From Smart Campus to Smart Cities: Issues of the Smart Revolution

Nicolas Verstaevel, Jérémy Boes, Marie-Pierre Gleizes

From Smart Campus to Smart Cities Issues of the Smart Revolution

Nicolas Verstaevel
University of Toulouse
IRIT, SMAC Team
118 rte de Narbonne, Toulouse
verstaev@irit.fr

Jérémy Boes
University of Toulouse
IRIT, SMAC Team
118 rte de Narbonne, Toulouse
boes@irit.fr

Marie-Pierre Gleizes
University of Toulouse
IRIT, SMAC Team
118 rte de Narbonne, Toulouse
gleizes@irit.fr

***Abstract*—With 7/10 of the population which will live in urban center by 2050, Cities face huge challenge inviting to rethink the very concept of a City. The Smart Cities concept proposes to use Information and Communication Technologies to design sustainable solutions for improving socio-ecological aspects of cities. In this paper, we present the challenge of designing IT applications in Smart Cities and present our own attempt to transform our university into a Smart Campus. Through examples of use cases, we discuss how the *Smart Cities* concept intends to put citizen back at the center of the city and highlights that inter-disciplinary work is mandatory to address the challenges of *Smart Cities*.**

I. Introduction

In 2007, for the first time in human history, the global urban population exceeded the global rural population, and the world population has remained predominantly urban thereafter. In 1950, 70% of worldwide population lived in rural settlements and less than 30% in urban settlements. In 2016, it is estimated that 54,5% of the worlds population is urban and the urban population is expected to continue to grow so that by 2050, it is expected that 7/10 of the population will live in urban centers [1]. This shift from rural to urban settlements has led cities to be bigger than never. Nowadays, there are 35 mega-cities with more than 10 million inhabitants, some of them with more than 30 million and the trend seems to be only increasing. This increase of urban population comes with new challenges which appeals for rethinking the concept of a city.

The *Smart Cities* concept is a resurgence of this need to rethink the city to face new socio-economic challenges. It proposes to use Information and Communication Technologies (ICT) to design technologies which should respond to people's needs through sustainable solutions for social and economic aspects [2].

In this paper, we raise questions from our perspective as IT designers and own attempts to make our University Campus *Smart and Sustainable* within the neOCampus initiative. The problematic addressed by this initiative, which initially comes from the will to study particular aspects of *Smart Cities*, are illustrative of the requirement for interdisciplinary work.

The goal of this paper is to share the challenges that emerged from this work, which we believe that not only, others will also have to face, but also to promote that a new multi-disciplinary approach to design smart city technologies is required.

Section II introduces the fundamental aspects of *Smart Cities* and illustrates its complexity. Section III highlights that Campuses are in many ways cities in microcosm by providing key metrics from the *neOCampus* operation. Section IV presents the neOCampus operation. At last, section V highlights the work being made within the neOCampus operation, focusing on how users are involved in the process.

II. The Smart Cities Concept

The concept of *Smart Cities* is a more and more recurring topic that started to be introduced in 1994 thanks to the rise of the Internet [3]. The concept of *Smart Cities* has not only spread among different scientific fields, but it has also impacted the civil society as the usage of the term by politicians, cities governments, and companies of all kinds illustrates. This broad and multidisciplinary usage of the term *Smart Cities* makes it difficult to propose an accurate and consensual definition of what a *Smart Cities* is. The scientific literature proposes many definitions and relative terms (such as Digital City) for *Smart Cities*. Those definition share four fundamental aspects of the *Smart Cities* concept:

- The use of **information and communication technologies** (ICT) to manage the city's assets, improving the efficiency of the services offered by the city.
- The improvement of the **quality of life** of residents by a digital transformation of their working and living environments.
- The central roles of **citizens** in this transformation, by orienting cities towards citizens needs and by an active implication of citizens in cities decisions thanks to the usage of ICT.
- The **inter-disciplinarity** aspect of researches on *Smart Cities*, implying many domains such as urbanization, social science or informatics.

