Sensors and the Smart City

Creating a Research Design for Sensor-based Smart City Projects

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***Abstract*—In this paper, we present a proposal for a research design, based on the argument that there is a connection between smart cities and the concepts of "smart buildings" and "smart users". Smart cities refer to "places where information technology is combined with infrastructure, architecture, everyday objects, and even our bodies to address social, economic, and environmental problems". Smart buildings refer to ICT-enabled and networked constructions such as traffic cameras and lights, buildings and other man-made structures. With inexpensive hardware such as the Raspberry Pi, Edison, Arduino, and their ecosystems of sensors, we can equip these structures with sensors. Smart users refer to the high level of education in western societies, which allows us to utilize technology such as smart phones to create better cities. Citizens can provide data through their smart phones, and these data can, together with sensor data from buildings, be used to analyze and visualize a range of different variables aimed at creating smarter cities. We propose that a first step of smart city research should be a thorough process of identifying and collecting input from relevant stakeholders in order to find the most relevant objectives for research.**

Keywords- smart cities; smart buildings, smart citizens; sensors; research design.

I. Introduction

As of 2009, more than 50 percent of the world's population lives in urban areas [1], and this number is forecasted to increase in the coming years. Cities occupy only 2 percent of the planet, but account for 60-80 percent of energy consumption [2]. As the sizes of cities grow, so do the challenges facing cities [3]. These challenges include issues related to public health and socio-economic factors [4], energy consumption, transport planning and environmental issues [5]. Air pollution caused by traffic jams is but one concrete example of the many challenges facing growing cities [6]. In order to reduce traffic and environmental impact it is necessary to implement safe, reliable, rapid and inexpensive public transport. Therefore, it is an obvious need for cities to be smart. Dameri and Coccia [7] summarize the major objectives of smart cities:

- Improve environmental quality in urban space, reducing CO_2 emissions, traffic and waste;
- Optimize energy consumption, by making buildings, household appliances and electronic devices more energy efficient, supplemented by recycling energy and use of renewable energy;
- Increase quality of life, delivering better public and private services, such as local public transport, health services, and so on.

In this paper, we argue for the application of sensors and data analytics for resolving some of the challenges facing cities. There is a connection between smart cities and the concepts of smart buildings and smart users. Smart cities refer to places where information technology is combined with infrastructure, architecture, everyday objects, and even our bodies to address social, economic, and environmental problems [8]. Examining how to achieve this connection between ICTs and the world around us is the focus of our paper.

Smart buildings and *smart homes* refer to the use of built-in infrastructure to provide safety and security, entertainment, improved energy management, and health monitoring [9]. A smart building or a smart home relies on the use of sensor technologies to achieve this. The data collected by such sensors can also be aggregated and used by the city for various purposes. Sensors can provide information to law enforcement, emergency response, power management, home care services, environmental protection, city planning, and intelligent transport systems.

The *Internet-of-Things* (IoT) refers to devices connected to the Internet that can exchange data with external computerized systems. In the context of smart cities, such devices can monitor traffic, pollution, noise level, use of electrical power, etc.

Inexpensive hardware such as the Raspberry Pi, Edison, Arduino, and their ecosystems of sensors, enables us to deploy sensor technology on a large scale. Such low cost devices can provide valuable information for optimizing energy use, infrastructure and public transport planning, as well as emergency response and other vital services. Applying sensors is just the first step towards smarter cities. The next step involves smart users.

Smart users refer to the high level of education in western societies, which allows us to utilize technology such as smart phones to create better cities. Cities in and of themselves are not smart, nor is a smart phone or computer smart unless the person using it does so with a specific purpose in mind. Actually, the apparent intelligence of the computing systems comes from the amount of human

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intelligence that was invested in it. Citizen participation is seen as an important element in smart cities [10]. Studies show a causal relation between high levels of education and growth in the number of available jobs [11]. In our context, we see citizens both as providing input through traditional participation projects, but also as providers of data for analysis. Citizens can provide data through their smart phones, either actively or passively (with consent), and these data can, together with sensor data from buildings, be used to analyze and visualize traffic patterns, movement through the city and between cities, environmental factors etc.

