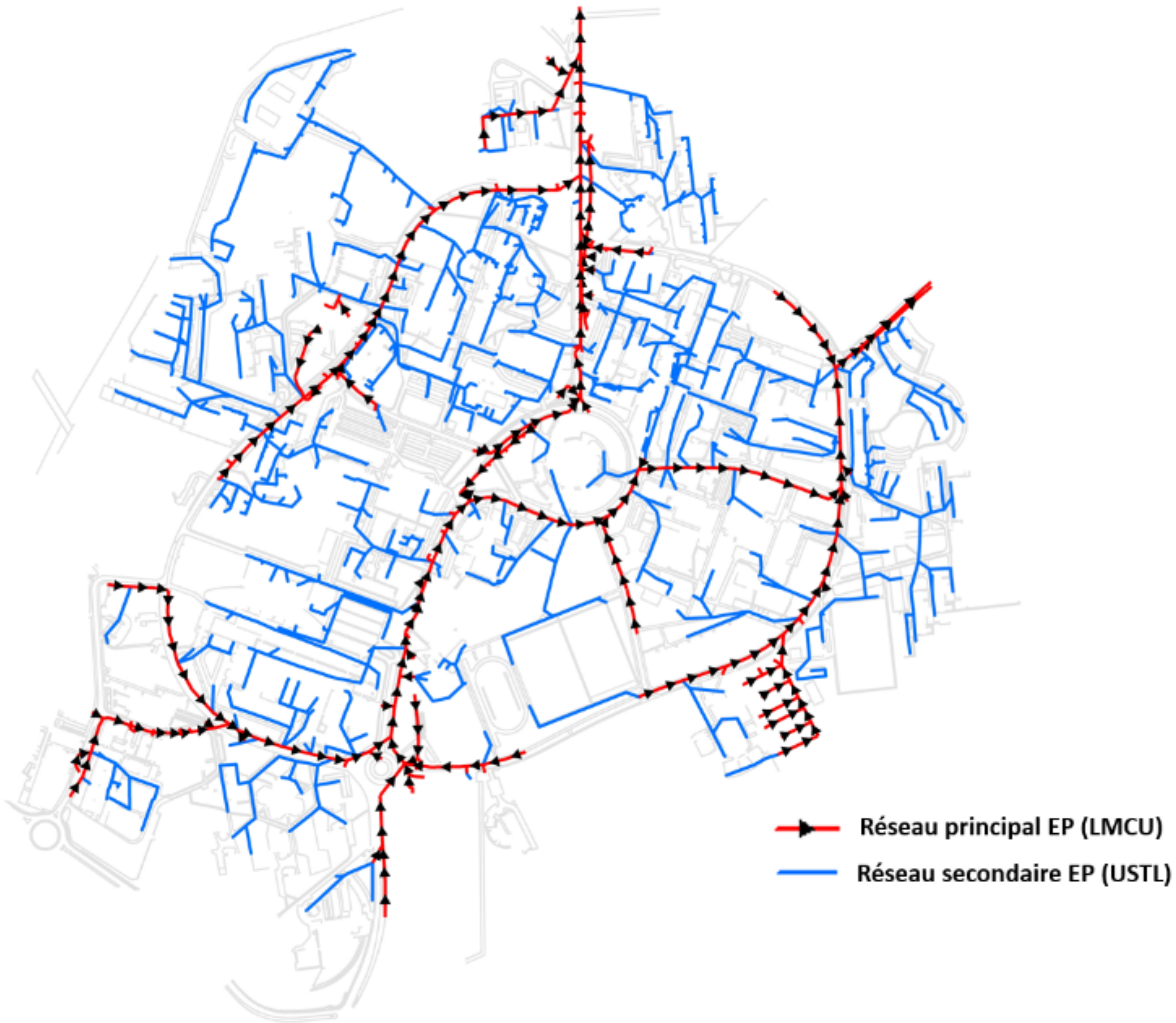

Figure 2-16: Stormwater networks

The campus is divided into two watersheds (Figure 2-17). The first one is located in the North of the campus. It has a surface of 50 ha and an impermeable coefficient of 0.4. The second one is located in the South of the Campus. It has a surface of 80 ha and an impermeable coefficient of 0.3.

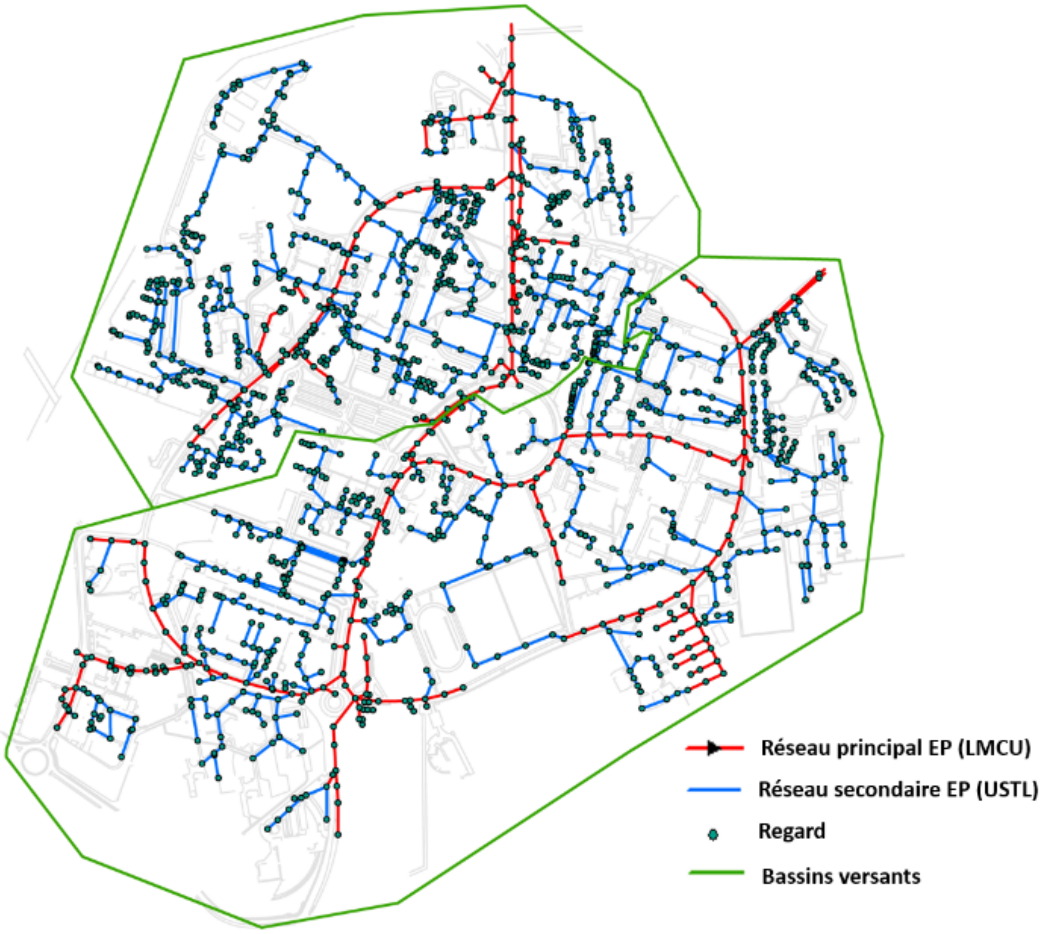

Figure 2-17: The stormwater system of the campus works with two watersheds

Table 2-17: Stormwater network layer structure and attributes table 1

OBJECTID	Diameter	GE start	GE end	Upstream	Downstream
1	600	37,17	37,31	33,17	33,1
2	150	40,01	40,01	39,63	39,62
3	150	39,93	39,95	39,39	39,36
4	150	41,28	41,29	40,62	40,37
5	160	38,44	38,29	37,45	37,37

Table 2-18: Stormwater network layer structure and attributes table 2

OBJECTID	Diameter	Ground Elevation	Raider	X	Y
1	0	37,78	36,57	710247,8	7057235
2	0	37,81	36,32	710246	7057252
3	0	37,8	35,95	710244,1	7057271
4	0	37,75	36,39	710260,8	7057266
5	0	37,49	35,99	710257,3	7057297
6	0	0	0	710255,4	7057299

2.5 Electrical Network (Sakr, 2016)

Figure 2-18 shows the electrical system of the Campus. The red color shows the Medium-Voltage grid (20 kV) which was built in 2012. The blue color shows the Low-Voltage grid, which is about 50 years old. The electrical system includes 19 sub-stations, which ensure local monitoring (current, voltage, frequency, and data transmission.), local regulation as well as the energy transformation from the Medium-Voltage grid to the Low-Voltage grid.

They are located in the following buildings: SUDES, SUIAO, C1, C5, BU, CN3, Sully, Bachelard, Pariselle, M6, P1, P5, IUT, COSEC, A1, Polytech'Lille, B5 and Barrois.

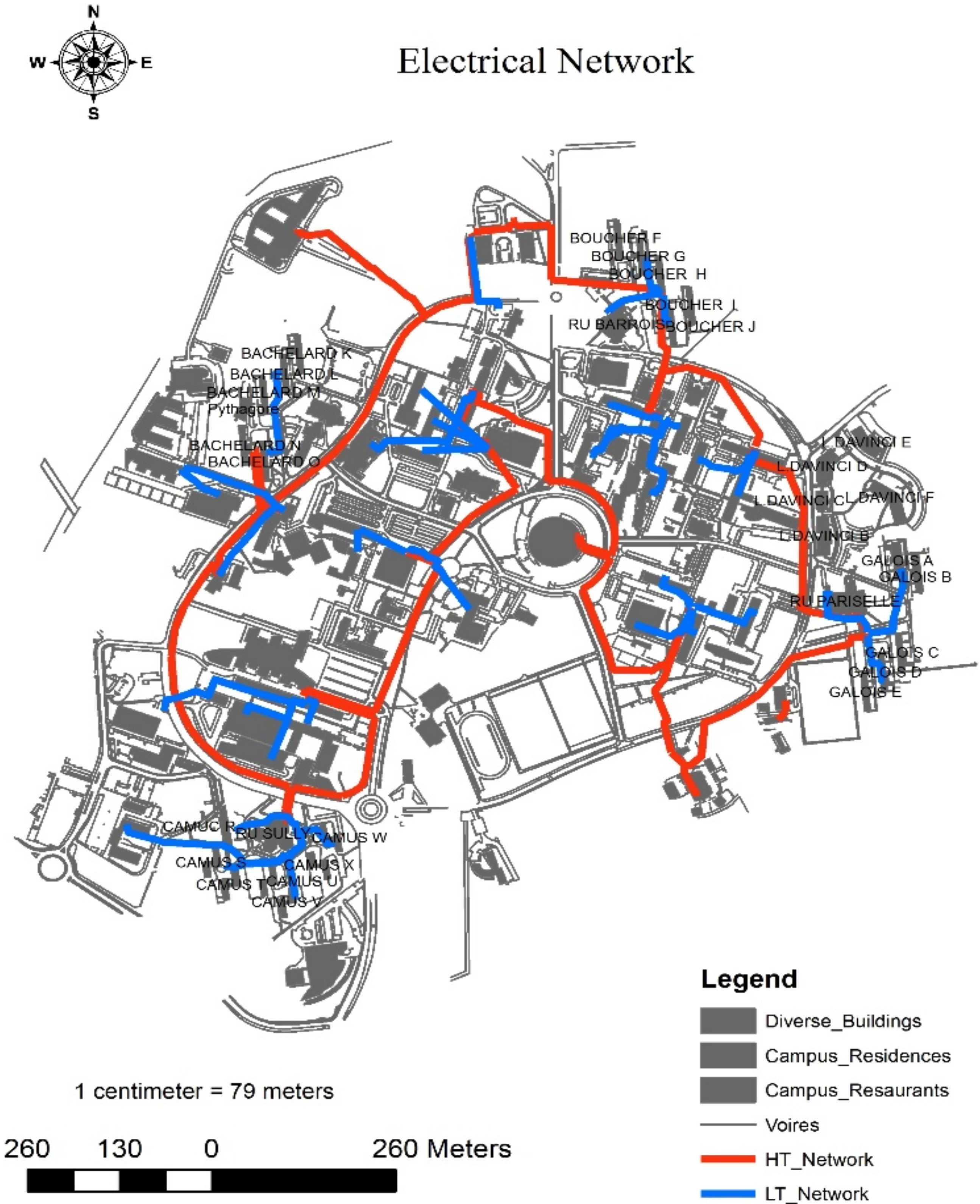

Figure 2-18: Electrical grid of the campus

The electrical company supplies the campus in building A2 in the north of the campus. From this supply section, electricity is distributed through two branches (East and West), which converge towards the sub-station in building (M6) with an open-switch.

In the case of any local fault, the concerned substation stops the current transmission by opening the switch, while the control switch (building M6) closes the switch to ensure the supply of buildings of the campus. Tables 2-19 and 2-20 shows the different structures of the network.

Table 2-19: Electrical network layer structure and attributes table 1

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Substation	Transformer#1 [kVA]	Distribution	Transformer#2 [kVA]	Distribution
A1	400	Chaufferie	400	A2
Sudes	160	Sudes		
IUT A	800	IUT A	1250	Reflex
SUP-SUAIO	400	Sup-Suaio, M5		
Bachelard	800	Bach. Residences, B8, Hall Vallin		
M6	800	CRI	500	M6, CPRM, Hall Gremeaux
B5	315	B5, F6		
Sully	630	Sully, Camus UV, Camus W	400	Camus R, Camus ST
Polytech	1000	Ecole Centrale	1000	Polytech, Batiment D, A4-A5
M1	500	M1, A3, Cups, Mass, Theses	400	M2, M3, M7, PECT, LIFL
P5	630	P5, P6, P7	1000	P5bis, Cerla
P1	1000	P1, P2, P3, P4, Espace Culture, MDE, SH4		
Barrois	400	RU, Boucher J	630	Boucher G
Pariselle	630	RU	800	Project Gallois
	630	Gallois		
	630	Boucle Secondaire		
Cosec	250	Cosec		
SN3	800	SN1, SN2, SN3, SN4, SN5, Serres, SN6, V2, Geo, CAS		
BU	250	BU		
C5	1250	C5, C6, C7, C12, C14 C16		
C1	1250	C1, SH2, SH3, C3, C4, C8, C9, C15, C17, C18		

Table 2-20: Electrical network layer structure and attributes table 2

Trans	Distribution	Trans_1	Distribution_1	Name	Thick.
800	IUT A	1250	Reflex	IUT	240
800	Bach. Residences, B8, Hall Vallin	0	0	Bachelard	240
400	Chaufferie	400	A2	PDL_A1	240
400	RU_Boucher J	630	Boucher G	Barrois	240
1250	C5,_C6_C7_ C12_C14_C16	0	0	C5	240
630	RU	800	Project Gallois	Pariselle	240
800	SN1_SN2_SN3_SN4_SN5_Serres_SN6_V2_Geo_CAS	0	0	SH1	240
250	Cosec	0	0	Cosec	240
500	M1_A3_Cups_Mass_Theses	400	M2_M3_M7_PECT_LIFL	M1	240
800	CRI	500	M6_CPRM_Hall Gremeaux	M6	240
1000	Polytech	1000	Camus R_Camus ST	Polytech	240
630	Sully_Camus UV_Camus W	400	Camus R_Camus ST	Sully	240
315	B5_F6	0	0	B5	240
400	Sup_Suaio_M5	0	0	Sup	240
1000	P1_P2_P3_P4_Espace Culture_MDE_SH4	0	0	P1	240
160	Sudes	0	0	Sudes	240
630	P5_P6_P7	1000	P5bis-Cerla	P5	240
250	BU	0	0	BU	240
1250	C1_SH2_SH3_C4_C8_C9_C15_C17_C18	0	0	C1	240

2.6 Public lighting Network

The public lighting network covers the whole area of the campus Figure 2-19. The majority of the light system in the campus is a point type, the data concerning this layer includes the type of the light and the XY coordinates.

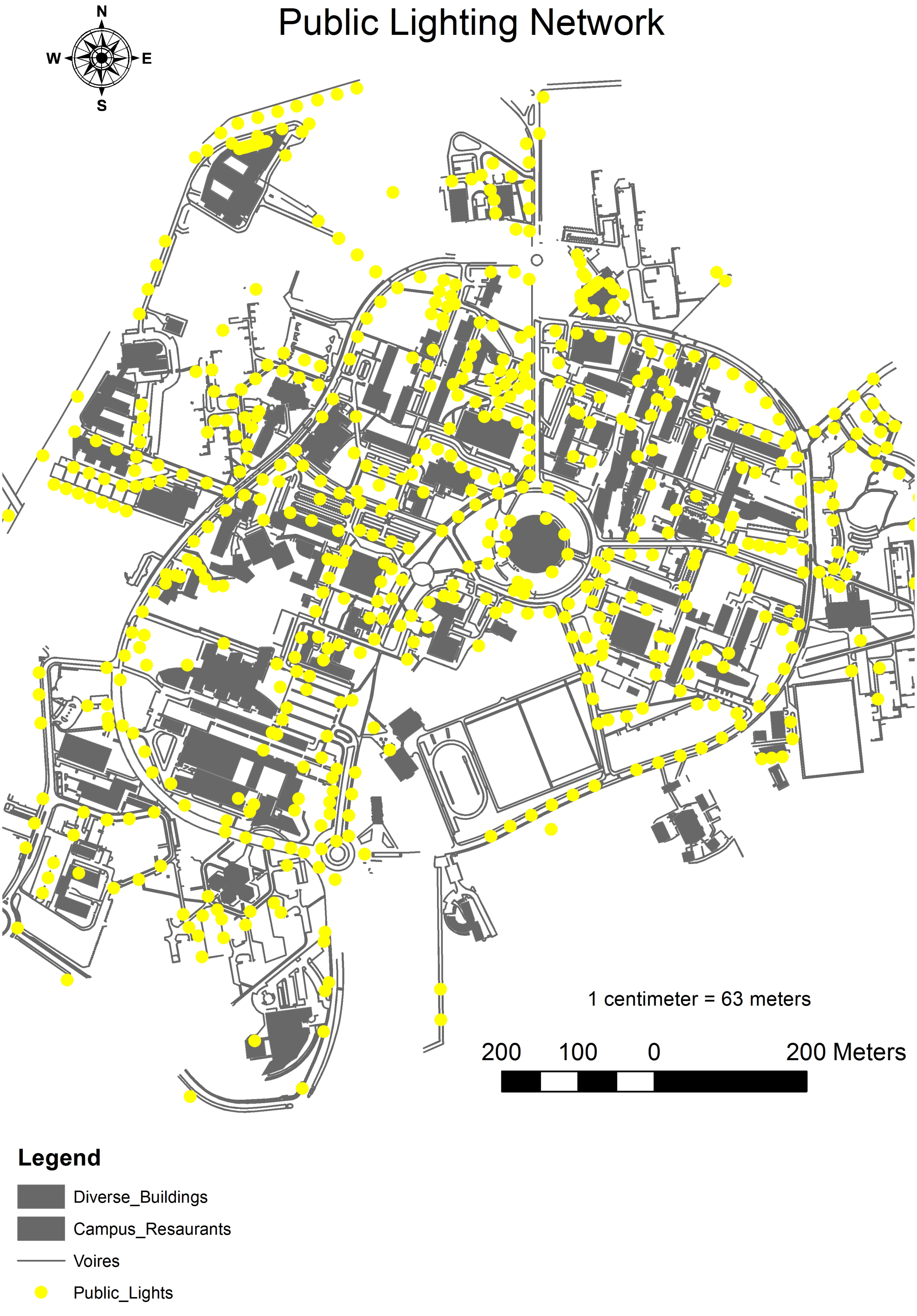

Figure 2-19: Public Lights Network

Table 2-19 shows some examples of the components and the attributes table for this layer.

Table 2-19: Public lighting network layer structure and attributes table

OBJECTID	Shape	X_Coordinates	Y_Coordinates
1	Point	709442	7057009
2	Point	709458	7057003
3	Point	709474	7056997
4	Point	709490	7056991
5	Point	709506	7056985
6	Point	709521	7056979
7	Point	709537	7056974

2.7 Presentation of combined information concerning water and energy

This section presents a combined maps for the water networks (drinking, sanitation, and storm) and it also shows the combined maps for the energy networks in the campus which include (district heating and electricity). This method of visualization provides an important explanation on how the networks are distributed in the entire campus with the intersection of layers.

2.7.1 Water systems

Figure 2-20 presents the sub-layer of each combined feature dataset for the water network; it includes the storm and drinking water pipes.