Thus, the *Smart Cities* concept is more than an economical approach to reduce maintenance costs of cities: it is a socio-ecological revolution, which intends to improve the symbioses between a city, the Environment and the citizens [4]. As a matter of fact, the term *Smart City* is now side-by-side with the term *Sustainable* where sustainability refers to *achieving*

a balance between the development of the urban areas and protection of the environment with an eye to equity in income, employment, shelter, basic services, social infrastructure and transportation in the urban areas [5]. The ITU-T FG-SSC (International Telecommunication Union Focus Group on Smart Sustainable Cities) [6] provides a definition based on the analysis and use of around one hundred definitions. They define a Smart Sustainable City as *an innovative city that uses Information and Communication Technologies (ICTs) and other means to improve quality of life, efficiency of urban operations and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects*. This definition emphasizes the interdisciplinary aspects of the *Smart Cities* concept, involving multiple challenges at various levels [8].

From an IT designer point of view, *Smart Cities* applications share common properties which makes *Smart Cities* complex systems [7]:

- **Heterogeneity**: *Smart Cities* are composed of various heterogeneous devices. This heterogeneity implies challenges at various levels. The observation of *Smart Cities* through a large scope of sensors, each sensor independently designed to observe a specific feature, results in producing large volumes of heterogeneous data. Those *Big Data* require new infrastructures to enable the exchange and storage of those information, but also requires to create new tools and norms to manage them. Indeed, sampling rates, data scales or data formats are as various as sensors are numerous. But this heterogeneity might also be a source towards innovative solutions. One example is *Smart Transport and Mobility*. It is no secret that the increase of urban population has a negative impact on traffic congestion. Transportation planning must consider various factors, such as the specific topology of the City or the evolution of its population. In a Smart City, the presence of numerous sensors at various locations offers interesting opportunities for transport management, from the real-time control of traffic lights to influence traffic congestion to the autonomous planning of bus routes. Reducing traffic and gas emission by exploiting all the data of the city is a key aspect of the ecological transformation of *Smart Cities*.
- **Non-Linearity**: In *Smart Cities*, even the smallest causes can have large effects. For example, a change in the timing of a traffic light may results in huge traffic congestions. A non-linear system is a system in which the change of the output is not proportional to the change of the input. This non-linearity is a huge problem for ICT as it may lead to unpredictable or counter-intuitive situations, which makes the task of controlling these systems very complex. *Smart Building* are illustrative of this property. Minimizing energy consumption and reducing the ecological footprint of human society, is a global challenge that we must face. Equipped with a lot of sensors, Smart Building are involved at a more local scale in this challenge. They can monitor and control their own devices while also communicating with other buildings. The real-time monitoring of those buildings enables the automatic detection of anomalies, opening many possibilities in terms of predictive maintenance such as identifying flawed sensors, broken effectors, leaks, mechanical failures and so on. Providing to buildings administrators the adequate tools may improve their ability to respond to incidents, saving time and money. Another aspect of those *Smart Buildings* is their capacity to communicate with their users, involving citizens in the energy management. Using the sensors of the building and by observing the activity of the users, buildings can send eco-feedbacks, which consists in pieces of information sent to users informing them on the environmental impact of their behaviour in order to rise their ecological awareness.
- **Openness**: The openness property characterises the ability of a system to deal with the appearance and disappearance of some of its parts. As *Smart Cities* are in constant urban mutations, ICT applications must deal with the appearance and disappearance of devices, and the data and action associated with. Adding a new traffic light or a new smart light in a building must not imply to rebuild, rethink or modify the already existing IT architecture. Openness is a crucial challenge for the large acceptance of new technologies and a key towards sustainability.
- **Large-scale**: Due to the amount of entities (physical and virtual) involved in the *Smart Cities*, *Smart Cities* IT applications reach unprecedented scale in many dimensions such has the number of lines of code to develop an application, the amount of data stored, accessed, manipulated, and refined, the number of connections and interdependencies or the number of people involved and interactions that may occurred. We may even talk of Ultra-Large-Scale Systems. One example may be found in *Smart Governance*, which is a class of system of systems. The classical pyramidal organization of cities can lead to the compartmentalization of information. In disaster crisis, this compartmentalization can lead to situations where the information arrives too late or is lost in the process. In Smart City, institutions interact with multiple decision makers (communities, citizens and business). Decisions are based on information coming from multiple sources, in multiple departments. For example, the construction of a shopping mall is affected by a lot of factors coming from different stakeholders: cadastres from public administrations, citizens, services offered from close providers, urban policies, etc... Using ICT to send the adequate information at the right time, enhancing decision making even in situation of crisis is then a great challenge of *Smart Cities*.
- **Unpredictable Dynamics**: As stated by Lorentz, (1963) any physical system that behaves non-periodically is unpredictable [10]. Unpredictability of a system does not mean the absence of order but a confusing interaction