We apply these concepts to the framework for smart city planning [10], in order to present an experimental research design for the application of sensors and analytics in Smart City planning. This approach is in part the result of an ongoing collaboration with regional analytics businesses. The rest of the paper is structured as follows: Section 2 discusses the use of sensors for data collection. Section 3 discusses how analytics can be applied as input for participatory planning, and section 4 presents the outline of a research design, using the Smart City framework of [10]. Section 5 presents a brief overview of a possible case where this design will be applied.

II. A World of Sensors

A sensor is a component able to detect a change in its environment and convert this change into an electrical signal. The signal returned by a sensor may be binary (on/off), a value within a range, e.g., temperature, light, wind, humidity, precipitation, position, and acceleration. Camera sensors return images or even image streams. Since sensors are operating in real time, they can produce large amounts of information. Therefore, sensors are normally connected to some kind of unit that monitors changes, and forwards information at regular intervals, or when the change is big enough. The left part of Figure 1 shows how sensors are connected to an aggregation and preprocessing unit.

Many mobile devices have built in sensors, e.g., a GPS sensor, camera or accelerometer. The number of built-in sensors is expected to increase with new versions. Newer cars also have built-in computers handling sensor input, local processing and communications [12]. According to Abdelhamid et al. [13] a 2013 model car has on average 70 sensors, while luxury models may have more than 100 sensors. The number of sensors is expected to grow.

Typical applications for hand-held or car mounted devices are traffic monitoring and prediction. The devices send their coordinates, and the server software receiving this information decides if a specific traffic route is clogged or not.

Another application is environmental monitoring. One example is the Green Watch project [14]. The project distributed 200 smart devices to citizens of Paris. The devices sensed ozone and noise levels as the citizens lived their normal lives, and the results where shared through a mapping engine. The project showed how a grassroots-sensing network could reduce costs dramatically, and also engage citizens in environmental monitoring and regulation. Bröring et al. [15], used the built-in diagnostic interface of cars (OBD-II) to obtain sensor data used to estimate current fuel consumption, CO_2 emission, noise, standing time and slow moving traffic.

Citizens can also act as sensors themselves, by reporting what they observe. One example is FixMyStreet.com, a web application that enables citizens to report problems with roads and other infrastructure.

Today, low cost devices (e.g., Raspberry Pi, Edison and Arduino), have both processing and communication capabilities. Such devices can easily be connected to different types of sensors [16] [17], and can do local processing of data, before packing the results and sending it to a central processing facility for further processing, analytics and visualization. Raspberry Pi 3 and Edison have built-in wireless communication capabilities, which make connection to city-wide WiFi networks even easier. Separate components are available to connect such devices to mobile networks.

A. Applications

Sensor networks may have a wide range of applications. The most obvious examples can be found within the following fields:

- Safety and security
- Energy monitoring and control: Smart power meters
- Environmental protection
- Health

B. Safety and Security

An important aspect of smart cities and smart buildings is to make people feel safe and secure. Sensors can be used for a multitude of application, both to secure property and to keep citizens safe. This includes intrusion alarms, surveillance cameras, fire detection and flood alarms. Such alarms can connect to law enforcement and emergency response, but also to private operators and trusted neighbors.

C. Energy Monitoring and Control

Sensors can be used to monitor temperature and lights. Detection of movements can turn lights on, and heating and air-conditioning can be optimized to not spill unnecessary energy. Smart meters can provide information useful for energy planning, and also prevent blackouts and brownouts by adjusting the price of electrical power.

D. Environmental Monitoring and Protection

By collecting environmental data, the building itself and the city can get early warnings on pollution levels and other environmental problems, and initiate necessary actions.

E. Health

Old people want to live in their homes as long as they feel safe. Sensors can be used for daily health monitoring, where data are sent to medical professionals, but also detect medical emergencies, like fall detection.

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F. Privacy Issues

Deploying large networks of sensors (proximity sensors, presence sensors, surveillance cameras, gas and smoke sensors), and in particular the data collection from personal devices raise some concerns related to privacy of the individual. Therefore, it is necessary to implement legal mechanisms to regulate how information can be obtained, what information can be obtained, and for what purpose the information can be used. The public must be informed and give their consent of use of the information.