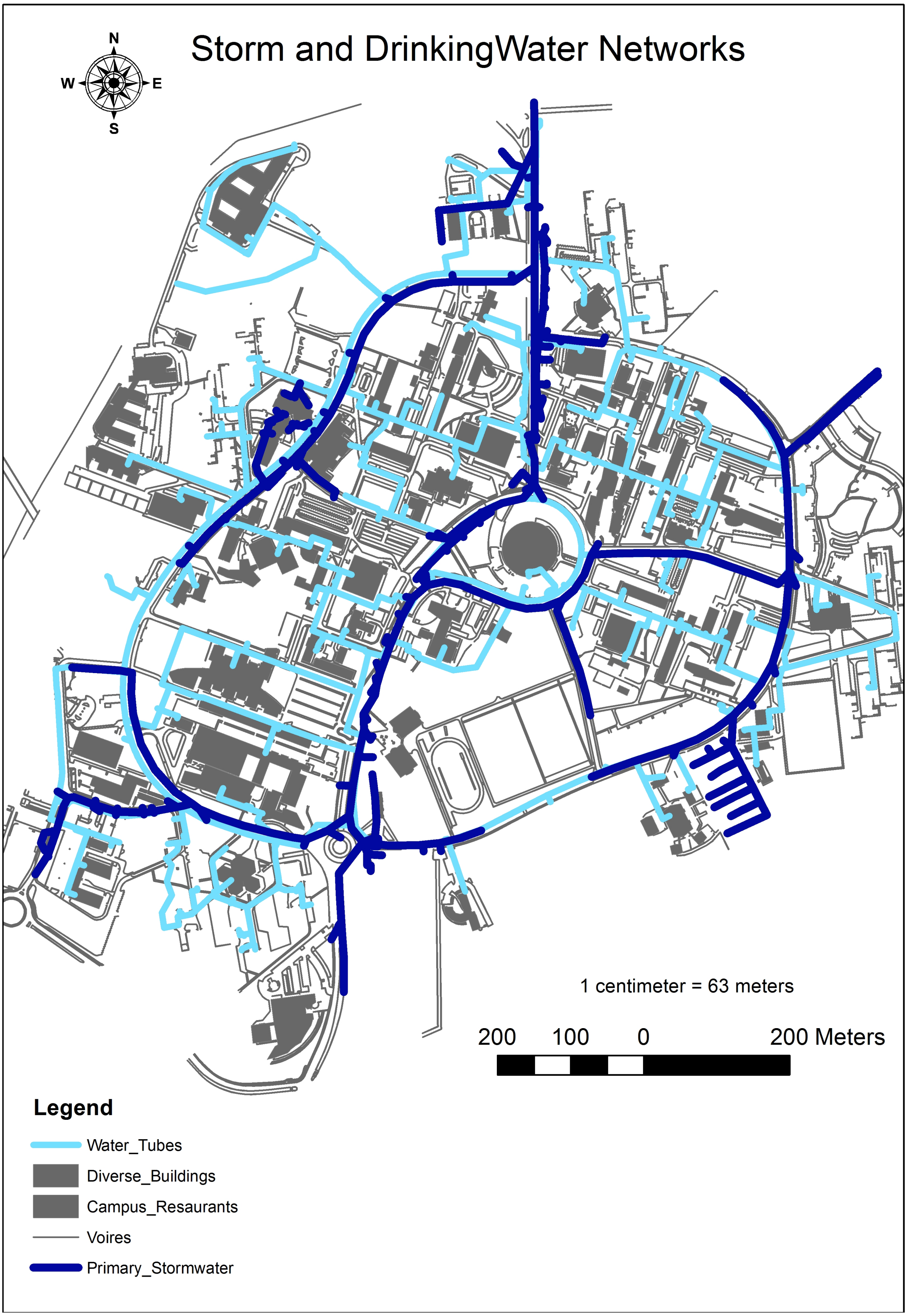

Figure 2-20: Combined map between drinking and storm water networks

Figure 2-21 presents the same combined layer and features dataset for the water network including the drinking, storm and sanitation networks

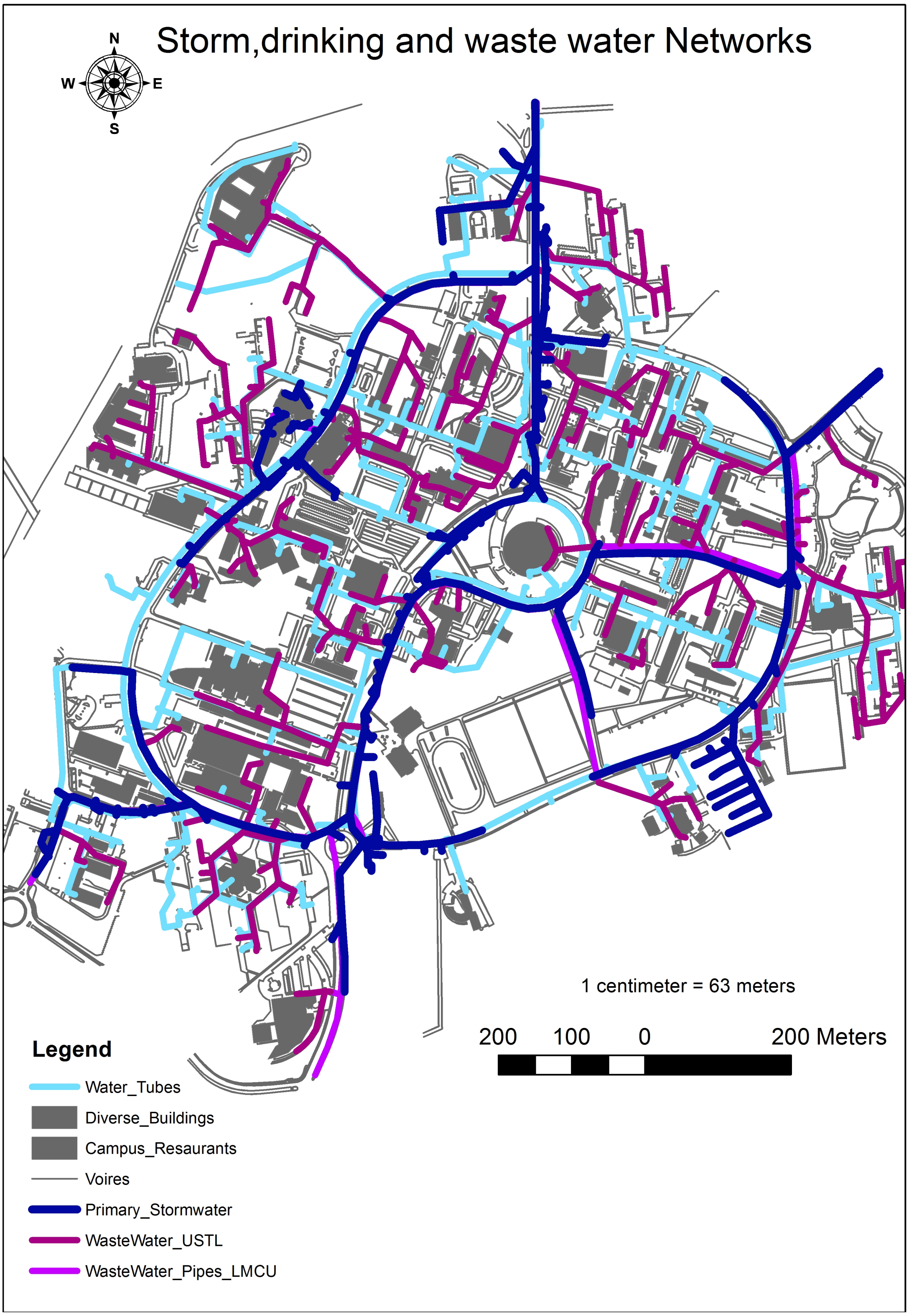

Figure 2-21: Illustration of the drinking, storm and wastewater networks of the campus

2.7.2 Energy Networks

Figure 2-22 shows the electrical and the district heating systems of the campus. The dark brown color presents the district heating network with primary and secondary sub-layers, which covers the entire campus with (go and return). For the electrical system, the red color shows the high voltage grid while a low voltage is presented in blue.

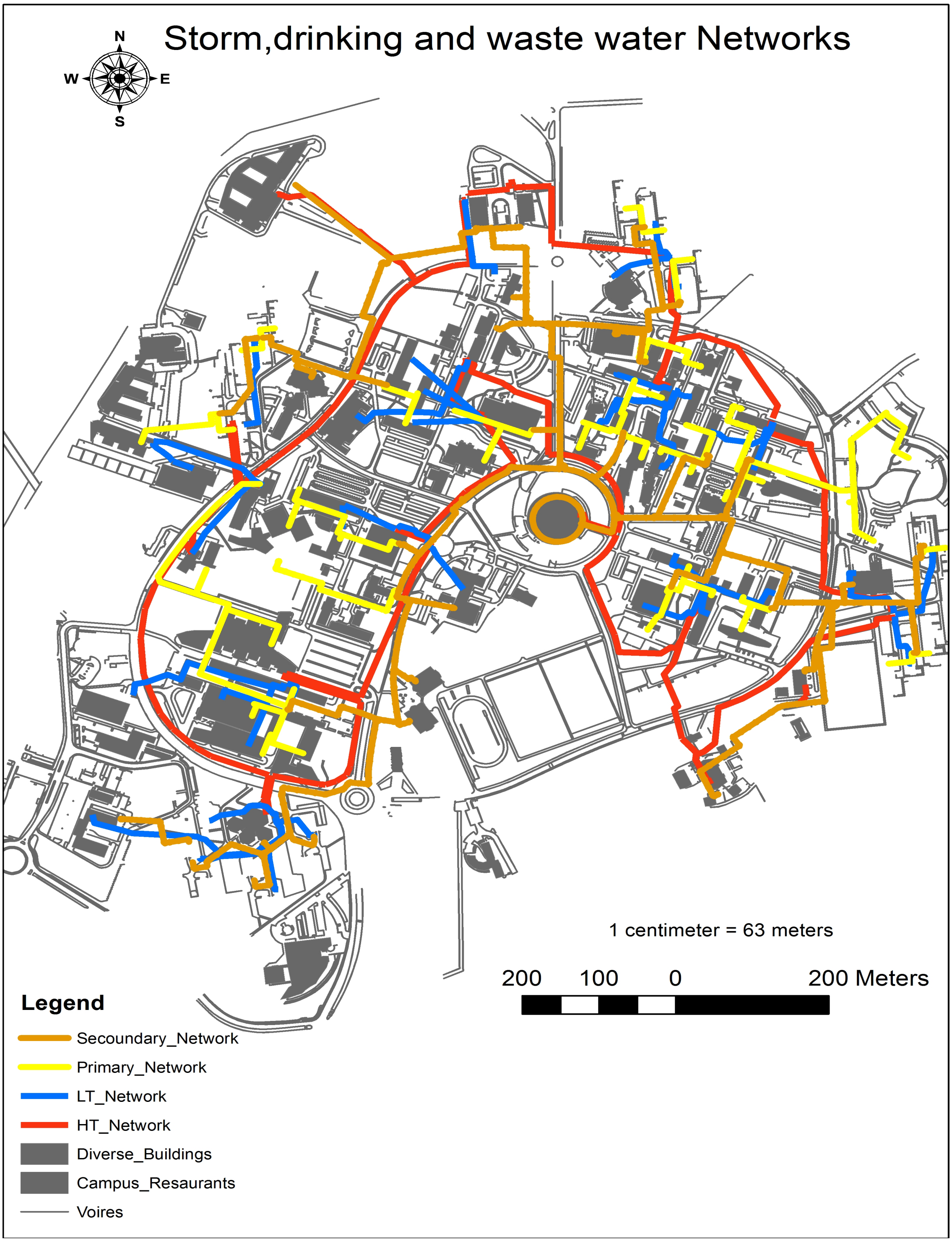

Figure 2-22: Illustration of the energy networks of the campus

Figure 2-23 presents the emergency and main roads layers in the campus with the emergency assembly points (in green color). The main routes (black color) includes Avenue Paul Langevin, Rue de la résidence Boucher, Avenue Mendeleiev, Avenue Carl Von Linné, Avenue Carl Gausse, Avenue Jean Perrin, Avenue Henni Poincarré.

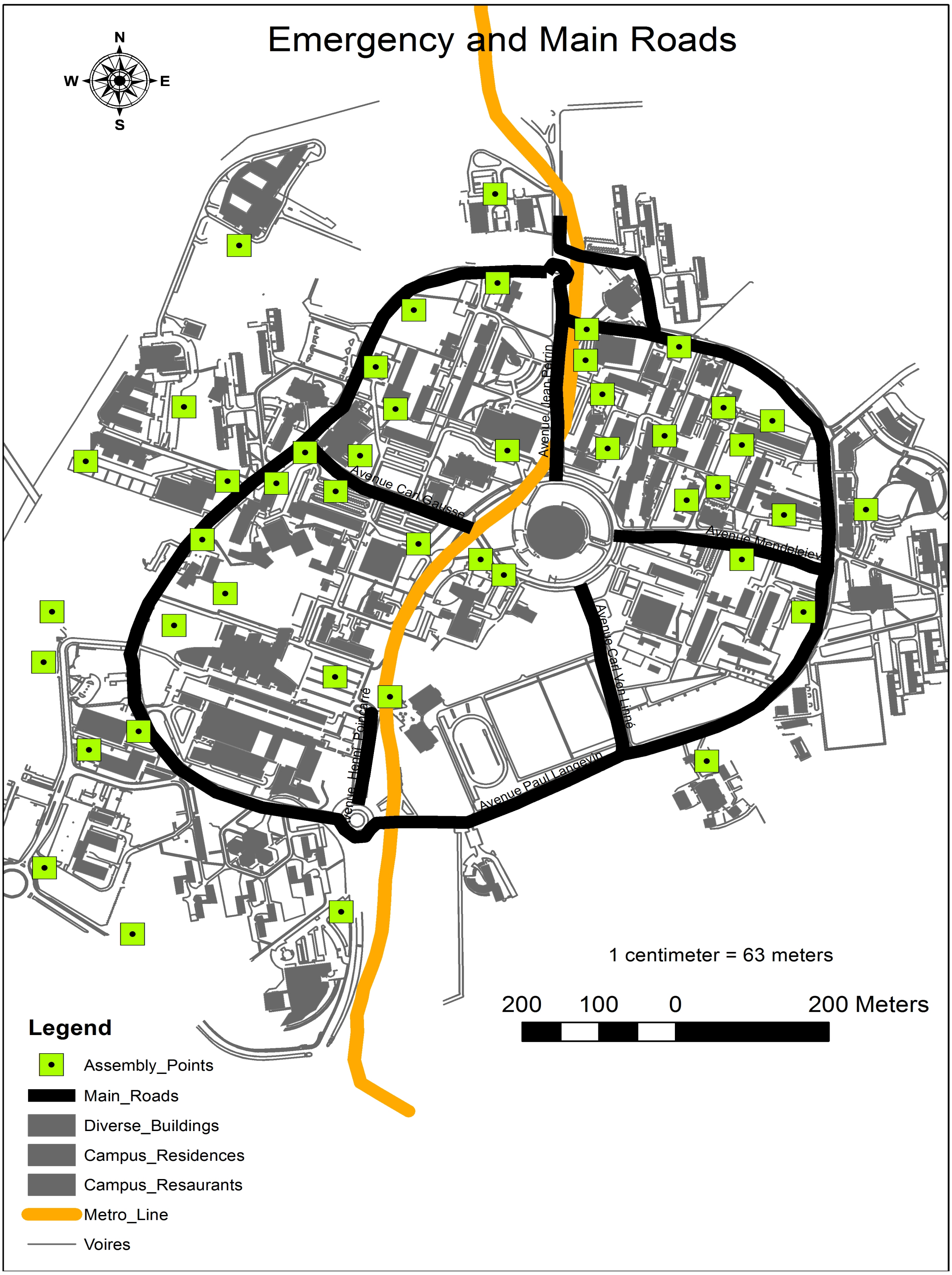

Figure 2-23: Emergency map

2.8 Conclusion

This chapter presented the construction of the GIS platform of the project SunRise. It presented first the Scientific Campus of the University of Lille, which is used as a support for the large-scale demonstrator of the Smart City "SunRise Smart City". This campus stands for a town of about 25 000 inhabitants.

The project SunRise Smart City is based on a GIS-based Urban Information System. This chapter presented the methodology followed for the construction of this system; then it presented the different layers related to buildings and urban networks (drinking water, sewage, and district heating and electrical grid).

Thanks to this work and that of other Ph.D. students (Ayari 2014, Abas 2015, Farah 2016, Abou Rjeily 2016, and Sakr 2016); the GIS-based Urban Information system has been constructed with update information concerning the campus asset as well as its maintenance.

In the following, we will present the dynamic data visualization that concerns data collected via smart sensors.

Chapter 3 : Dynamic Data Visualization

This chapter presents the dynamic data visualization of the SunRise project. It presents (i) the concept of the dynamic interaction data visualization, (ii) the tools and models used for the implementation of visualization system, which includes the historical and real-time consumptions data for the drinking water, (iii) the implementation of web application maps to interact with the current information.

3.1 Data Interactive Visualization

3.1.1 Emergence of interactive visualization

Data visualization concerns the presentation of data in a pictorial or graphical format. In the past, it was based on charts and maps to understand information more easily and quickly. Because of the way the human brain processes information, it is faster for people to grasp the meaning of data when they are displayed in charts and graphs rather than poring over piles of spreadsheets or reading pages and pages of reports.

Interactive data visualization goes a step further – moving beyond the display of static graphics and spreadsheets to using computers and mobile devices to drill down into charts and graphs for more details, and interactively changing what data you see and how it is processed (Ham & Wijk, 2004).

Nowadays, data visualization presents an important issue in almost all areas. Thanks to the progress in both digital material as well as software, it turned into interactive visualization, where users could interact in real time with data processing and visualization for a better understanding of scientific and business issues, and to develop innovative solutions that optimize management of systems (Few, 2013). Web applications are one of the most useful ways to create an interactive visualization. A web application or web app is any program that runs in a web browser.

In the following, we give a brief presentation of systems used in the interactive data visualization.

3.1.1.1 HTML

HTML Is a Markup language for describing web documents (web pages). It stands for Hyper Text Markup Language, which includes a set of markup tags. HTML tags describe the HTML documents. Each HTML tag describes different document content.

3.1.1.2 Apache 16

Apache 16 is a freely available Web server, which is distributed under an "open source" license.

Open source refers to a program in which the source code is available to the public for use and/or modification from its original design free of charge. This web server and MySQL database are available in software called WampServer (Rouse, 2014).

3.1.1.3 WampServer 17

WampServer 17 is a web development environment. It allows the user to create web applications with Apache2, PHP, and a MySQL database. Alongside, PhpMyAdmin allows the user to manage easily databases. There are many PHP frameworks, which make the application more efficient, organized, and secured. The CodeIgniter framework was selected for this application. It is a powerful PHP framework, which enables developers to create full-featured web applications (Bourdon, 2015). MVC (Model, View, and Controller) is one of the most famous and useful technique to encode a web application with all programming languages. MVC is an Architectural pattern that describes a way to structure applications and the responsibilities and interactions for each part of that structure.

Figure 3-1 shows the MVC's architecture. The application is organized into three main components. The Controller manages the user requests (received as HTTP GET or POST requests when the user clicks on GUI elements to perform actions).

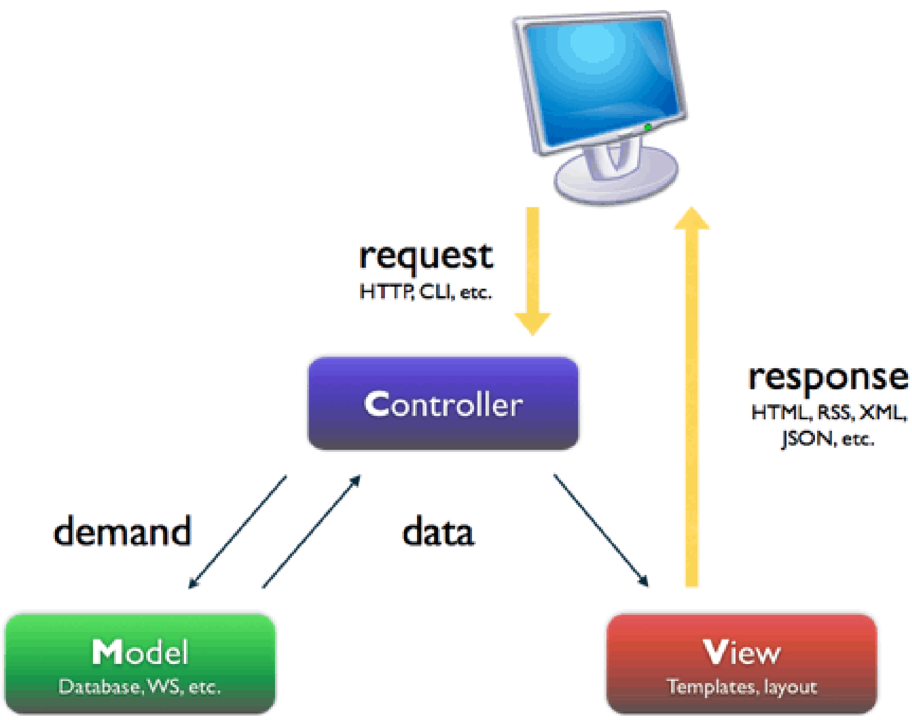

Figure 3-1: MVC system (Source: framework Symfony2)

Its main function is to call and coordinate the necessary resources/objects needed to perform the user action. Usually, the controller will call the appropriate model for the task and then selects the proper view.