between order and randomness. Human activity is a huge source of those unpredictable behaviours in *Smart Cities*. This unpredictability involves to provide to IT systems the ability to continuously self-adapt to changes that may occurs in the dynamics of the city.

- **Spatial Distribution**: As Smart Cities spread their urban areas, the different components of *Smart Cities* applications are physically distributed among the city. This physical distribution not only involves new types of communication technologies and new communication infrastructures, but also lead to a shift of paradigm in the way systems are developed. Traditionally, IT systems are centralized, information in sent to a central node which takes the decisions and exercises control over the different components. At the opposite, the spatial distribution of entities in *Smart Cities* invites to rest on the autonomy of the entities, decentralizing the control over the different entities. One example of application illustrating this decentralization are the *Smart Grids*. Traditional electrical networks are centralized, the energy flow is unidirectional and flows from a producer to consumers. The emergence of more and more local producers, helped by the active development of effective wind turbines and photovoltaic panels, has led to now consider that the energy flow is bidirectional. Those green power sources are promising solutions towards the energy self-sufficiency of Smart Cities. But as those energy are dependent of the weather conditions, they are intermittent and if the energy demand reaches a peak, traditional sources of energy must be used in complement with those new sources. The cohabitation between various types of energy production is a complex problem. On the one side, the anticipation of energy consumption involves to take into account a huge amount of factors, from seasons to human activities. On the other side, thermal power plant can't be activated instantaneously and cannot offer energy at-demand, requiring a planning which is based on the demand. Deploying Smart Grids solutions then involves multiple knowledge on electrical networks, infrastructures, meteorology, end-users' consumption habits, etc...
- **Privacy**: Smart cities are able to collect and gather large amount of information, and this could harm the privacy of citizens [11]. Privacy rises questions at various level, from the designer of IT applications to its users, transcending the previously unidirectional relationship between designers and users. The control by citizens in the behaviour of *Smart Cities* is probably a key to ensure this privacy, but allowing such control involves an ethical design of IT application. This implies new development methodologies taking from the very beginning of the design of an application the privacy into account.

This list of properties is not exhaustive, but it tends to illustrate the complex nature of designing IT application in *Smart Cities*. Addressing those challenges and properties is more than an IT problem, it requires a multidisciplinary approach, involving many actors from different sciences. However, the motor of this revolution, citizens, is also the key to address them by involving citizens in the *Smart City* revolution, by collecting their needs and co-building solutions with them. On the next section, we present the neOCampus operation, which tends to transform the University Paul Sabatier from Toulouse into an *in vivo* lab of the *Smart and Sustainable Cities* challenges.