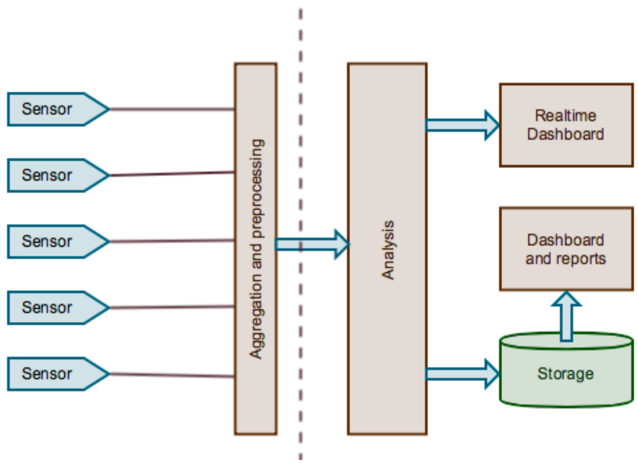

Figure 1. Sensor network, analyzing and visualization architecture

III. APPLYING ANALYTICS AND VISALIZATION IN PARTICIPATORY PLANNING

Mining and analyzing data has been on the agenda of researchers since the 1960's. However, the period from ca. 2000 to present is the most interesting one in the history of data mining, because of the emergence of the Web and the large amounts of data generated from the web [18]. A review of data mining literature between 2000 and 2011 reveals that a number of different areas have been developed, all of which can be used for various types of analysis [18]:

- Neural Networks - For classification, time series prediction, pattern recognition
- Algorithm architecture - For calculation, data processing, clustering
- Dynamic prediction - For prediction, forecasting and tracking
- System architecture - For association, decision making and Consumer behavior
- Intelligent agent systems - For autonomous observation and acting on external input
- Data modeling - For representation or acquisition of expert knowledge
- Knowledge-based systems - For knowledge discovery and representation

Most of these can be applied in collecting data from sensors, and there are many examples from literature. One study shows how data mining and predictive analytical techniques can be applied to predict the number of vacant properties in a city [19]. Geographic information can be combined with a plethora of different data to provide valuable information for decision makers. Massa and Campagna show how geographic data extracted from social media can improve urban planning in a smart city context, and present a methodology for social media geographic information analytics [20]. A similar study mines data from the location-based social network FourSquare to identify under-developed neighborhoods [21].

De Amicis et al. [22] have developed a geo-visual analytics platform for land planning and urban design, and argue for the importance of visual, 3D analytics. Another system, STAR CITY, uses sensor data from both machine and human-operated sensors to analyze traffic patterns in cities. The prototype has been tested in Dublin, Bologna, Miami and Rio de Janeiro [23]. Another study uses sensor data to model traffic noise and predict which areas were most likely to experience noise on a given day [24].

Energy monitoring for the purpose of reducing the city's carbon footprint is another area made possible by analytics. Researchers are working on a framework, which would allow for integration of energy monitoring in entire neighborhoods [25].

Visualization of the results produced by the analytics, can help decision-making. Information can be presented real time through the use of dashboards, using different types of graphical visualizations show issues that need to be dealt with. The combination of analytics and visualization is shown in the right portion of Figure 1.

This section has provided a brief overview of analytics and its coupling to visualization, and also given examples of existing systems that at various levels and from several perspectives provide decision makers with important input. The combination of sensors, geographic information and user-generated data can, especially when coupled with some form of visualization, be a powerful instrument for decision makers. Coupled with citizen participation [26] projects, this can be a great resource for the development of smart cities. In the next section we provide a brief outline of a possible research design for participatory- and sensor-based smart city projects.

IV. TOWARDS A RESEARCH DESIGN FOR PARTICIPATORY PLANNING OF SMART CITIES

Chourabi et al. [10] presents a framework for smart city initiatives, which is separated into internal and external factors (Figure 2). These factors influence each other, and depending on the type of project, some are more important than others. The framework can be applied as a tool for planning smart city initiatives, and we will in this section discuss how it can be applied as the foundation for a research design.