The Model represents the data and the rules applying to the data. In software systems, everything is modeled as data that we handle in a certain way. What is a building, an adapter or a sensor for an application? Only data that must be handled according to specific rules (date cannot be in the future, e-mail must have a specific format, the name cannot be more than x characters long, etc.).

The model gives the controller a data representation of whatever the user requested (an adapter, a list of sensors, a building, etc.). This data model will be the same no matter how we may want to present it to the user. The model contains the most important part of our application logic that applies to the problem we are dealing with (a forum, a shop, a bank, etc.). The controller contains a more internally organizational logic for the application itself (more like housekeeping). The View provides different ways to present the data received from the model such as templates where that data are filled or views.

A web application is usually composed of a set of controllers, models, and views. The controller may be structured as a main controller that receives the requests and calls specific controllers that handle actions for each case. HMVC is an evolution of the MVC pattern used for most web applications today (Figure 3-2). Each triad operates independently.

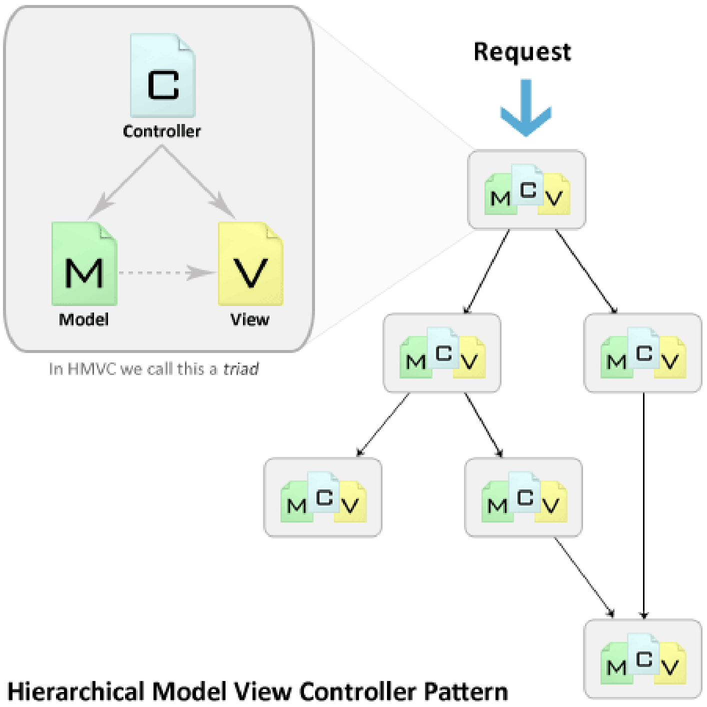

Figure 3-2: HMVC system (Source: Java World)

A triad can request access to another triad via controllers. Both of these points allow the application to be distributed over multiple locations.

The layering of MVC triads allows for robust application development with the following advantages:

- **Modularization**: Reduction of dependencies between the disparate parts of the application.

- **Organization**: Having a folder for each of the relevant trials makes for a lighter workload.

- **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.

3.2 SunRise Dynamic Geo-Database Visualization

3.2.1 Data Implementation

The drinking water system in the Campus is used as an example for the dynamic data visualization. As presented in the second chapter, this system is monitored by 93 AMRs, which are illustrated in Figure 3-3.

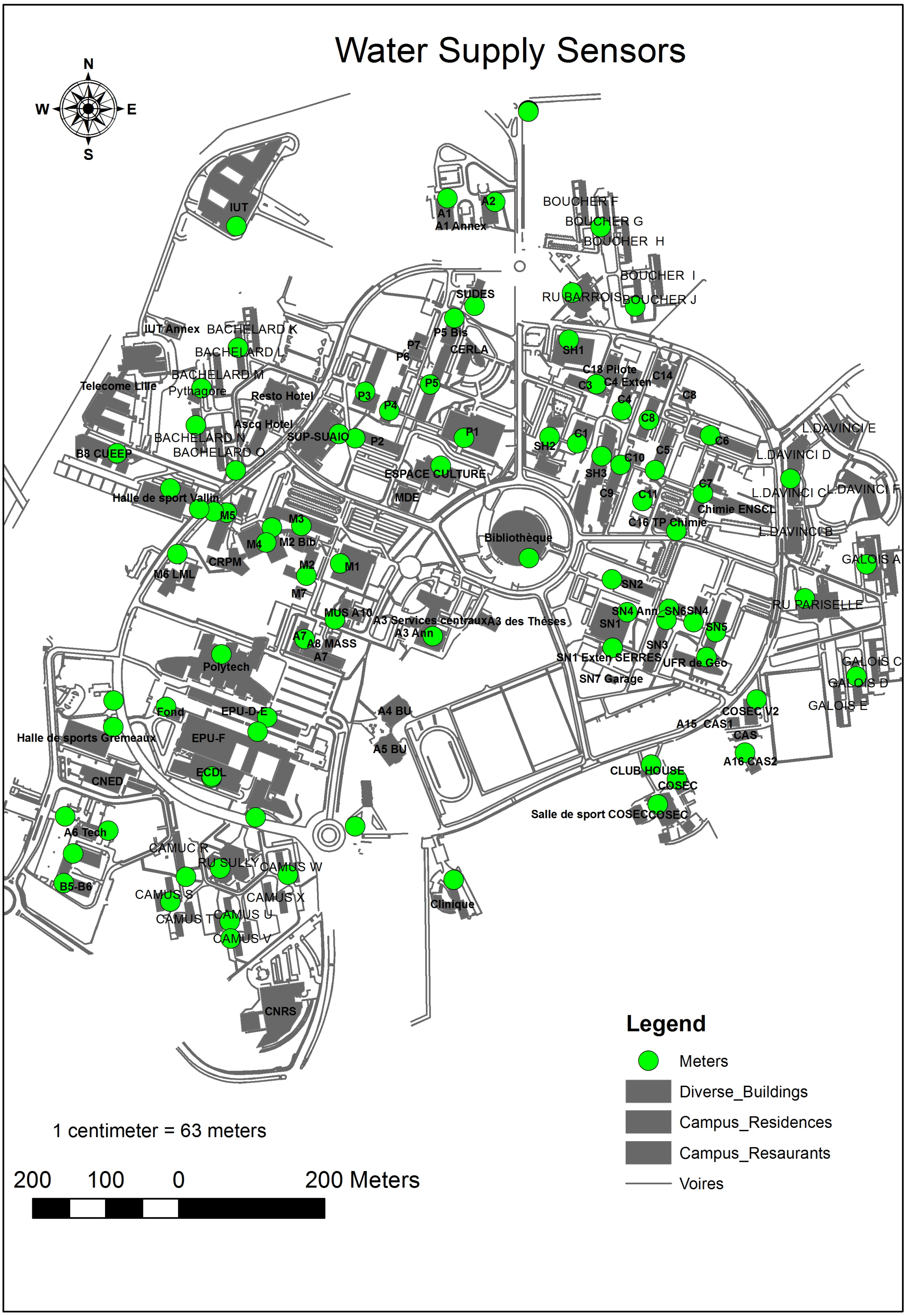

Figure 3-3: The drinking water network is monitored 93 AMRs (Automated Meter Reading) Interaction ArcMap - web Application

The raw data is received in excel sheets, which is converted into MySQL using FME workbench software.

To create an interactive visualization for this database a web application was developed. It operates in two ways:

- As a normal website with interactive interfaces to represent and filter the data.

- As a popup window in ArcGIS, in this case, it receives a parameter from ArcGIS.

Table 3-1: Water meters components and attributes table

OBJECTID	Shape	Elevation	Label	X	Y	LABEL_SQL
1	Point	37	J-8-A1CHAUFFERIE	709977	7057396	A1
2	Point	37	J-10-A2ATELIERS	710042	7057391	A2
3	Point	38	J-16-RUBARROIS	710148	7057267	BARROIS
4	Point	38	J-19-BOUCHERG	710187	7057357	G
5	Point	39	J-21-BOUCHERJ	710234	7057248	J
6	Point	39	J-24-SH1	710143	7057202	SH1
7	Point	38	J-27-SUDES	710014	7057249	SUDES
8	Point	38	J-28-P5BISCERLA	709986	7057232	P5_BIS
9	Point	40	J-33-C3	710181	7057142	C3
10	Point	39	J-37-C4	710216	7057106	C4
11	Point	39	J-44-C08	710253	7057092	C8
12	Point	39	J-46-P3	709864	7057131	P3
13	Point	38	J-48-C06	710337	7057071	C6
14	Point	37	J-52-LDEVINCI	710447	7057012	C_D_DEVINCI

The best way to build the connection between ArcGIS and the web application consists in the use of HTML popup feature, which is available in ArcGIS (Figure 3-4). HTML popup windows enable users to access formatted content, including web-based content such as graphics referenced by URLs, by clicking on features on the map.

They are especially useful for layers that users want to share as packages; they can access richly formatted information about features when they open the user's package in ArcGIS Desktop or ArcGIS Explorer Desktop.

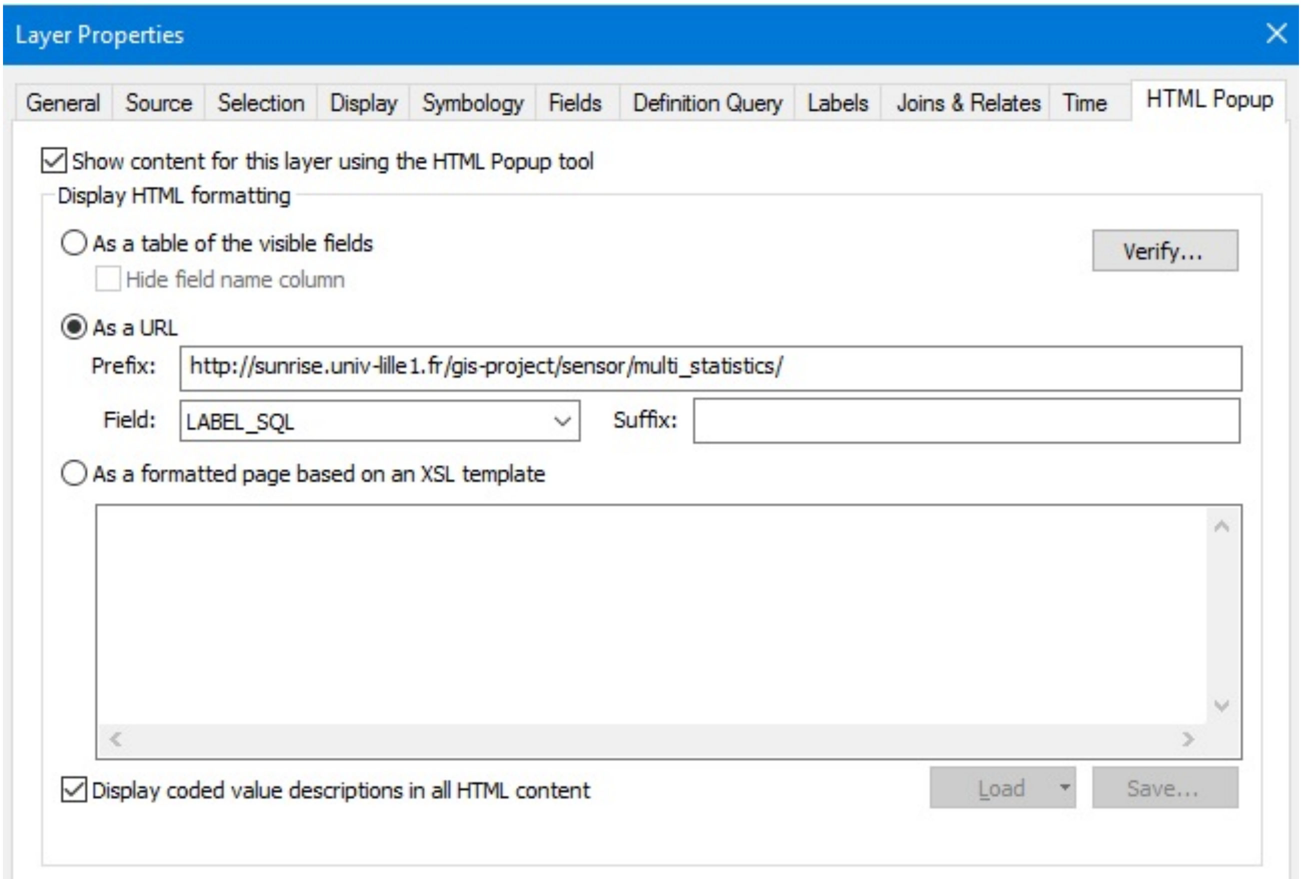

Figure 3-4: Setting the HTML Pop-up properties

By linking the application with ArcGIS, users can get charts and statistics for each element, which could be selected from the map by clicking on the element from ArcGIS. These charts could be filtered.

Figure 3-5 displays the sensors integrated into the database. Users can conduct the following operations:

- See the list of the sensors existing in the database.
- Select any month to display the water consumption: the results can be visualized using charts; users can also access to other consumption data such a; the average, minimum and maximum.
- Select a specific day to see the chart about the consumption values and statistics during the day.

- Select two dates and times to see the range of consumption values and statistics between these dates.
- Compare data of two sensors.
- Detect any problem in the network by finding abnormal sharp peaks in the chart and inform the administrative department.
- Compare by selecting two or more sensors from ArcGIS map.

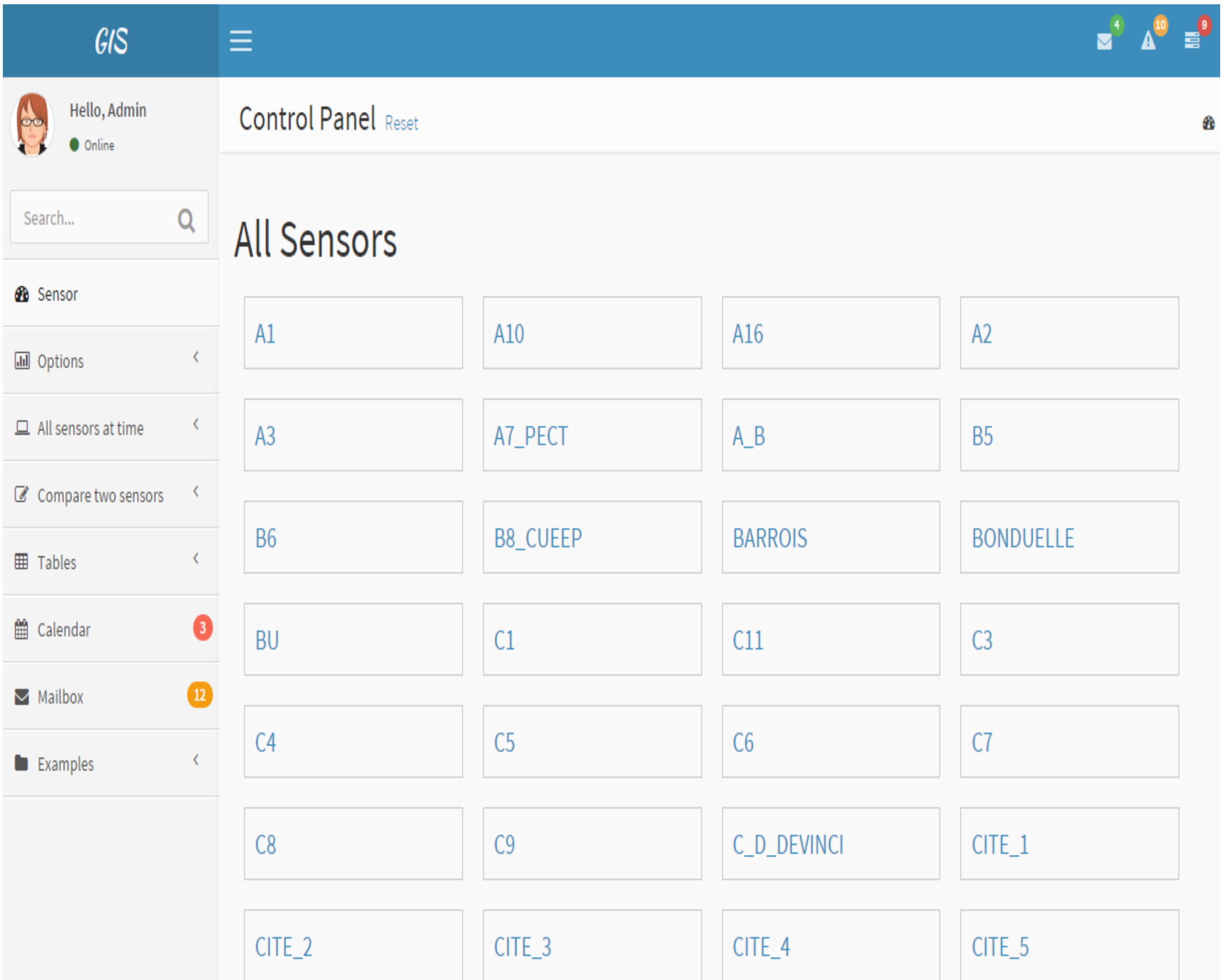

Figure 3-5: List of sensors listed in the web Application

Figure 3-6 shows an example of the monthly consumption of the building C7 in 2014. The database can be linked to any external database.

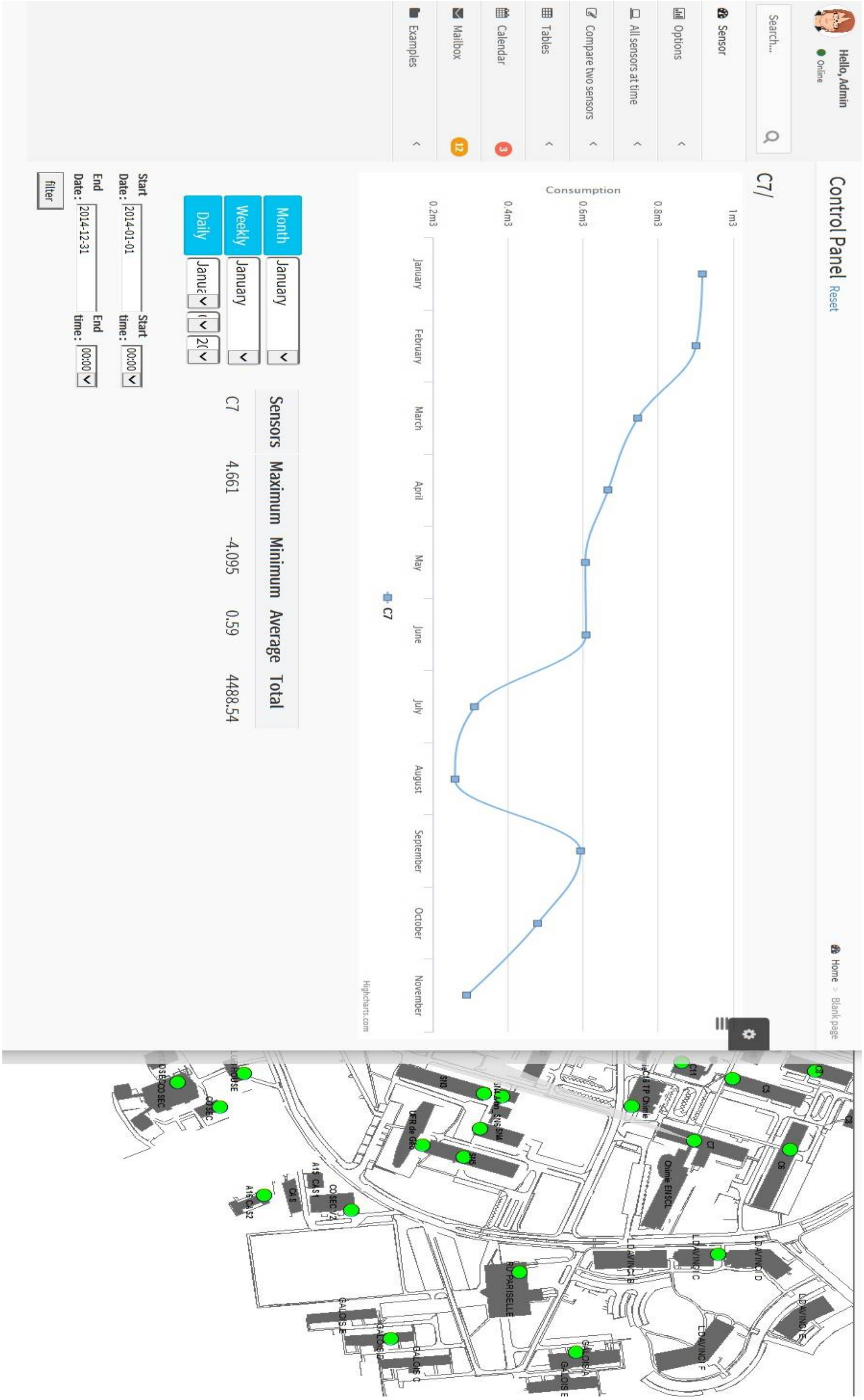

Figure 3-6: Example of a building C7 monthly consumption in 2014

3.3 SunRise Interactive Map

The online version of the ArcGIS for desktop allows creating interactive web maps, share maps on the internet, access content shared by other users and make maps with Esri Maps for MS Office.