III. Smart Campus: Living Labs for Co-Building Applications for Smart Cities

A University Campus is generally spread on several hectares and populated with a lot of buildings, lawns, and transport infrastructures. Some of those buildings are dedicated to specific activities, such as research, sports or living, but others have more varied usages. For example, an amphitheatre might be used for education, but also for administration meetings, during scientific conferences or either for cultural activities such as concerts or plays. Thus, each building is unique, not only by its architecture, but also by the way campus users appropriate it. A University Campus is frequented by several types of end-users with different needs and habits. Students, faculty members, university staff, service providers, visitors and so on meet throughout the day leading to a dynamic flow of human activities. These activities consume resources, such as energy or water, and produce wastes who must be evacuated. Integrated in a city, a University Campus also disposes of its own communication networks in addition with the services already offered by cities (such as the Internet and telephony). Like the cities, a University Campus is living, with its own input and output flows, feeding on resources and producing wastes. A University Campus is not static, it is alive, evolving with its users, with policies, and with its environment trying to ensure the highest quality of living and education possible. Due to their size, users and mixed activities, university campuses can be considered as districts or small cities. As a matter of facts, more and more researchers looks to Universities Campuses as great places to experiments innovative services and techniques for *Smart Cities*, building what is called a *Smart Campus*.

There are many *Smart Campus* initiatives that may be found in the scientific literature, each of them focusing on particular aspects. At Lisbon, for example, the focus is made on energy efficiency [13]. At Lancaster University, the focus is made on socio-digital sustainability [14]. Those initiatives share many common points:

- They are innovating on pre-existing infrastructures, which involve to face many constraints.
- They intend to improve quality of living and teaching through the usage of ICTs.
- They put at the center of any design process the end-users and their well being.
- They intend to create replicable innovations, that might be used in other universities or cities.

Pinto & al. [12] explain that the *the focus of a Smart Campus is to provide an innovative multidisciplinary learning experience*

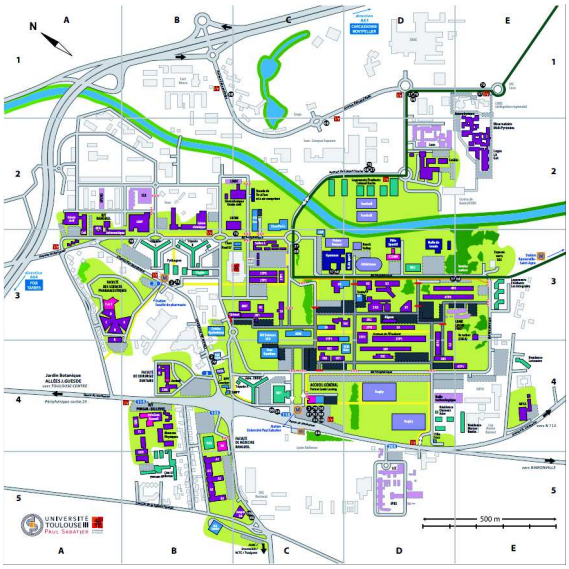

Fig. 1. A map of the Toulouse III Paul Sabatier University. 388 656 m^2 of built-up areas welcome each day more than 35 000 peoples.

using the campus as prototyping space and support the education of the citizen engineer, through solutions to real problem, in order to multiply them in the urban context supported by innovative thinking and with commitment with the environment, social responsibility and be replicable in others countries. On the next section, we present our own initiative, entitled neOCampus, before giving feedbacks on different use-cases that highlights the need for inter-disciplinary interactions.

IV. neOCampus: building a Smart and Sustainable Campus at Toulouse III Paul Sabatier University

The Toulouse III Paul Sabatier University (http://www.univ-tlse3.fr) has been founded in 1969 and has grown over the years allowing it to now be compared to a small town (Figure 1. It is composed of 70 research structures and 11 doctoral schools. 31 238 students were enrolled in university studies in 2016, for 2 570 teacher-researchers, 2 006 engineers and technicians and 2 993 staff members in the different laboratories. The University has 388 656 m^2 of built-up areas, representing a total area of 264 ha, mainly in Toulouse, but also in 7 other towns. Inside the Tmain campus, several solutions of mobility exist: pedestrian, bicycles, vehicles, cars, buses and subway. The cost of functioning of the university represent 21% of its budget of more than 400M euros. All the activities on the campus consume 140 GWh a year and produce 23 250 tons of CO2 (diagnosis made in 2010).