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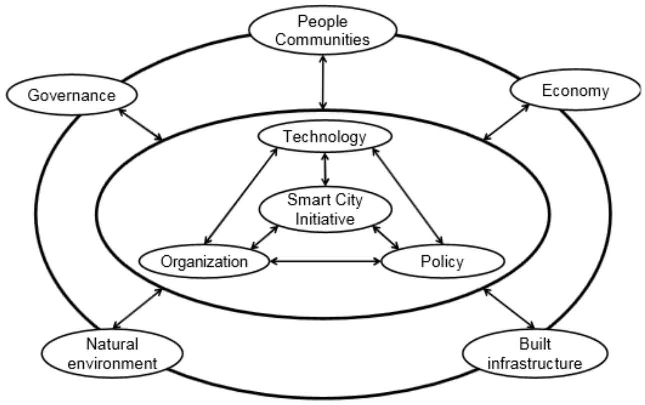

Figure 2. The Smart City Initiatives framework [10].

Our objective is to create a research projects where sensor data from buildings, cars and people are collected, analyzed and visualized, so that decision makers have access to data about issues related to transport and movement, pollution and city planning. With this in mind, the framework of Chourabi et al. [10] can be used for the initial project planning:

The *Smart City Initiative* is as described above. In our home regions, there are several smaller cities in close distance to each other, and we are working to set up a case study of how sensor technologies can help these cities become even more integrated as one single job and housing region. The approach may be influenced by urban congestion and by city topographic classes: compact, river and seaside.

The *Technology* consists of sensors, software and hardware for data mining and analytics. Using existing technologies such as the Raspberry Pi, Edison, Arduino and smart phones would be a natural first step of such projects. A second step could be to evaluate the use of existing technology in order to examine if there is a need for further custom development. We have already developed a unit for environmental monitoring based on the Edison platform and one Arduino-based unit for detecting physical proximity, e.g., to detect if a parking spot is occupied or not.

Technological challenges include IT skills of the end users, and issues related to organizational culture [27]. One of our projects partners is a company specializing in analytics, and the population generally has good IT skills, so this challenge is not a major one. The bigger challenge would be to overcome organizational barriers. We propose that the cities involved in the project be responsible for setting goals and objectives, recruiting participants and for procurement of necessary hardware and software, as well as placement of sensors. Local media could also be a partner in recruiting participants. The analytics companies would implement the software solution (collecting, analyzing and visualizing data) and we, as researchers would be responsible for the overall project organization and coordination between other actors.

For the *Organization* and *Policy* factors, there are some challenges to be addressed. Organizational issues include alignment of goals and turf wars, and both formal (legal) and informal(normative) challenges as issues to consider when making new policy [10]. The region in which our project will take place already has a formalized collaboration on a range of different issues. This means that most of the factors related to governance and policy have already been addressed in previous collaborations. The major challenge will be to get the different cities to agree on a set of goals, as well as what these goals mean in practice.

The external factors of our projects will also have implications. The framework lists collaboration, leadership, participation, communication, data-exchange, integration, accountability and transparency as typical *Governance* issues. Again, the established collaboration between the project partners should help alleviate these challenges.

The *People and Communities* factor involves issues such as accessibility, quality of life, education, communication and participation. Citizen participation through the use of smart phone sensors will be a key factor in our project, so recruiting participants is a major issue. As the objective of the project ultimately is to create regions that are better to live and work in, and to travel between, we will need to be very clear about the potential benefits of participation. Communicating these through traditional and new media will most likely be essential. We address this factor in more detail below.

Economy and Built infrastructure: Smart city initiatives are easier to implement in areas with high levels of education, entrepreneurial businesses and a good ICT infrastructure [10]. The cities we are trying to set up our project with all have challenges related to growth, but there are several innovative businesses and industries in the region. A challenge often facing these businesses is how to attract the right employees, so it is likely that they will be positive towards any initiative where this could be an outcome. The IT infrastructure in the region is good, but there will likely be some challenges in more remote parts. For example, there are still areas without 3G or 4G mobile data coverage, and some of these areas could be in places where it would be useful to place sensors.

The final factor, *Natural environment*, addresses the need for more sustainable and greener cities. Therefore, placing sensors that monitor traffic patterns, building usage and learning more about how and where the people in the region travel, are objectives in our proposed study. Knowing more about travel patterns allows for optimal use of available public transport, and could also facilitate the creation of apps for carpooling. Another use of sensors could be to scan cars passing tollbooths, and to impose higher tolls on vehicles with higher CO_2 and NOX emissions.