We have created the account “SunRise” (Figure 3-7).

In order to create our interactive maps for the project, the ArcGIS Online has an option to upload all the data concerning the project as layers and locate it on the map. The online platform is a collaborative web GIS that allows users to create and share maps, scenes, apps, layers, analytics, and data.

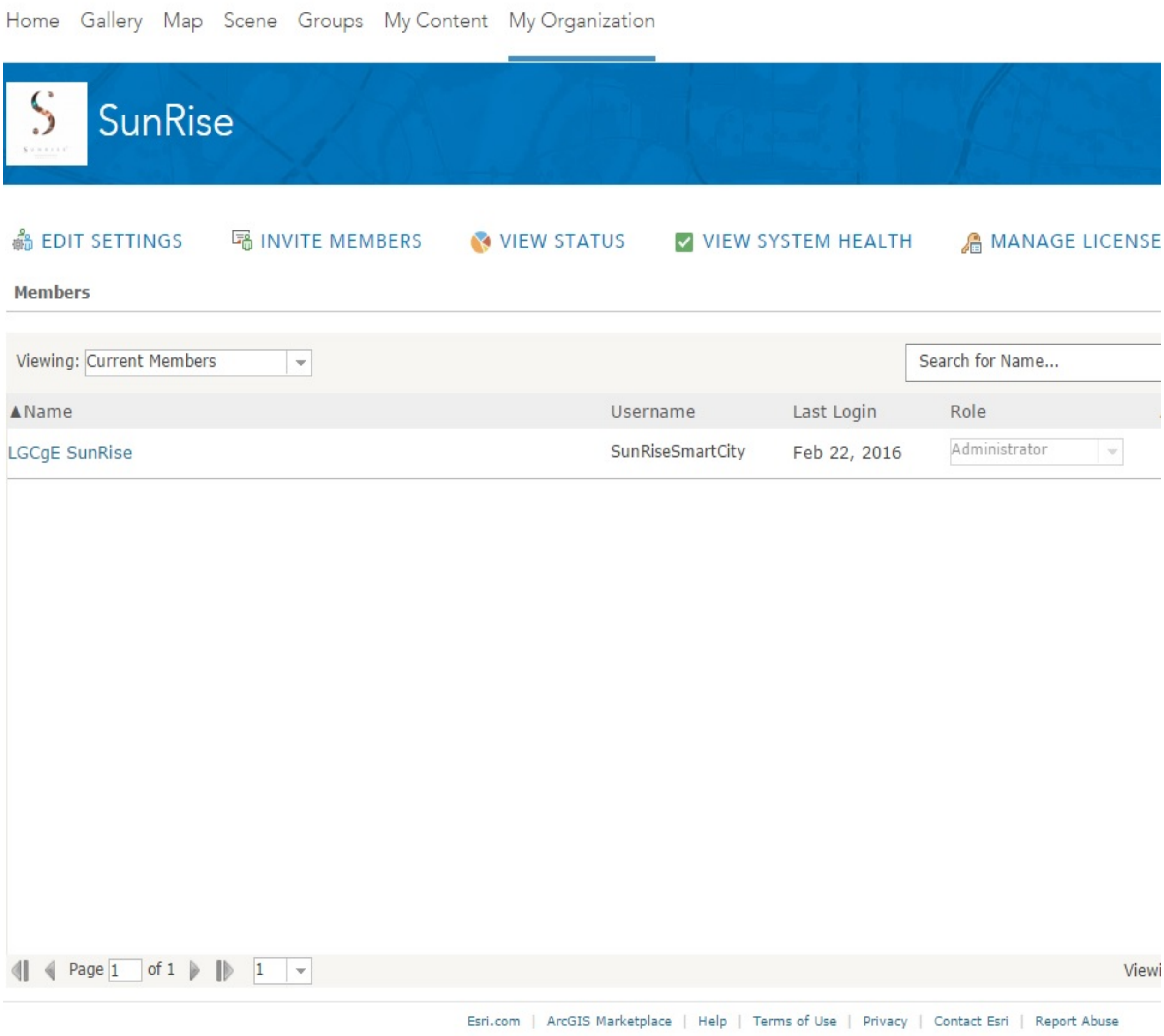

Figure 3-7: SunRise Interactive Map Account

Figure 3-8 shows the SunRise interactive map "ArcGIS Online".

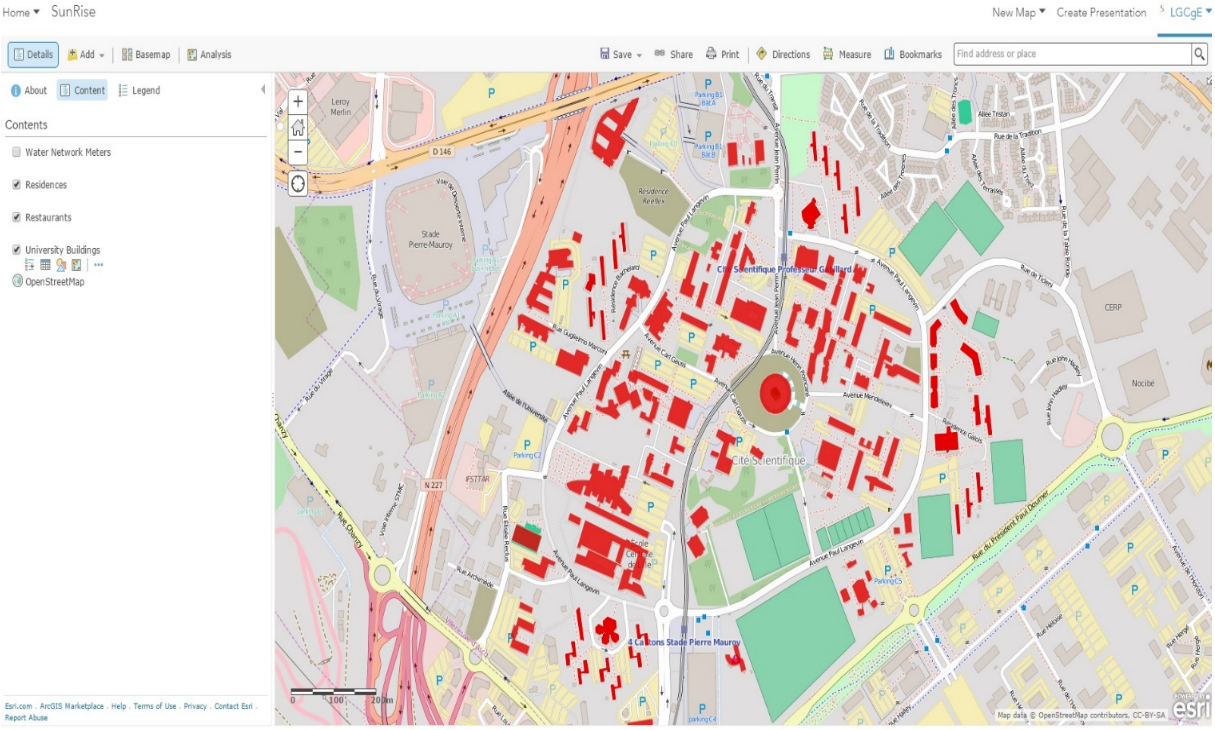

Figure 3-8: SunRise Interactive map "ArcGIS Online"

3.4 SunRise Web Mapping Application

Web AppBuilder for ArcGIS provides tools for building web applications in ArcGIS. Build intuitive, focused apps that run anywhere, on any device, without writing a single line of code (Figure 3-9).

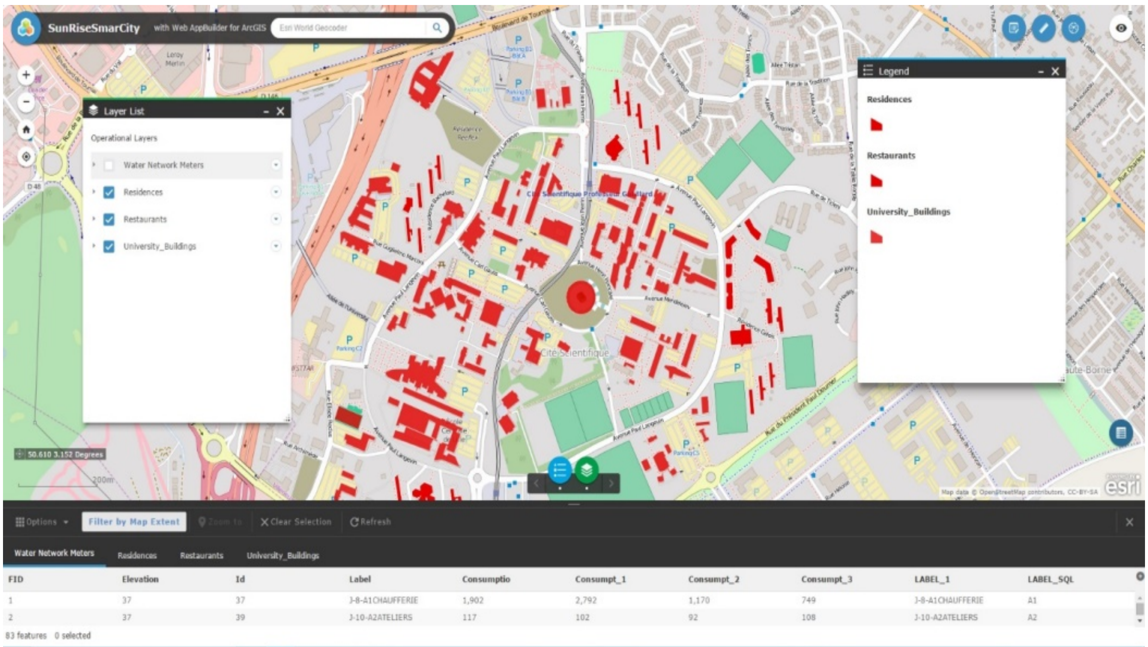

Figure 3-9: SunRise web application

Using the Web Application, the ability to show, hide and share data between users is easier than the desktop application. For example, to tell a story about your project you only need a photo for the location on the map and you upload it and you can write a description about the project in detail on different places for different dataset features.

Figure 3-10 illustrates how stories could be displayed.

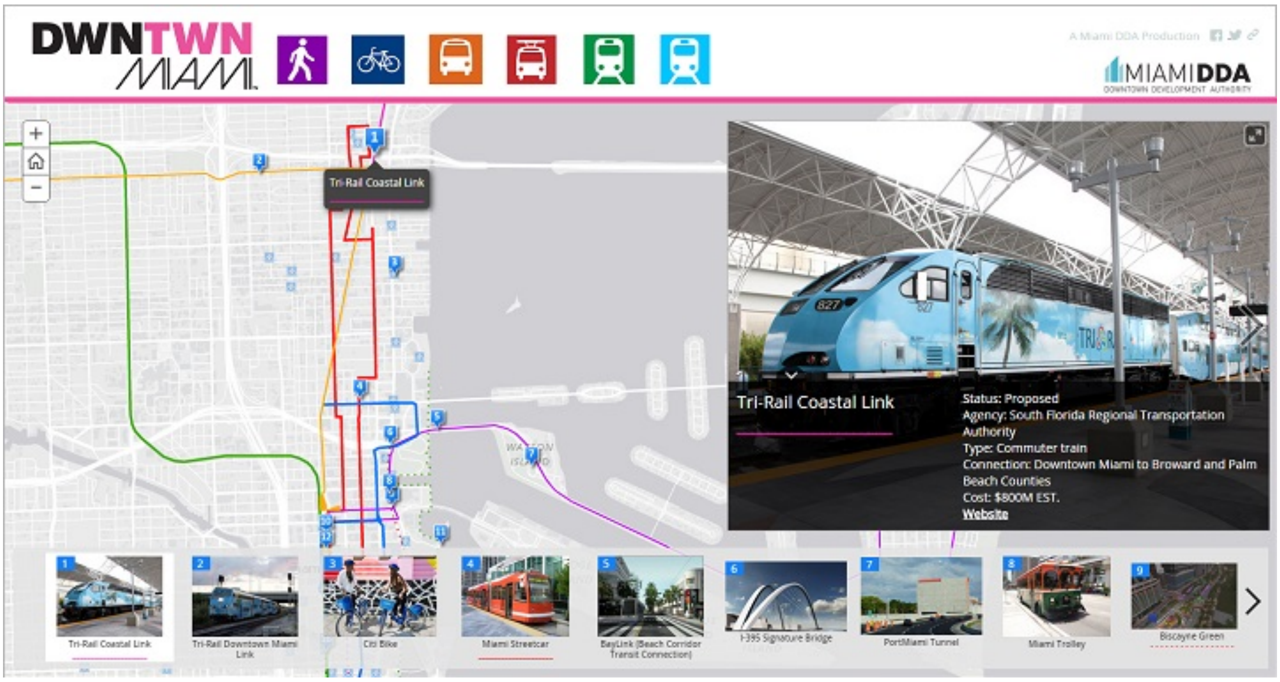

Figure 3-10: Map Story in ArcGIS Web Application (Source: Esri map story)

3.5 Conclusion

Dynamic data visualization constitutes an important issue in Smart City projects. It enhances the understanding of urban issues as well as their interaction. This chapter presented a survey of tools used for data visualization, which could be used in SmartCity projects.

The chapter presented also the methodology followed to implement the dynamic data visualization in SunRise Smart City project, which includes the data transfer between SunRise information system and ArcGIS as well as the connection of ArcGIS to web applications using HTML popup feature.

The developments were illustrated through the visualization of data related to drinking water consumption. This chapter included also the development of the urban model, which enable users to share and enhance their data using web application stories.

Chapter 4 : Use of BIM in the SunRise urban information system

The Building Information Modelling (BIM) presents powerful tools for the design, construction, and management of the buildings and facilities. It allows at each stage of the building to access via 3D modeling to any component of the buildings as well as all related information. In a Smart City project, the integration of both the GIS and BIM in the same platform will allow access and analyze data related to use all the facilities offered by them. This chapter presents firstly the Building Information Modelling and then its integration with the SunRise GIS system.

4.1 Building Information Modelling (BIM)

According to Wikipedia[1], the US National Building Information Model Standard Project Committee gives the following definition for the BIM "the Building Information Modelling (BIM) [2] is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition". A building information model is a project simulation consisting in the 3D modeling of the project components with links to all the required information connected with the project planning, design, construction, and operation.

The building information modeling (BIM) provides powerful tools for the design, construction, maintenance and management of buildings. It is based on a 3D modeling of buildings with a complete database concerning the buildings components. The BIM offers powerful 3D visualization capacity, which allows visualizing any component or set of components of the building in a 3D environment.

It also uses the virtual reality technic to visit any part of the building at any stage of its life (in the past or in the future). Building Information Modelling (BIM) is transforming the way of managing how large projects could be construction projects (Boyes et al., 2015).

[1] https://en.wikipedia.org/wiki/Building_information_modeling[Retrieved: 31 Aug. 2016].
[2] "Frequently Asked Questions about the National BIM Standard-United States Nationalbimstandard.org. [Retrieved 17 October.2014].

Although BIM is recent, large research efforts have been conducted in order to enhance its capabilities in design and construction. With its unparalleled capacity to improve coordination between design teams, construction contractors, and operators, BIM offers large facilities at a low cost. Countries in North America, Europe, and Asia use already BIM in both project delivery as well as in asset management. (BIM) provides architectural 3D visualization and a standardized way to share and exchange building information. Recently, there has been an increasing interest in using BIM, for not only design and construction, but also for the post-construction management of the built facility.

BIM is also interesting for the emergent smart built environment (SBE) technology, which consists of the monitoring of buildings with smart objects in order to enhance the building's efficiency, security and comfort (Bin & Yu, 2010). The purposes and objectives of implementing BIM are summarized in figure 4-1. They include 5 major categories and 18 subcategories (Kreider & Messner, 2013).

BIM Use Purpose				BIM Use Objective	Synonyms
01	Gather			to collect or organize facility information	administer, collect, manage, acquire
	01	Capture		to represent or preserve the current status of the facility and facility elements	collect
	02	Quantify		to express or measure the amount of a facility element	quantity takeoff
	03	Monitor		to collect information regarding the performance of facility elements and systems	observe, measure
	04	Qualify		to characterize or identify facility elements' status	follow, track, identify
02	Generate			to create or author information about the facility	create, author, model
	01	Prescribe		to determine the need for and select specific facility elements	program, specify
	02	Arrange		to determine location and placement of facility elements	configure, lay out, locate, place
	03	Size		to determine the magnitude and scale of facility elements	scale, engineer
03	Analyze			to examine elements of the facility to gain a better understanding of it	examine, evaluate
	01	Coordinate		to ensure the efficiency and harmony of the relationship of facility elements	detect, avoid
	02	Forecast		to predict the future performance of the facility and facility elements	simulate, predict
	03	Validate		to check or prove accuracy of facility information and that is logical and reasonable	check, confirm
04	Communicate			to present information about a facility in a method in which it can be shared or exchanged	exchange
	01	Visualize		to form a realistic representation of a facility or facility elements	review
	02	Transform		to modify information and translate it to be received by another process	translate
	03	Draw		to make a symbolic representation of the facility and facility elements	draft, annotate, detail
	04	Document		to create a record of facility information including the information necessary to precisely specify facility elements	specify, submit, schedule, report.
05	Realize			to make or control a physical element using facility information	implement, perform, execute.
	01	Fabricate		to use facility information to manufacture the elements of a facility	manufacture
	02	Assemble		to use facility information to bring together the separate elements of a facility	prefabricate
	03	Control		to use facility information to physically manipulate the operation of executing equipment	manipulate
	04	Regulate		to use facility information to inform the operation of a facility element	direct

Figure 4-1: BIM Uses proposes and objectives (Source: BIM.com, The Use of BIM 2013)

4.2 BIM process and the conventional process

The principal difference between BIM and conventional 3D CAD, is that the latter describes a building by independent 3D views such as; plans, sections, and elevations, while the BIM offers a relational database for the design and documentation, an active access and sharing to all the building components during all the stages of the building life (Azhar et al., 2008). Figure 4-2 shows the traditional CAD process and the BIM process.