The neOCampus operation (www.irit.fr/neocampus) started in June, 2013 and aims to transform the Toulouse III Paul Sabatier University into an "in vivo" incubator for *Smart and Sustainable Cities*. It involves students, administration staff and the teachers and researchers of 10 laboratories of the Toulouse III Paul Sabatier University: CESBIO, CIRIMAT, ECOLAB, IRIT, LA, LAAS, LAPLACE, LCC, LERASS, LMDC each laboratory bringing its own scientific expertise. These laboratories aim to cross their skills in order to improve the comfort of living and working at the University, while decreasing the ecological footprint of buildings and reducing the costs of functioning (fluid, water, electricity...).

Within the neOCampus operation, the Toulouse III Paul Sabatier University is turning into a platform for innovative experiments performed at large scale and in vivo (with real end-users, in real situations) and welcomes partnerships with independent companies. In this context, many initiatives have been launched to address problematic of *Smart Cities*. On the next section, we present some of those initiatives and put a focus on the necessity of an interdisciplinary approach.

V. Interdisciplinarity in neOCampus

This section presents some of the ongoing projects of neOCampus, highlighting the cooperation between scientists from different fields and the mutual benefits for researchers management, and technical staffs. Some of these projects help involving users into the ecological philosophy of *Smart Campus*.

Collaborative WiFi. Due to tight budgets and complicated infrastructure, some parts of the library of the Health Library of Paul Sabatier University lacks a proper wi-fi network. Through neOCampus, computer scientists have developed a mobile app able to dynamically and spontaneously create a wifi network. Mobile phones with the application installed cooperate when they are in the area of the library to create and share a wifi network. They perform this differently regarding their battery level and their allowed data consumption. Driven by cooperation principles, they decide which phones should become hotspots and when a given hotspot should stop, thus creating a dynamic and self-adaptive wifi network and providing a much needed service to students.

This is an example of how technical staffs can find solutions to their problems in the works of researchers, while providing challenging applications and validation material for researchers.

Open Data Platform Data are the core of the smart campus. Everything relies at some point on the data that are collected in the campus, although not all services need to access to all of the data. Management needs them, researchers need them, technical staff needs them, and they can be useful for students, teachers, and visitors. This is why designing a platform where data is shared to all, is a core project in neOCampus.

But, when designing the data collection and storage infrastructure, it is impossible to know in advance who exactly the end-users will be, yet alone what they will need. Another difficulty is that new sources of data are continually added in the campus. Hence, the infrastructure needs to be flexible, modular, and incremental. The goal is to easily give access to data that come from multiple sources (sensors managed by various administrations in the campus, data manually collected by various laboratories, etc) to researchers from many fields,

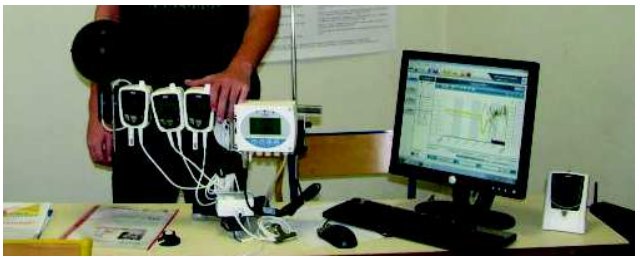

Fig. 2. Monitoring the comfort of users involve to monitor various aspect of the environment such as the temperature, CO2 levels, humidity, etc.

to management, and to the public. This raises the problems of privacy and security, as some data should be anonymized before being shared and not all data should be public. This is why ethical, legal, and safety committees are also involved in the design of our platform.