A. Recruitment and Participation

We would argue that the people and communities factor is essential in our proposed project. Close collaboration with the people who would be affected by any policy changes that might come from the project might help alleviate some of the resistance that could otherwise arise. As the brief overview of sensor technology and existing research projects show, there are so many possibilities that some kind of process is needed to narrow the scope of the project. Because cities and regions have different challenges, we propose to gather relevant stakeholders in a planning workshop, where the objective is a) to identify the most pressing objectives for the region in question, and b) to figure out the technical, legal and organizational challenges facing each individual objective. Identifying relevant stakeholders can be done for example through the stakeholder framework of Podnar and Jankic [28].

Participation and collaboration between government, citizens and organizations is seen as essential in the development of smart communities [29]. Many of the activities (parks and recreation, planning and community development) typically involved in smart city projects can benefit greatly from citizen participation [26], and there is a clear correlation between cities' adoption and implementation of sustainability policies and public participation in policy formulation [30].

The EU-supported NET-EUCEN thematic network has proposed a framework for measuring user involvement, with indicators for how well users are involved in defining, developing and assessing digital government [31]. While this framework was developed for eGovernment in general, the principles of involvement can be transferred to the Smart City context. The individual indicators for the three dimensions are presented in Table I.

Our goal is to involve users and stakeholders in all phases of the project. In the definition phase, the users and stakeholders will discuss and decide on issues where senor input, analytics and visualization will be of most value. In the development phase, the users and stakeholders will be involved in the design and development process to make sure that both technology and visual output is useful to handle the issues found during the definition phase. In the assessment phase, the users and stakeholders will be asked to provide feedback on possible modification or extensions.

TABLE I. DIMENSIONS AND INDICATORS OF USER INVOLVEMENT [31].

Dimension 1: Definition		**Dimension 2: Development**		**Dimension 3: Assessment**	
Engagement of citizens/users in elicitation of needs	Yes:0.25 No : 0.00	Involvement of users/testers in common shared environment	Yes: 0.20 No: 0.00	Involvement of ALL user categories in the assessment	Yes: 0.33 No: 0.00
Involvement of users in the service definition	Yes:0.25 No : 0.00	Involvement of user in interface test and refining	Yes: 0.20 No: 0.00	Instrument used gather the users' feedback: phone calls	Yes: 0.0825 No: 0.00
Involvement of users in functionalities definition	Yes:0.25 No: 0.00	Involvement of user in functionalities test and refining	Yes: 0.20 No: 0.00	Instrument used gather the users' feedback: web modules	Yes: 0.0825 No: 0.00
Involvement of users in the complete interaction definition	Yes:0.25 No : 0.00	Involvement of user in check of documentation / guidelines	Yes: 0.20 No: 0.00	Instrument used gather the users' feedback: consultations	Yes: 0.0825 No: 0.00
		Involvement of ALL user categories in the tests	Yes: 0.20 No: 0.00	Instrument used gather the users' feedback: workshops	Yes: 0.0825 No: 0.00
				Scope: improvement of the service usability	Yes: 0.165 No: 0.00
				Scope: definition of new features	Yes: 0.165 No: 0.00
I1	**Max score 1.0**	**I2**	**Max score 1.0**	**I3**	**Max score1.0**
Total score: I1/3 + I2/3 + I3/3					

V. CONCLUSION

In this paper, we propose a research design for smart city projects where sensors are used to collect data on a range of variables related to transport, energy use, safety, health and the environment. The sensors may be stationary (., fixed to buildings), mobile (e.g., mounted in cars) or part of smartphones and their ecosystem (e.g., smart watches containing sensors).

The collected data can be analyzed and visualized so that decision makers are able to make better informed decisions related to day to day management of cities. The collected data can also be used for prediction of what will happen in the future.

We apply the smart city framework of Chourabi et al. [10] to address the potential issues involved in such projects. In addition, we argue that it is essential for smart city projects to find ways of involving key stakeholders, as different cities and regions are faced with different challenges. Key stakeholders should be involved in both project definition, project development and project assessment.

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