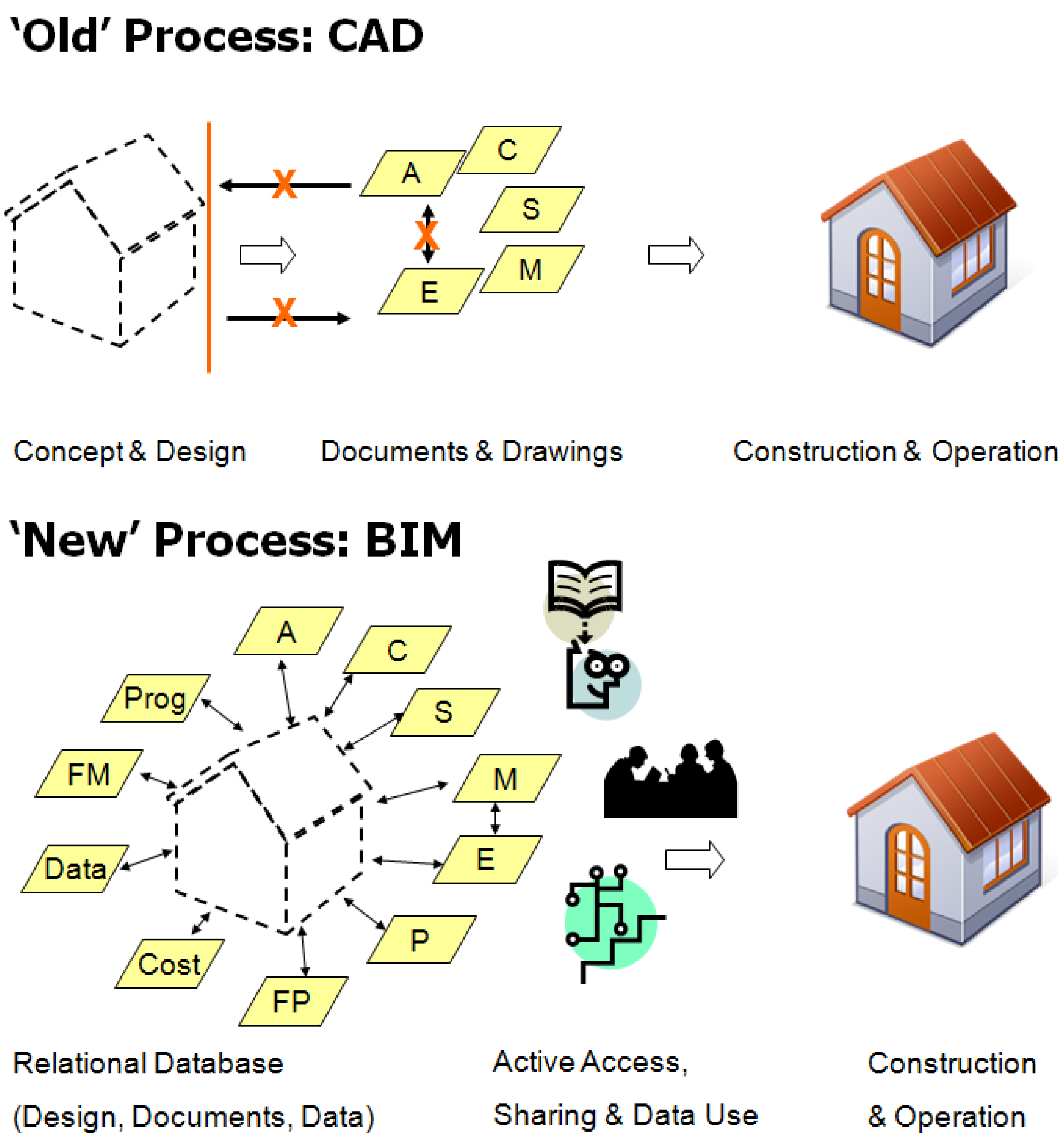

Figure 4-2: Comparison between traditional process and BIM process (Source: McWhorter School of Building Science, Auburn University 2014 USA)

As a result, it is necessary to note that the BIM characterizes the geometry, spatial relationships, geographic information, quantities and properties of building elements, cost estimates, material inventories and project schedule (Azhar et al., 2008). This model can be used to demonstrate the entire building life cycle (Bazjanac, 2004).

In this work, we have used Revit from Autodesk Company. Revit is specifically designed for BIM, including features for architectural design, MEP (mechanics, electricity, and plumbing) and structural engineering, and construction (Autodesk, 2015). Revit is a powerful design and documentation system offering productivity, coordination, and quality benefits to architects, builders, and other building industry professionals (Revit, 2015)

4.3 Industry Foundation Classes (IFC)

The Industry Foundation Classes (IFC) data model is intended to describe buildings and construction industry data. It is a neutral platform open file format specification that is not controlled by a single vendor or group of vendors. It is an object-based file format with a data model developed by building SMART (formerly the International Alliance for Interoperability, IAI) to facilitate interoperability in the architecture, engineering and construction (AEC) industry, and is a commonly used collaboration format in Building information modelling (BIM) based projects (Laakso & Kiviniemi, 2012).

The IFC model specification is open and available. Figure 4-5 b shows the collaboration possibilities offered by ICF: conversion 2D – BIM 3D, management of heritage, technical synthesis and access to heating, ventilation and electricity systems.

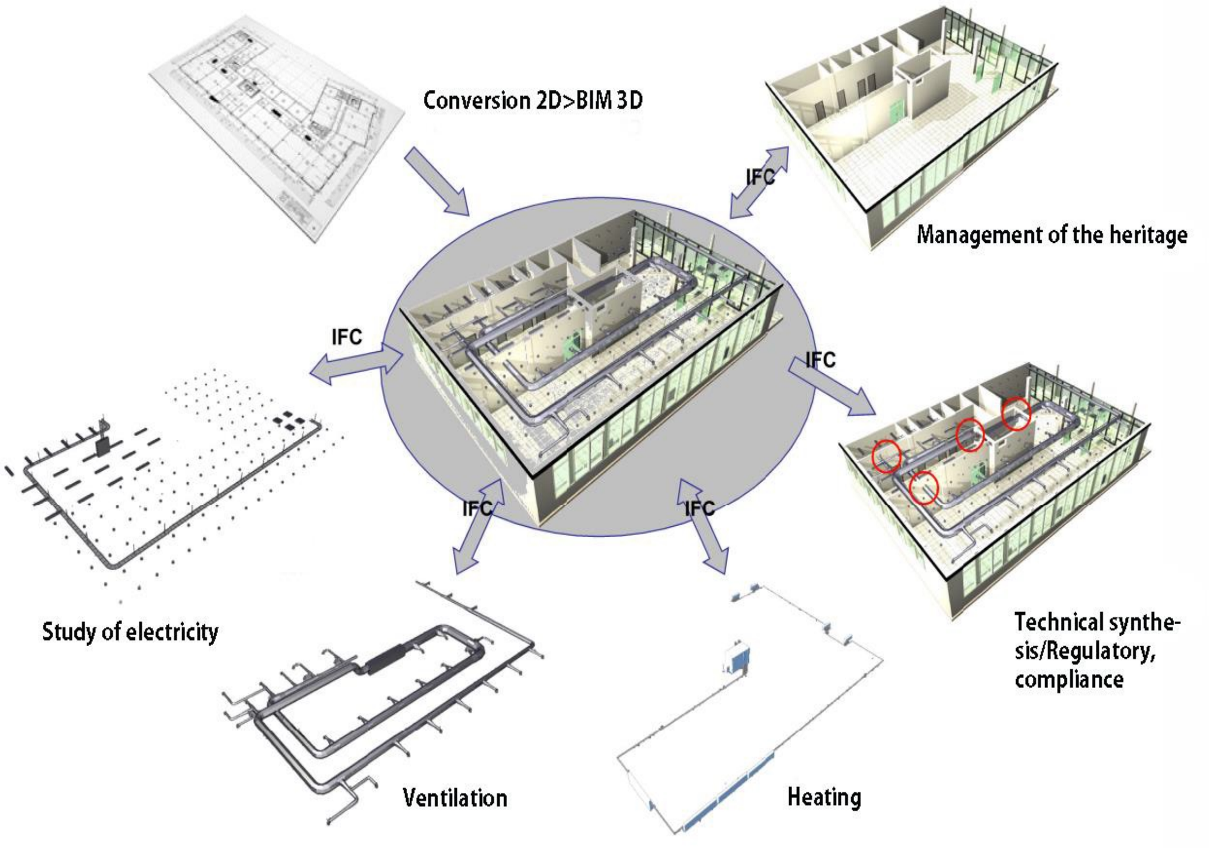

Figure 4-3: The collaboration facilities provides by the IFC format (Source: https://www.nationalbimlibrary.com/)

4.4 BIM and GIS integration

Today the BIM and GIS worlds are operating in seemingly separate spheres but each has value to the other if they could exchange data effectively (Bush, 2013).

4.5 Integration of BIM in SunRise-GIS Platform "The integration methodology"

The SunRise urban information system includes all the data concerning the operating system of the urban infrastructures networks. The methodology used to implement the BIM in the SunRise platform started from; (i) preparing the transaction databases, (ii) creating the 2D CAD file, (iii) creating the 3D model for the demonstrator, using Revit 2015 Autodesk software and finally export the outputs files using IFC standard conditions in BIM.

4.5.1 Application to "Restaurant Barrois"

In this section, we present the integration of a building of the campus (restaurant Barrois) in the urban information system of SunRise. Revit was used for this integration. Figure 4-4 shows the restaurant Barrois.

Its ground surface is around 1250 m^2. It contains two main restaurant rooms, one for students and the second one for the staff, a basement level containing technical rooms, storage rooms, and cooling rooms.

[1] https://en.wikipedia.org/wiki/FME_(software) [Retrieved: 31 Aug. 2016].
[2] https://www.safe.com/ , [Retrieved 31 Aug. 2016].

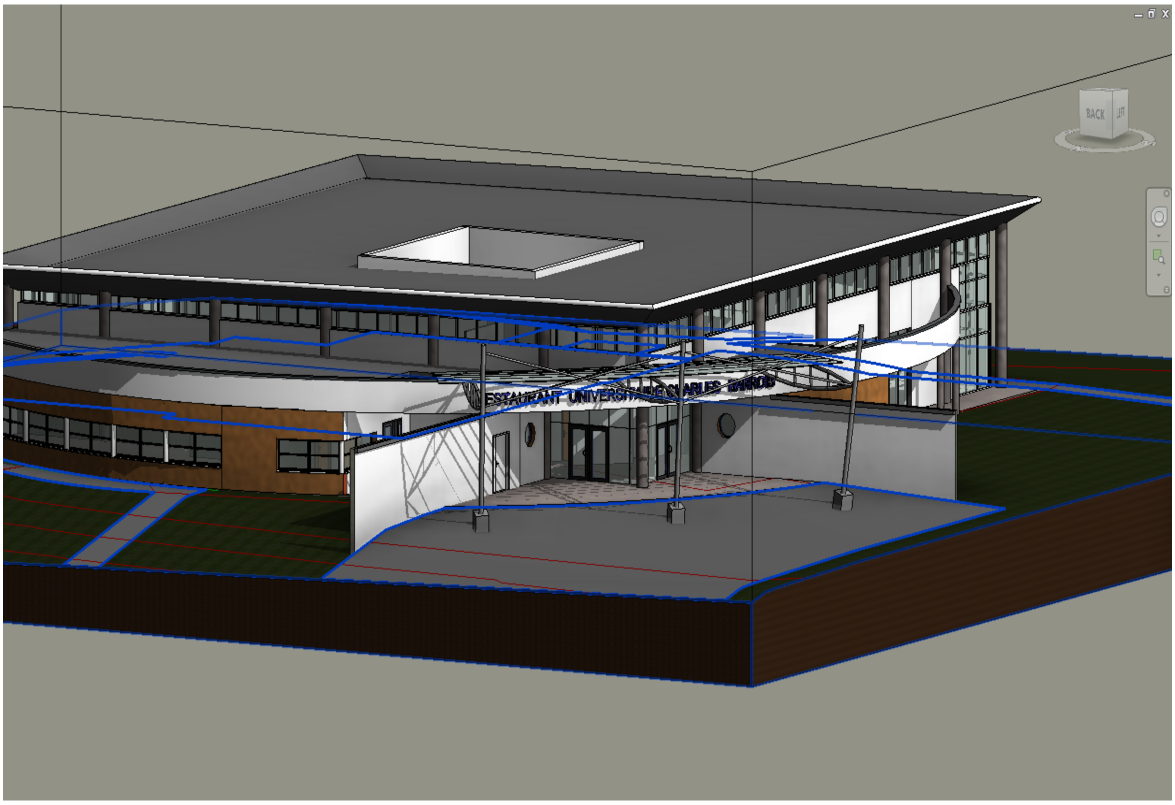

Figure 4-4: 3D architectural model for restaurant Barrois

4.5.1 Construction of BIM for the Barrois restaurant

The software FME was used in this work. According to Wikipedia[1], the FME is a spatial tool for data transformation and data translation produced by Safe Software; it includes several extensions as shown in Figure 4-5.

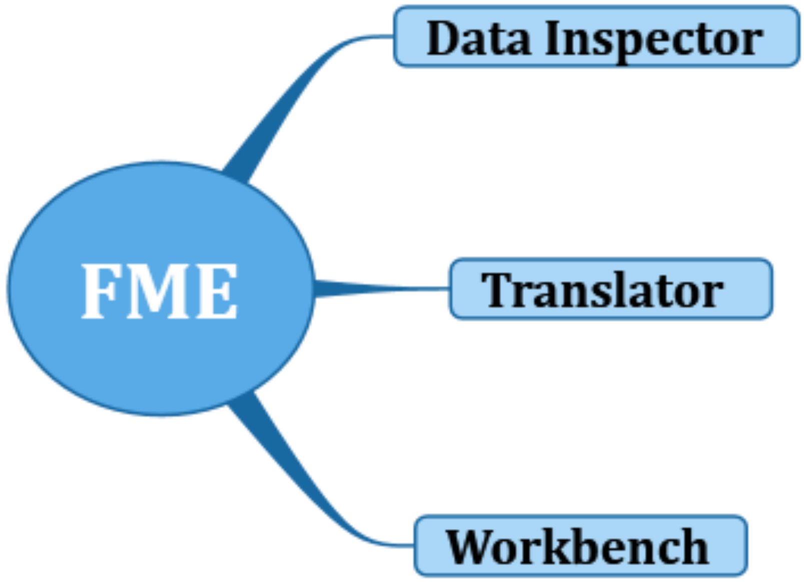

Figure 4-5: FME Extensions

The integration was conducted according to the following steps:

- **Step N1 - Preparing the IFC file**: It was conducted using the Revit software and the plugin tool of FME integrated into Revit.

- **Step N2 - FME transformation process Figure 4-6:** It was conducted using FME workbench with the Reader file (BARROIS.IFC) and the Writer file (Esri Shape for GIS, ArcGIS; and KML for google earth). We have used "create vertex" to transform all required data from Xls sheets to a usable file by the GIS available tools and soft wares.

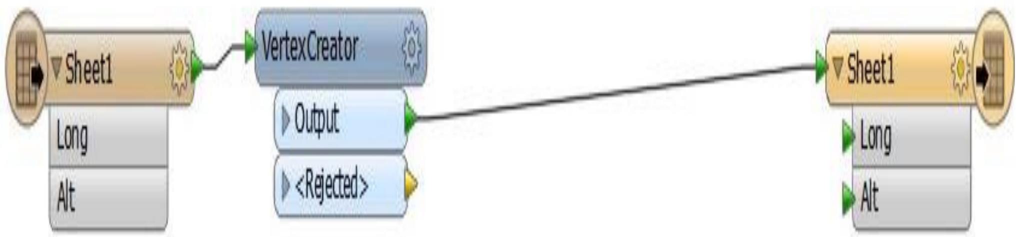

Figure 4-6: Transformation process in FME

- **Step N3 - Choosing the FME transformer.** The following transformers have been used:

1. **Create vertex:** Appends coordinates to null, point, text, line, and arc geometry, or replaces existing geometry with point geometry. If the feature turns into a closed polygon because of adding the point, it will be tagged as an area feature; otherwise, it will be tagged as a line or a path ending in a line for arcs.

2. **KML Property Setter:** Sets common properties for groups of vector and raster features destined for the OGCKML Writer.

The integration and the transformation processes allowed the creation of two files:

- **KML file:** Compatible with Google Earth.

- **Shapefile:** compatible with ArcGIS.

Figure 4-7 shows the result of the integration of the BIM of restaurant Barrois in Google Earth. The file includes all the features and the characteristics of the building; it includes also the data concerning the entire infrastructure of the model such as the water, heating, and electricity.

The model could be modified by adding or removing any kind of data, it also linked with an external database to provide the data in real time.

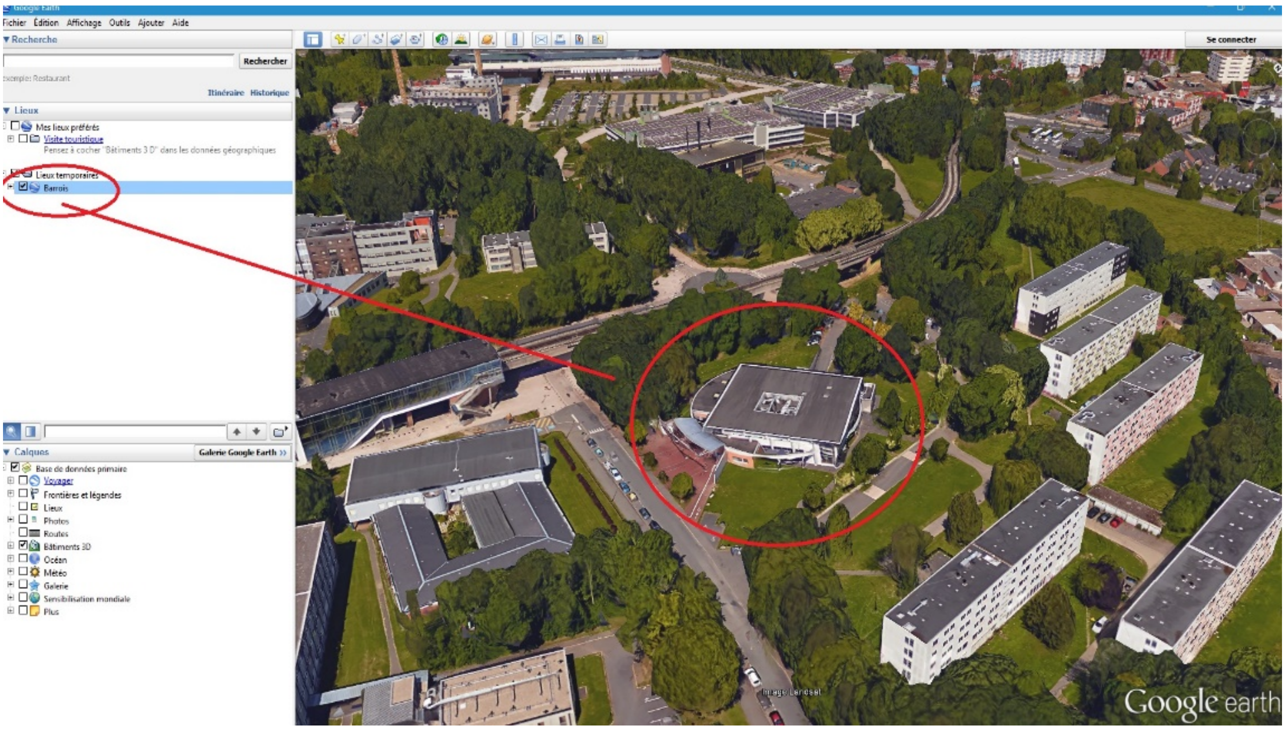

Figure 4-7: Visualization of the BIM "Barrois" model using Google Earth

Following this methodology, any 3D model could be shown in Google Earth by clicking on the exported KML file.

4.5.2 Integration of Barrois BIM in SunRise GIS Platform

Figure 4-8 shows the 2D model of restaurant Barrois in ArcGIS. It could be displayed as a 3D using ArcScene program. The layer, which contains the file, is linked also with external database use in order to provide the real-time data for each urban infrastructure networks.

The properties of the model contain the main features and details about the building in Google Earth. It also includes the data about the geolocation and the references of the restaurant in the campus.