The Open Data Platform is another example of how the smart campus can benefit from and to people working in different (scientific and non-scientific) domains. It is also a striking example of one of the main obstacle in building a smart campus/city. The difficulty is actually not technological, nor scientific. It is for the people involved to understand each other and to learn to work together, while they come from very different fields. This difficulty stems from the compartmentalization of fields in almost every aspects of the campus from the administration to the labs. The neOCampus operation aims at shifting this paradigm towards more horizontal cooperation.

Ecocitizenship. One aspect of the Smart Campus is the will to reduce the ecological footprint of human activities. This involves not only automatic procedures to optimize energy consumption, but above all, it implies to address the ecological consciousness of users. To this end, several initiatives are being made in the neOCampus project. Those initiatives share the idea that ICTs may be used not to replace users, but to send feedbacks to them, in order to improve the ecological behaviour of users through pedagogy. One of those initiative proposes to monitor the front of the buildings with camera and image processing to detect the places where lights stay on at night. This automatic detection enables to warn adequate services that can intervene to turn off the lights, but also inform the regular users of the building that they may have leave the building without turning off the light. This initiative also comes with a participatory application provided to the users of the Campus enabling them to easily to rise in real time information about anomalies such as lights on, a window left open or a leak of water and easily locate them, allowing both the appropriate services to intervene quickly but also allowing to imply everyone in the ecological philosophy of the *Smart Campus*. In complement, this use of ICTs to send feedbacks to users is being deployed into classrooms in a project entitled consOCampus. Classrooms are equipped with sensors to monitor both energetic aspects such as electricity consumption and the well-being of users (through the monitoring of temperature, CO2, humidity, etc... see figure 2). This project studies the use of autonomous machine learning systems coupled with the indoor environment quality expertise. This expertise concerns thermal, visual, acoustic comfort, air quality, the impact of occupants behaviours on the thermal performance of buildings, the control and optimization of energy networks, systems and buildings and the thermal and acoustic characterization of materials. The project aims at learning to optimize in real time both the well-being of users and the energy consumption of the classroom.

Fig. 3. Illustration of the Biodiversity application. Campus users can help to monitor fauna and flora using their smartphones. Those data help researchers to dress an up to date list of the fauna and flora.

Biodiversity. With a surface of 388 656m, the University of Toulouse harbours a rich fauna and flora. Studying the impact of human activities into this ecosystem in order to protect the fauna and flora is a key aspect of *Smart Cities*. Within the project, a participatory application between computer scientists and ecologists, has been deployed to identify and locate the fauna and flora present in the University. Using their smartphones, users can photograph the species, which are automatically located using the GPS informations, and add information about them (Figure 3). Those data enable researchers to dress a list of the fauna and flora and follow the evolution of those species. The project is also working on the development of new monitoring methodologies of small and medium fauna based on sensor networks. The idea is to have at disposal up to date information about the environment in order to study the impact of human activities and take into account this impact during the urbanization process.

VI. Conclusion

Smart Cities propose to improve the quality of life of their citizen by using information and communication technologies. There are a wide rang of application of the Smart City concept, from economising energy to the protection of the fauna an flora.

In this paper, we present the neOCampus initiative, which aims to study and implements the concepts of *Smart Cities* into the campus of the University of Toulouse III Paul Sabatier. Many initiatives have been started, mainly studying the impact of human activity on the ecological footprint of the campus. But those applications have to face some technological challenges such has their heterogeneity, their spatial distribution or the number of entities involved. Those characteristics make mandatory to see *Smart Cities* as complex systems, and address them with an interdisciplinary approach.