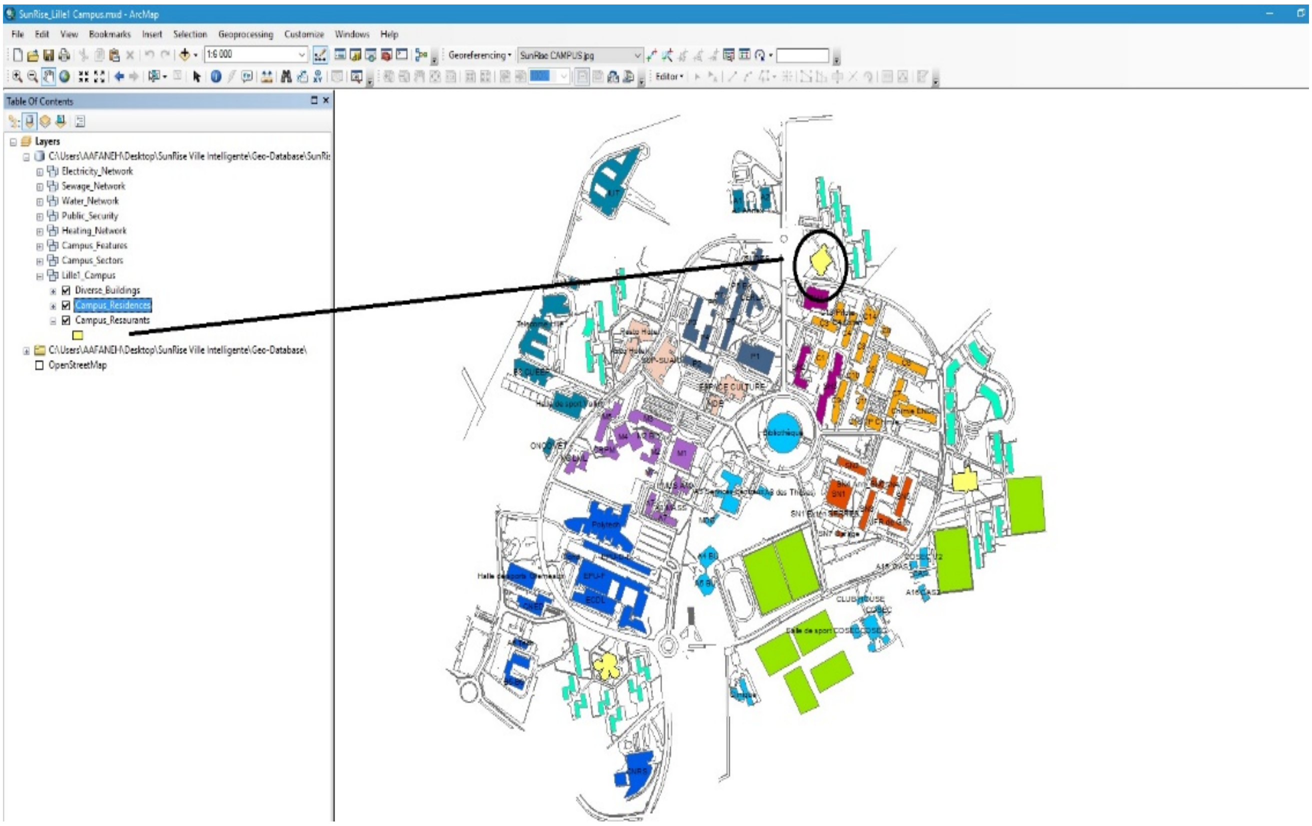

Figure 4-8: Visualization of the BIM "Barrois" model on Arc Map

The integration process offers flexibility to add, remove and edit the main characteristics of the building using the software itself. Following these steps and methodology, any CAD or Revit files could be integrated into ArcGIS.

The SunRise urban information platform could include the entire data of the campus, including urban infrastructures networks and buildings.

4.6 Conclusion

BIM is one of the most effective processes for the building data integration and sharing. It provides a concrete base of data analysis, simulation for any building as well as enabling improved and innovative solutions. Thanks to BIM collaboration within project teams should increase, which will lead to improved profitability, reduced costs, better time management and improved customer/client relationships (Azhar et al., 2008).

This chapter explored the methodology to incorporate BIM in SunRise information system through its coupling with GIS. The integration is conducted in four steps: (i) preparation of the proposed model in Revit and IFC process, (ii) transformation of data between different sources, (iii) construction of BIM models, (iv) integration process in Google Earth and ArcGIS by linking the files to the external database. Through this integration, the SunRise information system could include the information concerning both the infrastructures and buildings components.

General Conclusions

The Smart City concept is based on the information system that includes static and dynamic data on both physical and social components of the city.

Since the city is composed of complex and large infrastructures, the "Smart" information system should include a high quantity of data that describe these infrastructures and their functioning. The achievement of this goal requires the use of an efficient system such as GIS to manage data related to infrastructures.

Buildings and facilities are also complex urban components with huge data. The use of BIM constitutes also an efficient tool to deal with these data, in particular for Smart Buildings projects.

The combination of GIS and BIM systems for the construction of an integrated urban information system will allow using their capabilities for the collection, storage, analysis and visualization of urban data, which constitute the heart of any Smart City project.

The research conducted in this thesis aimed at implementing the GIS and BIM in an integrated smart urban system and to use this system for the management of a large-scale demonstrator of the Smart City (SunRise), which is conducted at the Scientific Campus of the University of Lille in the North of France.

The first chapter of the thesis presented a literature review of works conducted on topics related to the development of a GIS, Smart Cities and the use of GIS in Smart City projects. It showed that GIS is already largely used for urban issues and presents large opportunities for the implementation of the Smart City projects, mainly for the construction of structured and geo-localized database enhanced with both analytical and graphic tools.

The second chapter presented the construction of the GIS-based urban information system for Smart Cities and its application to SunRise demonstrator. This work resulted in the establishment of a methodology for the construction of a GIS information system for Smart Cities and the use of this methodology for the integration of data concerning the urban networks (drinking water, sanitation storm water, electrical grid and district heating) of the Scientific Campus of the University of Lille. This system constitutes the heart of SunRise project, which is used for research, education and industrial innovation in the field of Smart Cities

The third chapter concerned the integration in GIS system of the visualization of dynamic data related to urban infrastructures. Within a Smart City project, this visualization is important for enhancing our understanding of urban systems as well as their interaction and management.

This work resulted in the implementation of the dynamic visualization in SunRise system through the construction of tools for data transfer between this system and ArcGIS as well as the connection of ArcGIS to web applications using HTML popup feature. The developments were illustrated through the visualization of data related to drinking water consumption. This chapter included also the development of the urban model, which enable users to share and enhance their data using web application stories. Thanks to this work, SunRise system allows users to use graphic facilities to follow and analyse dynamic urban data in GIS environment.

The last chapter explored the methodology to incorporate BIM in SunRise information system through its coupling with GIS. The integration was achieved by the preparation of the proposed model in Revit and IFC process, the transformation of data between different sources, the construction of BIM models and the integration in Google Earth and ArcGIS by linking files to the external database. Thanks to this work, the capacity of SunRise was extended to the integration and analysis of data related to buildings by using BIM.

This work focused on the development of a methodology for the construction of a smart urban information system using both GIS and BIM systems. The capacity of this system was illustrated trough its application to SunRise Smart City project. Since the Smart City project should also deal with social and users' data, it should be important in the future to implement additional tools for the management and analysis of these data as well as the interaction of these data with those related to infrastructures.

It is important to observe that the new technologies will continue growing up for providing a concrete base for Smart City projects. We conclude that the most effective design tools for Smart City are GIS, dynamic data interactive, and BIM. In this research, we have integrated BIM technology in SunRise GIS platform using a digital model. The idea was to have an asset in digital form that enables those who interact with the building to optimize their actions, resulting in a greater whole life value for the asset. The results of the integration process have shown throughout a 3D model demonstrator the capabilities of BIM to be transformed and displayed in Google Earth and ArcGIS using several tools.

Therefore, the implementation of BIM in SunRise project will bring many advantages particularly for the management of urban information system. BIM data can be used to illustrate the entire building life cycle, from inception and design to demolition and materials reuse.

The main advantage of implementing these technologies is obviously reflected in providing a modern system of measurement, monitoring and control (smart system) that tracks real-time data consumption for the urban infrastructure networks. The smart platforms would set up a better-experienced people and it will increase the proficiency of the users.

The concept of the smart city has inspired supportive changes in many fields related to urban planning. We hope that our study will expand further work, contributes to existing knowledge and will find a practical application.

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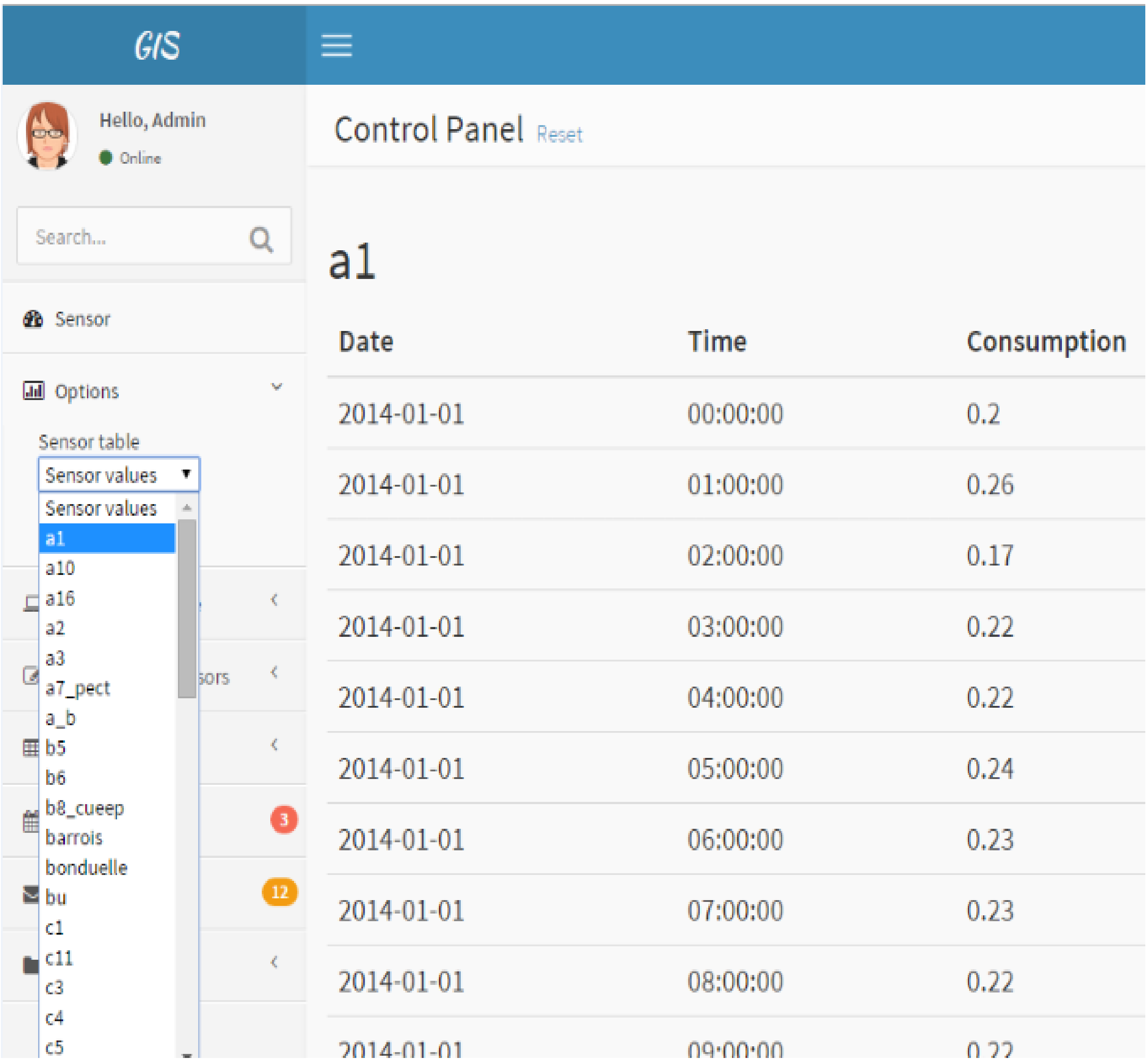
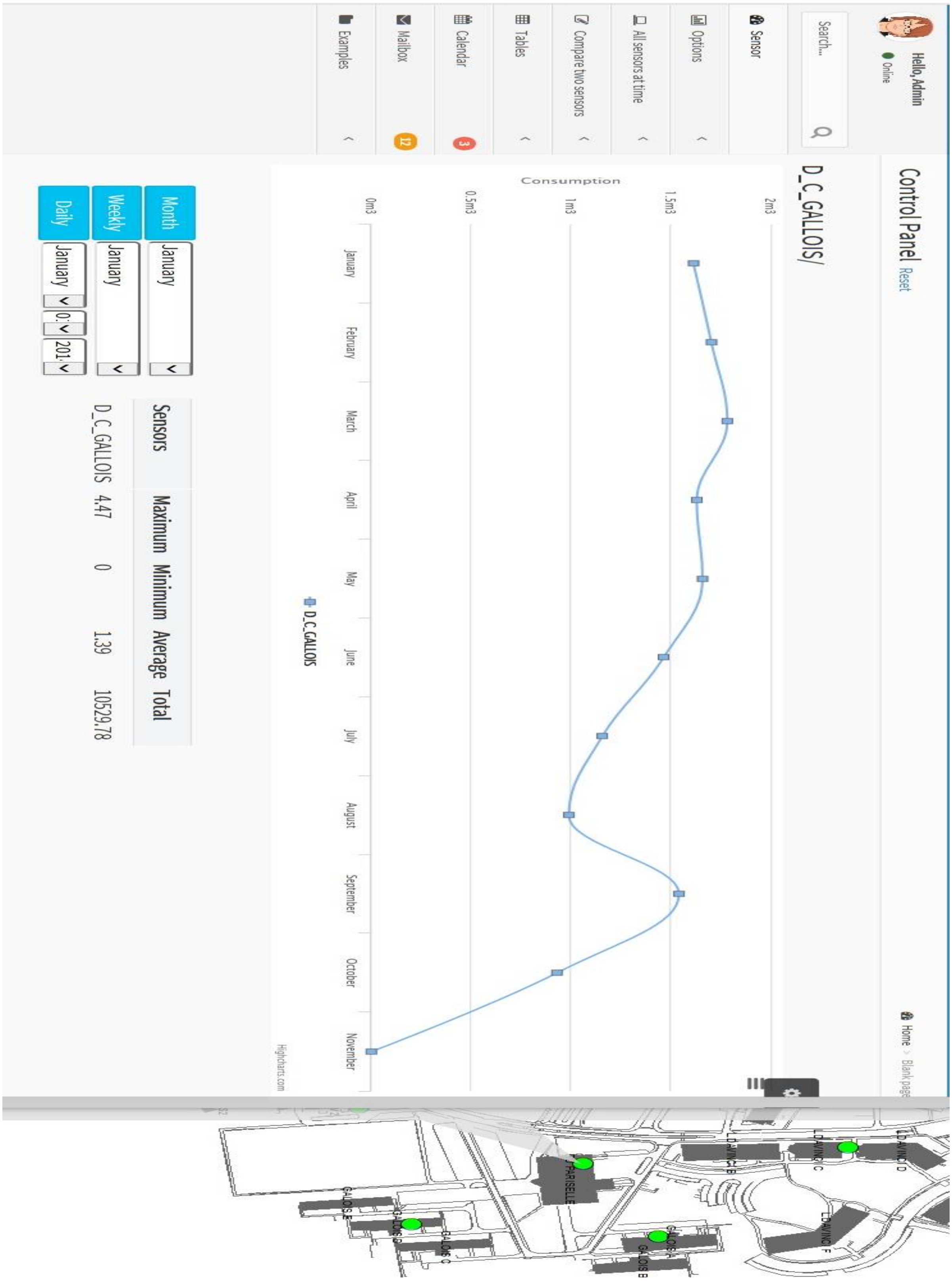
Annexes

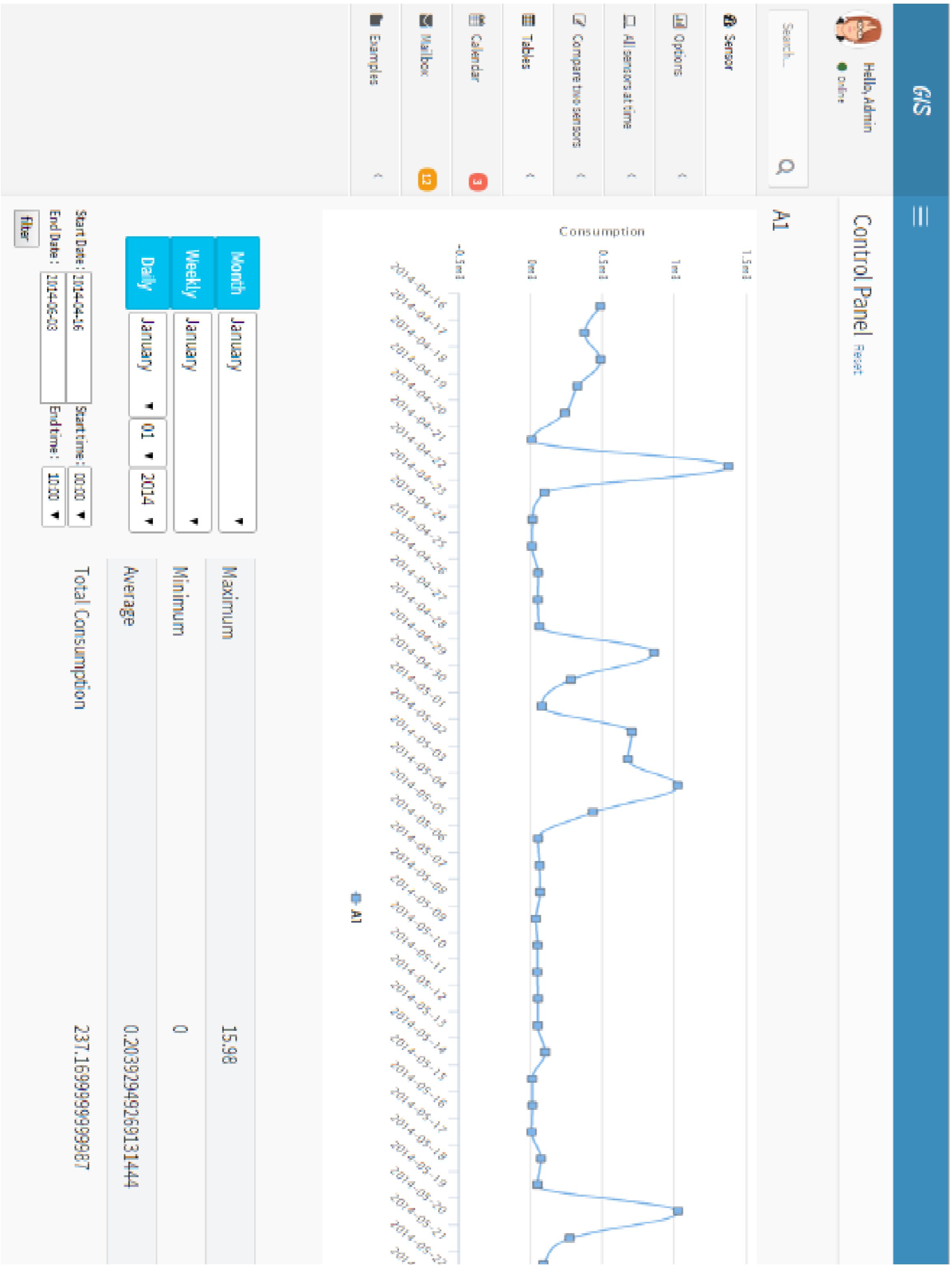
1) **One Static Method:** it retrieves statistics (Minimum value, Maximum value, Average value and Total consumption) for the sensor, which was selected from the drop-down list on the main page; it retrieves the average consumption for all the year, clustered by months. It sends this data to “statistic” view file; in this file Jquery, the code was added to draw a chart for the data, which is received, from the controller.



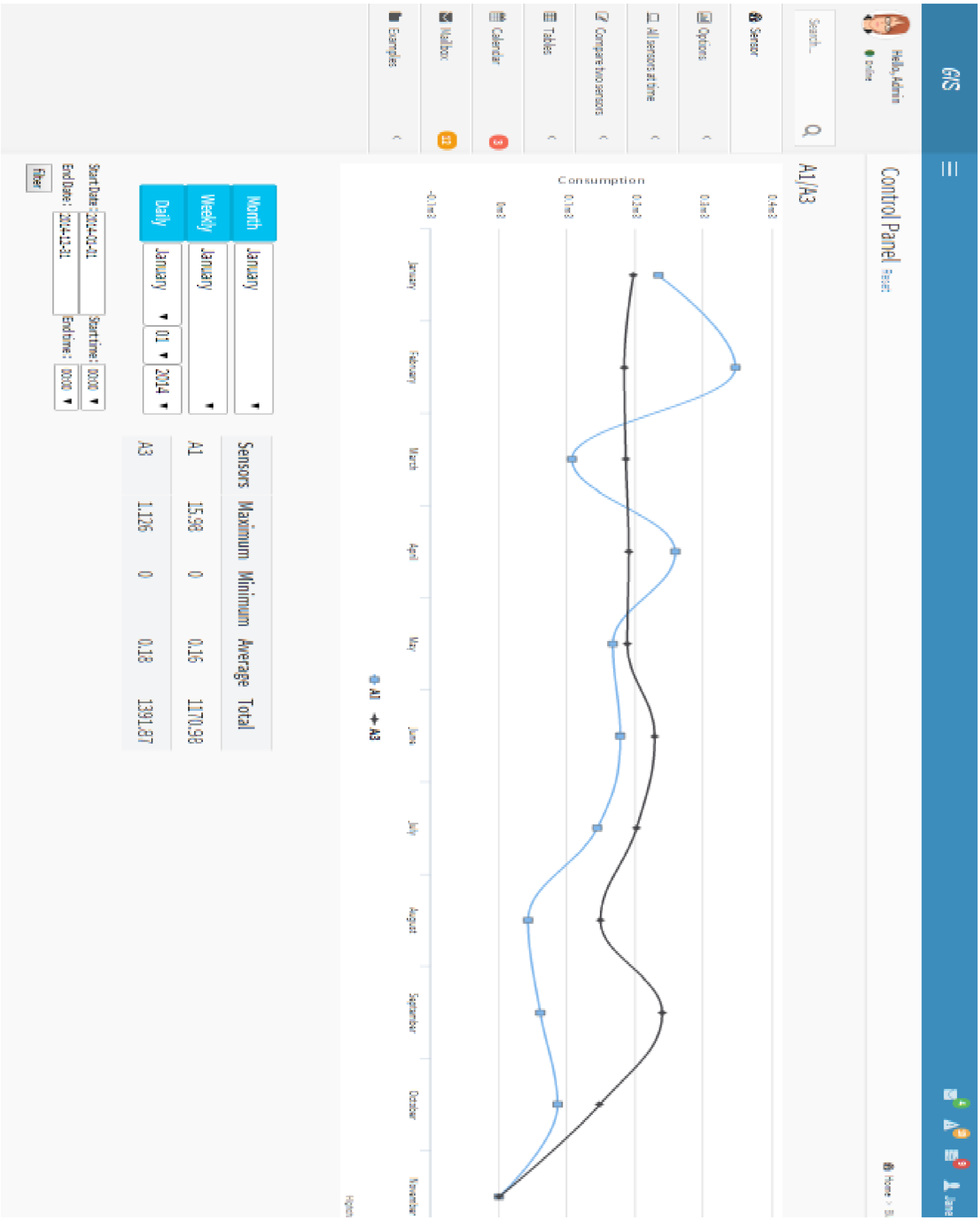
2) **One sensor Method:** It retrieves whole table values for the sensor, which selected from the drop-down list in the main page and sends it to "sensor table" view file. This view file represents data in the following picture.



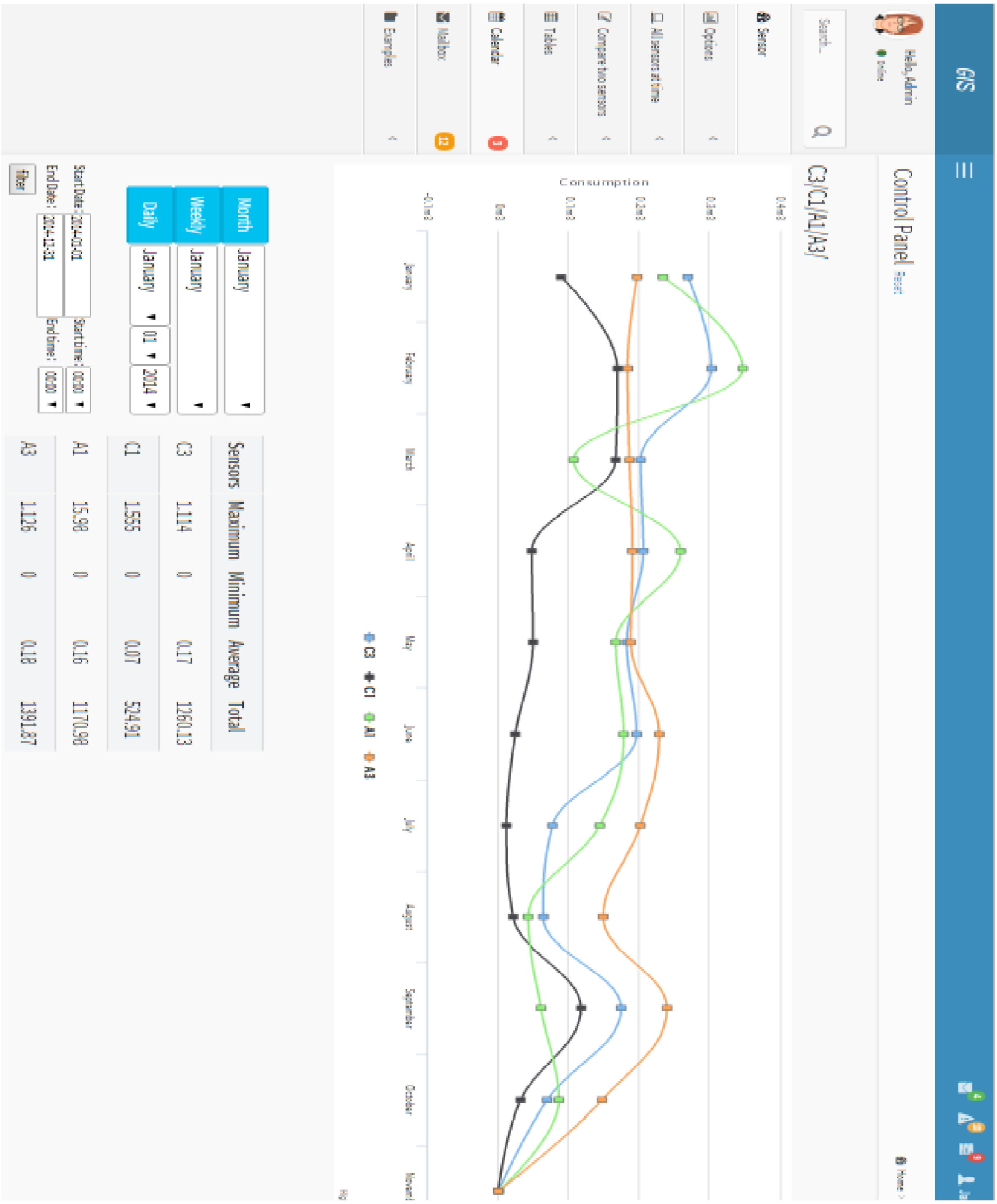
3) **Filter Statistic Method:** It receives data (sensor name, start date, start time, end date, end time) from the view and custom query was encoded to retrieve the statistics and all consumption values in this period clustered by days (average consumption for each day) and send this data to “statistic” view file.



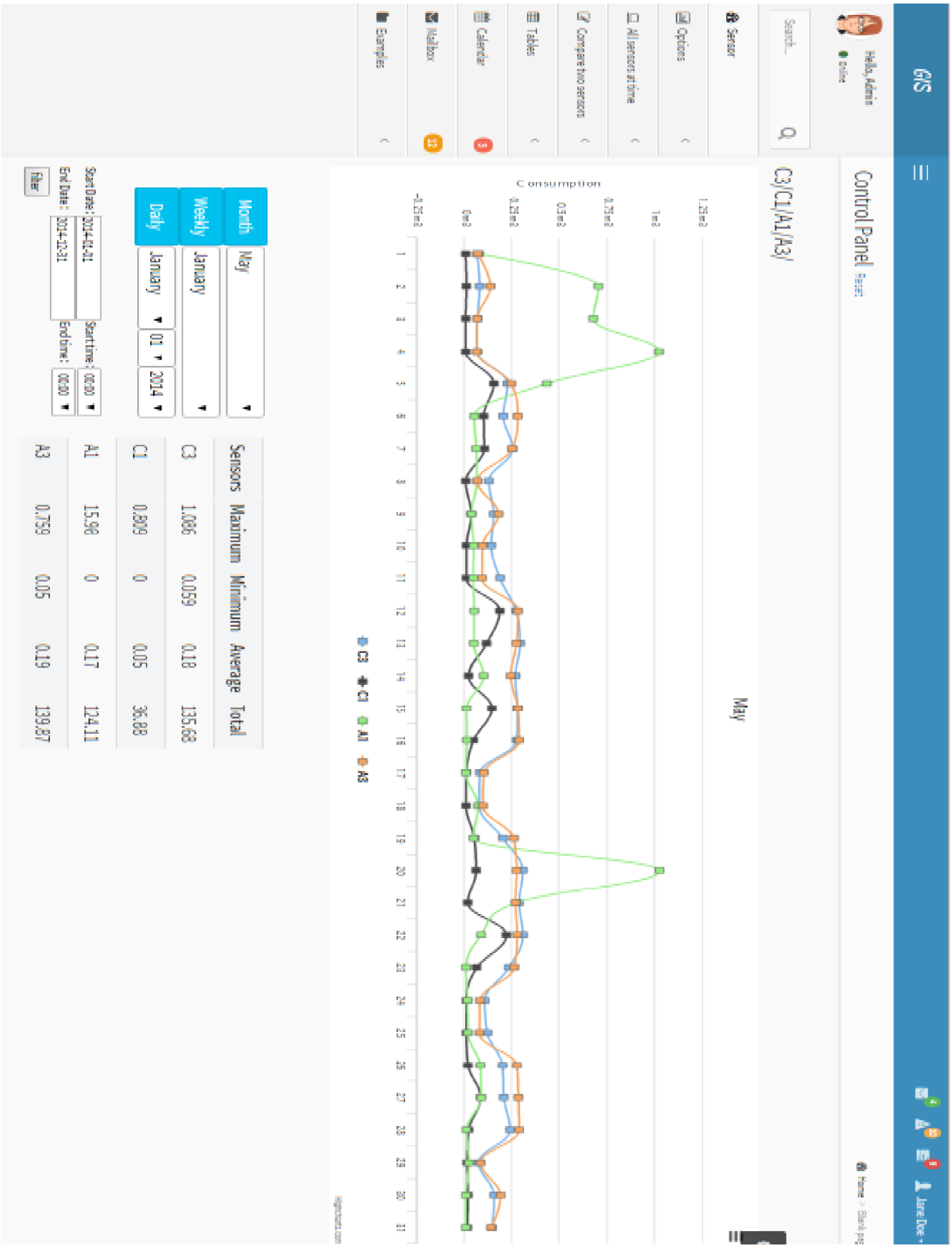
4) **Compare Method:** to compare the data between two sensors, which were selected from the drop-down lists on the main page, it retrieves the average consumption for all the year, clustered by months and sends this data to "statistic" view file to draw the chart.



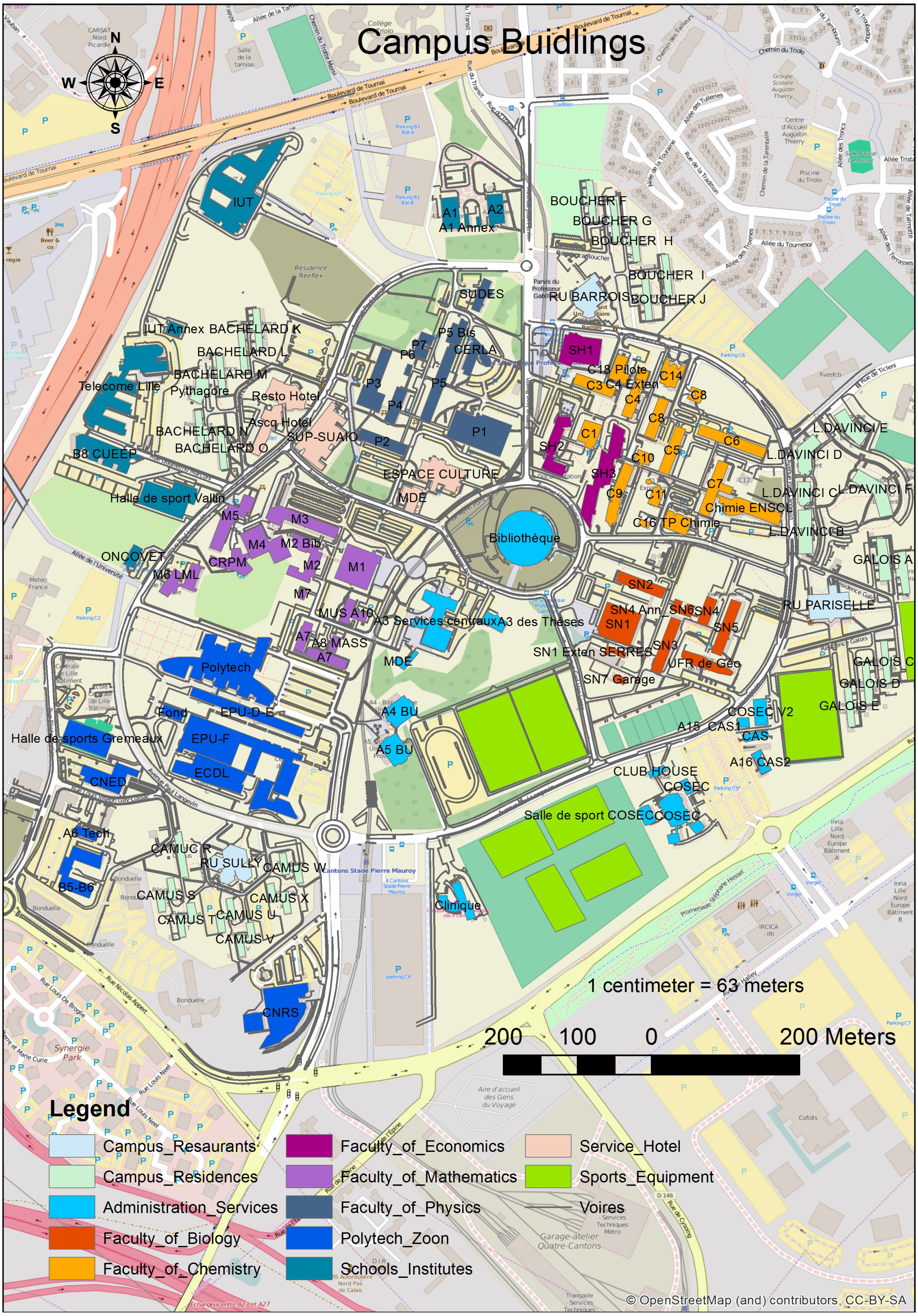
5) **Multi_statistics method:** It saves sensor name, which selected in $_SESSION array, retrieves statistics and the average consumption for all the year, clustered by months for all sensors which are in $_SESSION array and sends this data to "multi_statistics" view file to present it in tables and draw charts for all sensors using Jquery code which was encoded in this file. This method receives parameters (sensor's name) from ArcGIS.



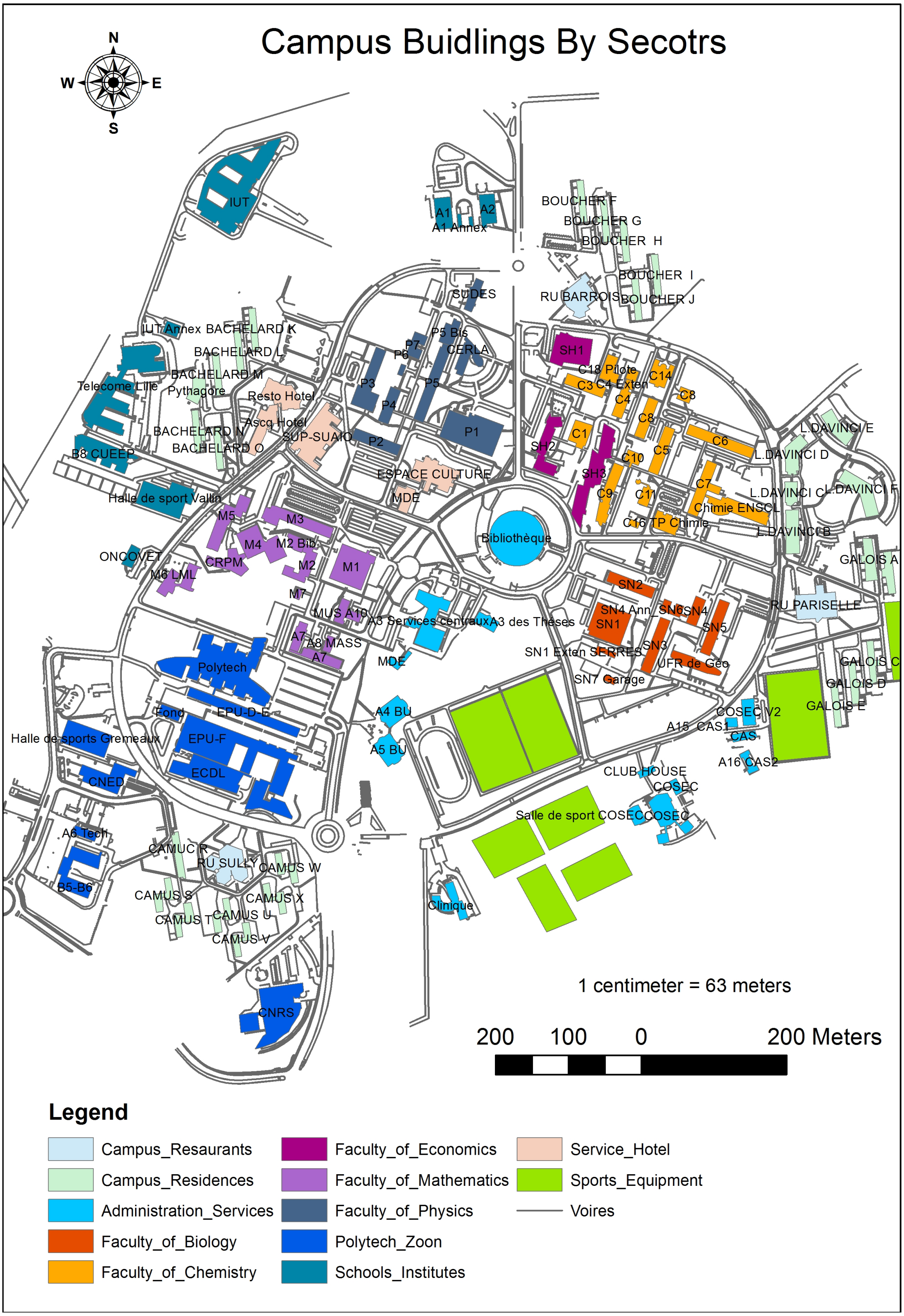
6) **Multi_statistics_filter method:** It filters the data, which were already received from "multi_statistics" method according to "pop" variable, which has been explained previously and sends the data to "multi_statistics" view file to presents this data in tables and draw charts for all sensors.