Indeed, *Smart Cities* propose a real revolution in the way innovations are made. Through the examples of applications illustrated in this paper we have highlight that it is mandatory for biologists, IT scientists, ergonomists, sociologists, and others to work together to fully address all aspects of the challenges of *Smart Cities*. With this paper, we intend to promote the idea that complexity in *Smart Cities* can only be addressed through an interdisciplinary work, highlighting the emergence of a science of the complex.

ACKNOWLEDGEMENT

This work is partially funded by the French Midi-Pyrenees region, within the neOCampus initiative (www.irit.fr/neocampus/), by the INS2I CNRS organism and by the Paul Sabatier Toulouse III University.

REFERENCES

[1] United Nations, *World Urbanization Prospects 2014: Highlights*. United Nations Publications, 2014.

[2] Albino, Vito, Umberto Berardi, and Rosa Maria Dangelico. *Smart cities: Definitions, dimensions, performance, and initiatives.*, Journal of Urban Technology 22.1: 3-21,2015.

[3] Dameri, R. P., and A. Cocchia. *Smart city and digital city: Twenty years of terminology evolution.* X Conference of the Italian Chapter of AIS, ITAIS, 2013.

[4] Ahvenniemi, Hannele, et al. *What are the differences between sustainable and smart cities?*. Cities 60: 234-245,2017.

[5] Hiremath, Rahul B., et al. *Indicator-based urban sustainabilityA review.* Energy for sustainable development 17.6 (2013): 555-563.

[6] Xuemei Bai, Ryan RJ McAllister, R. Matthew Beaty, and Bruce Taylor. *Urban policy and governance in a global environment: complex systems, scale mismatches and public participation*, Focus Group Technical Report, 10/2014.

[7] Harrison, C., & Donnelly, I. A. *A theory of smart cities*. In the 55th Annual Meeting of the International Society for the Systems Sciences, The University of Hull, Hull, U.K,2011.

[8] Neirotti, Paolo, et al. *Current trends in Smart City initiatives: Some stylised facts.* Cities 38:25-36, 2014.

[9] Julien Nigon, Nicolas Verstaevel, Jérémy Boes, Frdric Migeon, Marie-Pierre Gleizes. *Smart Is A Matter of Context*.International and Interdisciplinary Conference on Modeling and Using Context (CONTEXT 2017), 2017.

[10] Gleick, J. *Chaos: Making a new science (Second ed.)*. New York: Penguin Books Ltd, 2008.

[11] Antoni Martnez-Balleste, Pablo A Perez-Martnez, and Agusti Solanas, *The pursuit of citizens privacy: a privacy-aware smart city is possible*, IEEE Communications Magazine 51 , no. 6, 136141, 2013.

[12] Pinto, Luciana Gomes Pereira, Regiane Relva Romano, and Matheus Akira Tomoto. *From the University to Smart CitiesHow Engineers Can Construct Better Cities in BRICs Countries: A Real Case from Smart Campus FACENS.* Advances in The Human Side of Service Engineering. Springer International Publishing, 347-354,2017.

[13] Gomes, Ricardo, et al. *Towards a Smart Campus: Building-User Learning Interaction for Energy Efficiency, the Lisbon Case Study.* Handbook of Theory and Practice of Sustainable Development in Higher Education. Springer International Publishing, 381-398, 2017.

[14] Bates, Oliver Emile Glaves, and Adrian John Friday. *Beyond data in the smart city: learning from a case study of re-purposing existing campus IoT.*, IEEE Pervasive Special Issue on Smart Buildings and Cities, 2017.

[15] Julien Nigon, Estelle Glize, Fabrice Crasnier, et Jérémy Boes. *Use Cases of Pervasive Artificial Intelligence for Smart Cities Challenges.* IEEE Workshop on Smart and Sustainable City, Toulouse, juillet. 2016.

[16] Catriona Manville et al., *Mapping Smart Cities in the EU*, Report of the European Parliament, Directorate-General for Internal Policies, Policy Department A: Economic and Scientific Policy, Jan. 2014.