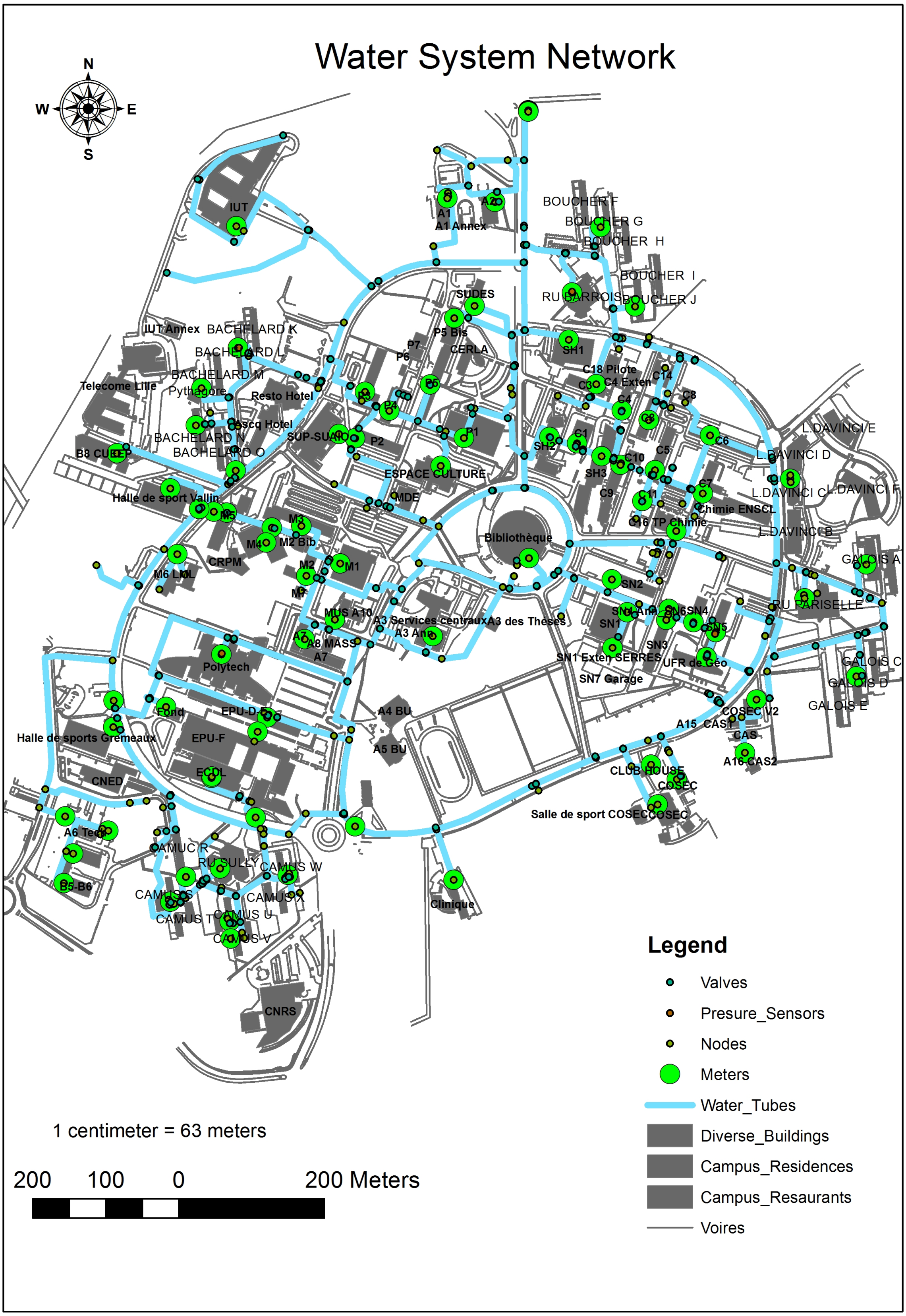
7) ArcGIS Map : Shows the entire campus of the university with al layers



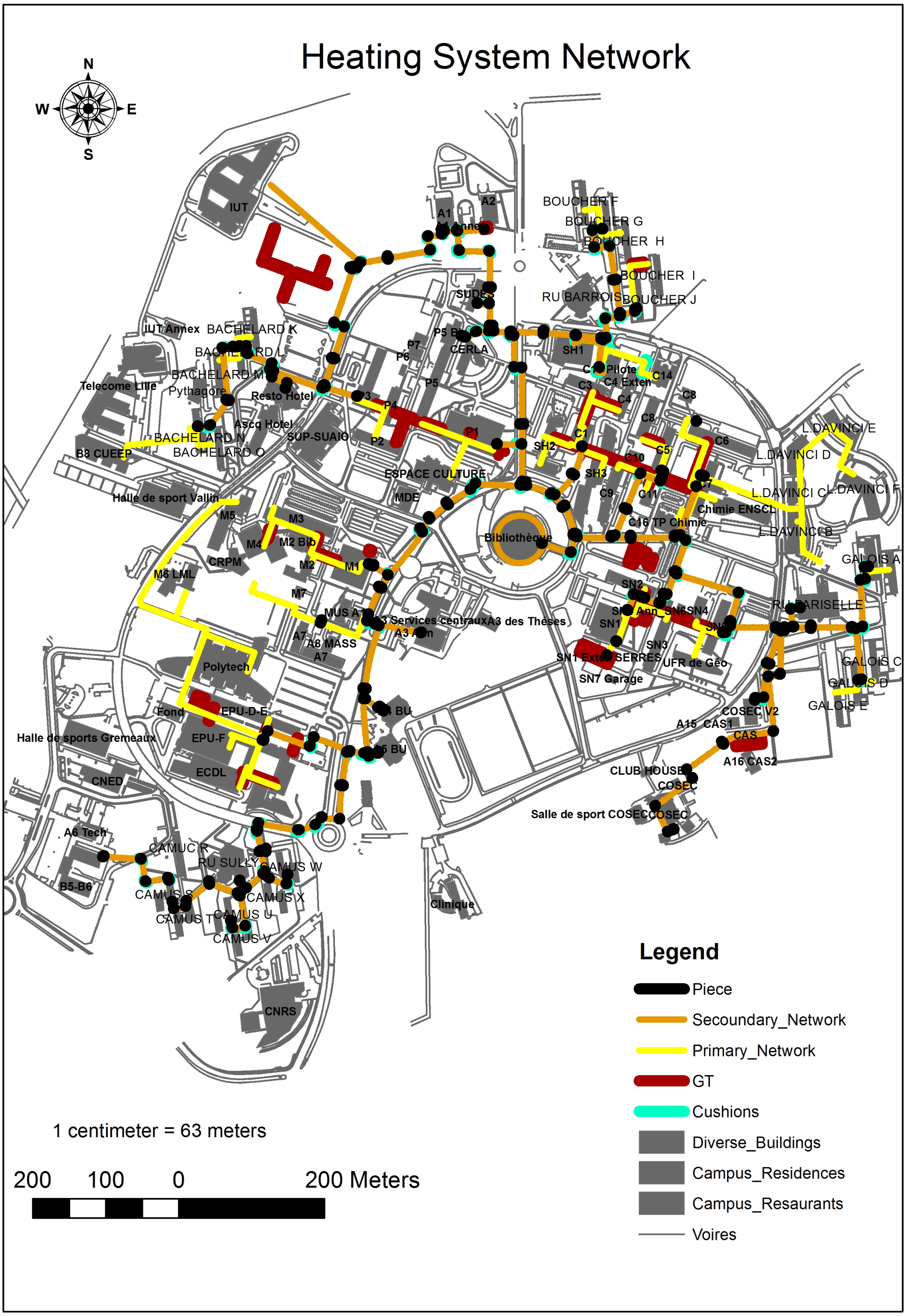
8) **ArcGIS Map:** Shows the campus buildings in layers



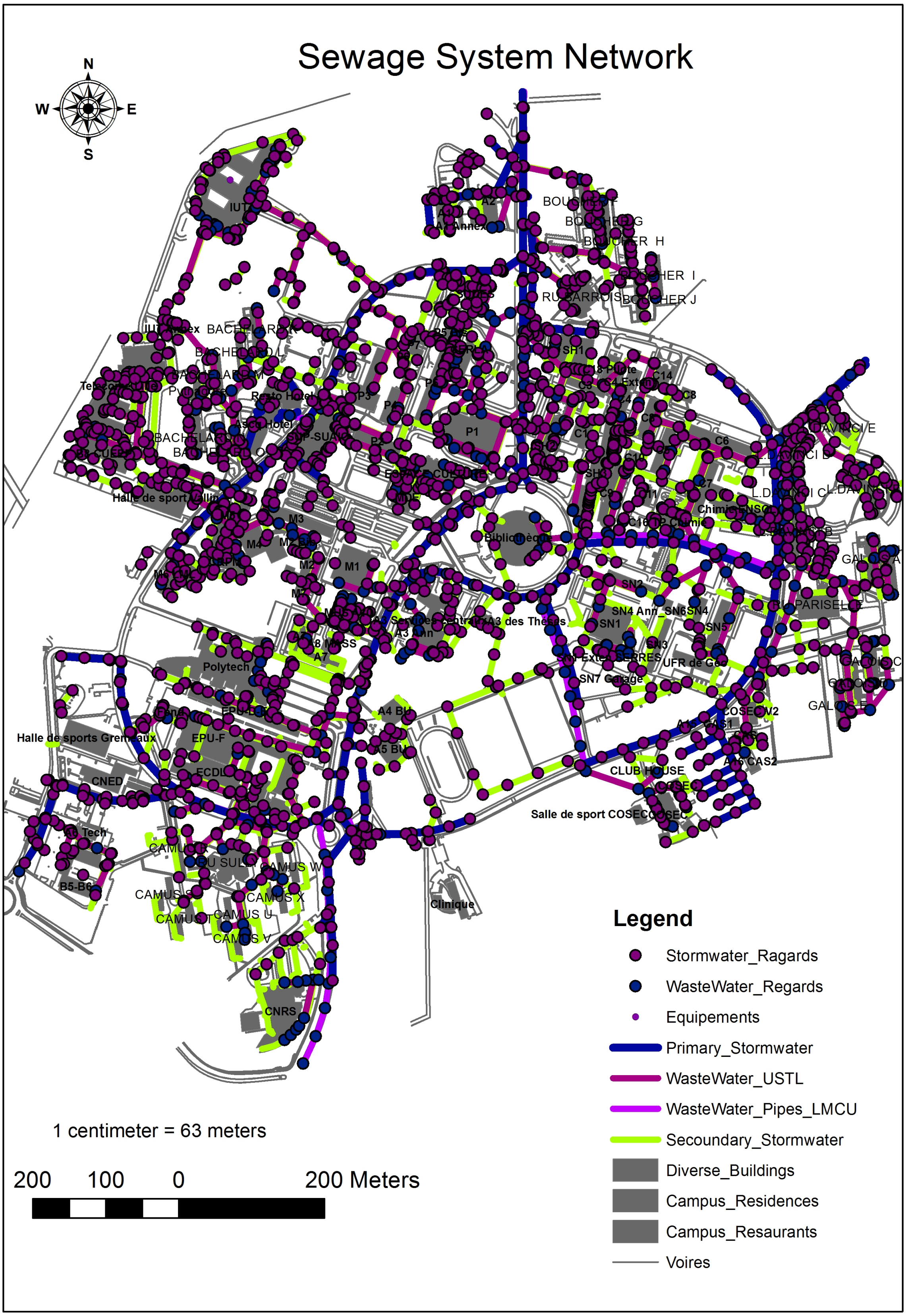
9) ArcGIS Map: Shows the water system in the campus



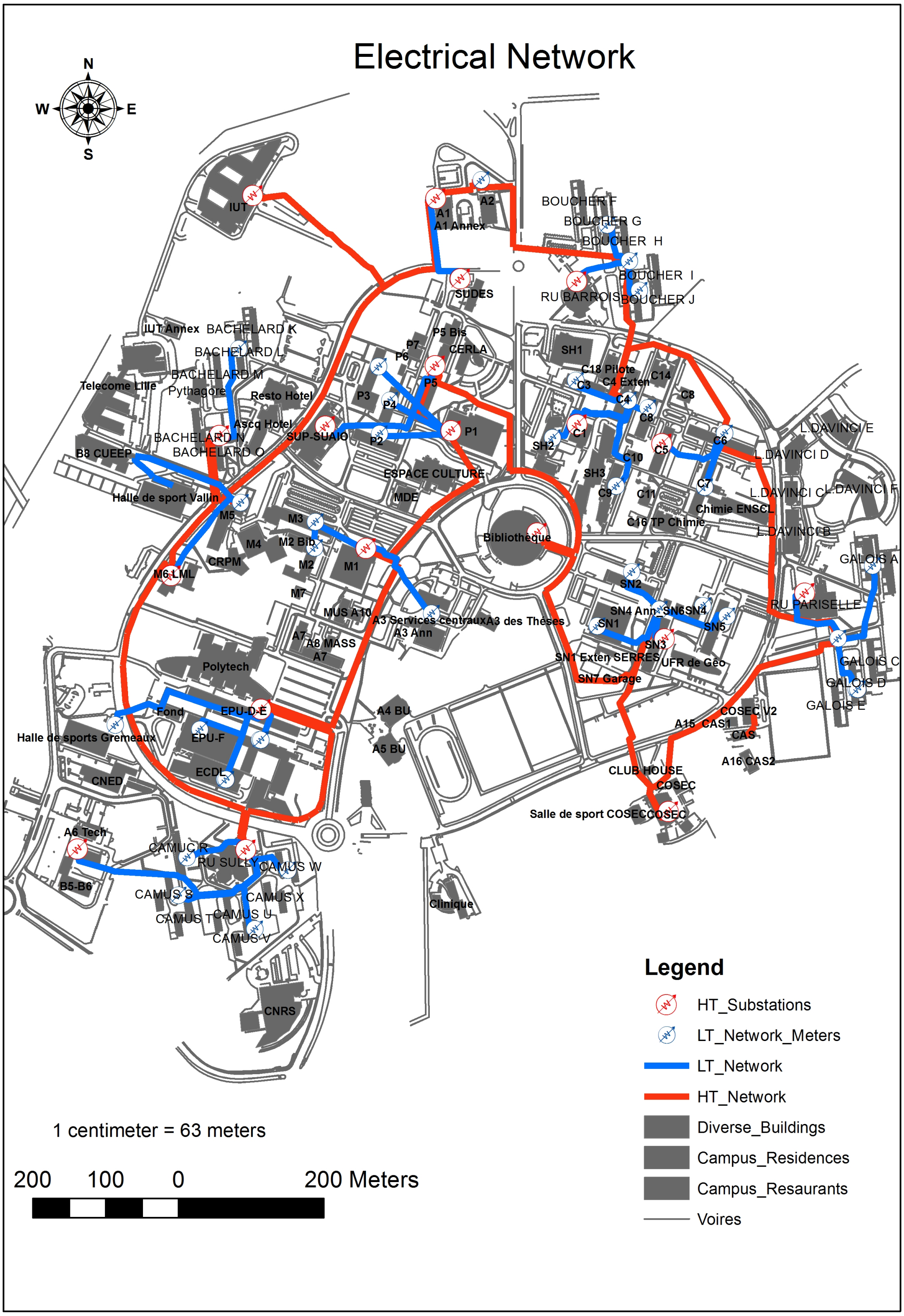
10) **ArcGIS Map:** Shows the district heating network



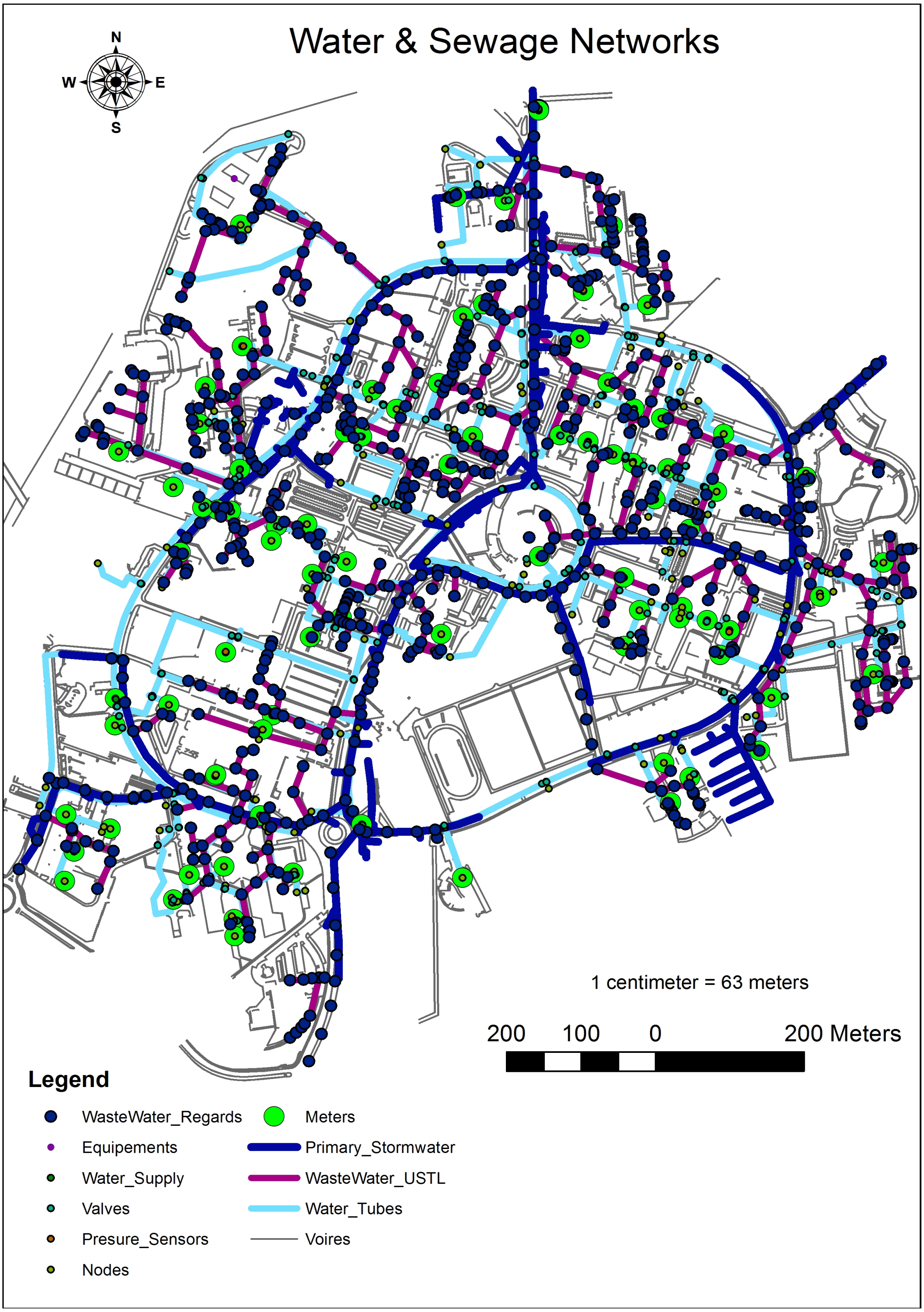
11) **ArcGIS Map:** Shows the sanitation network



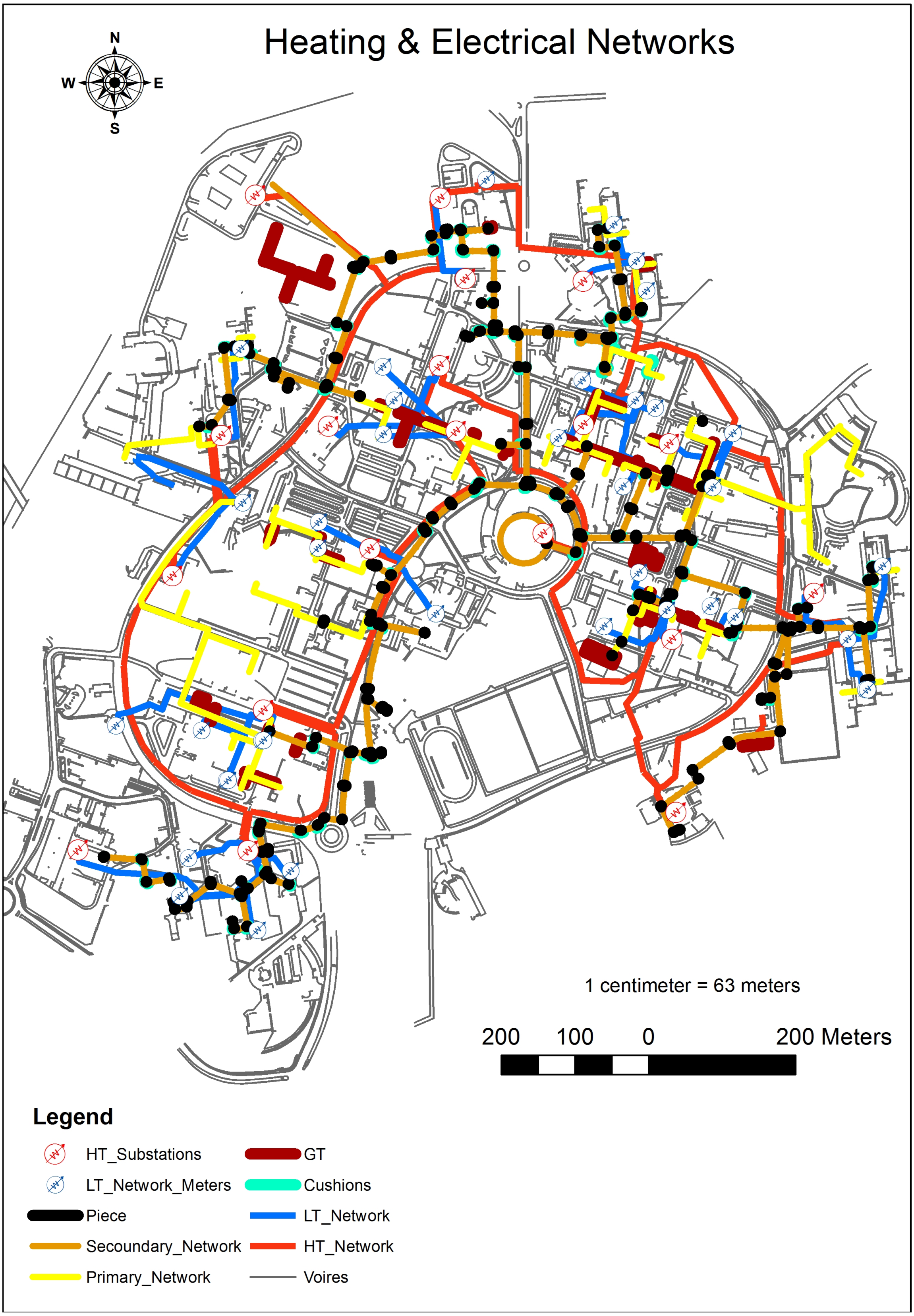
12) **ArcGIS Map:** Shows the electrical network



13) ArcGIS Overlapping Map: Shows the water and the sewage networks



14) ArcGIS Overlapping Map: Shows the energy networks



15) ArcGIS Overlapping Map: Shows entire layers of the SunRise platform