Smart Cities: Challenges and a Sensor-based Solution

A research design for sensor-based smart city projects

Lasse Berntzen, Marius Rhode Johannessen
School of Business
University College of Southeast Norway
Norway
{lasse.berntzen, marius.johannessen}@hbv.no

Adrian Florea
Faculty of Engineering
"Lucian Blaga" University of Sibiu
Sibiu, Romania
adrian.florea@ulbsibiu.ro

Abstract - **In this article, we present a research design for smart city initiatives, 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, Intel Edison, Arduino, NodeMCU and their ecosystems of sensors, we can equip these structures with sensors. Smart users refer to the high level of education in developed societies, allowing 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. Finally, we present case evidence from a pilot study that has followed our approach, which has now received funding for further development.**

Keywords - smart cities; smart buildings; sensors; sustainability; research design.

I. INTRODUCTION

This paper extends the previous work that was presented at the Fifth International Conference on Smart Systems, Devices and Technology (SMART 2016) [1], by presenting evidence from a pilot study of developing an environmental monitoring unit. Starting from a research design for smart city that identifies and collects first the inputs from relevant stakeholders in order to find the most relevant objectives for research, we then present our experiences from a pilot project for environmental monitoring using an integrated hardware-software system, sensors-based. This represents an important contribution to the field of environmental monitoring using the idea of the car as a sensory device and generating some profile indicators for cities per certain periods of time through the project platform.

As of 2009, more than 50 percent of the world's population lives in urban areas [2], 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 [3]. As the sizes of cities grow, so do the challenges facing cities [4]. These challenges include issues related to public health and socio-economic factors [5], energy consumption, transport planning and environmental issues [6]. Air pollution caused by traffic jams is but one concrete example of the many challenges facing growing cities [7]. In order to reduce traffic and environmental impact it is necessary to implement safe, reliable, rapid and inexpensive public transport. Therefore, itis an obvious need for cities to be smart. Dameri and Coccia [8] 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 [9]. 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 [10]. 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 concept of *Internet-of-Things* (IoT) is characterized by 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. [11].

Inexpensive hardware such as the Raspberry Pi, Intel Edison, Arduino, NodeMCU 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 developed societies, allowing 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 intelligence that was invested in it.

Citizen participation is seen as an important element in smart cities [12]. Studies show a causal relation between high levels of education and growth in the number of available jobs [13]. 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 [12], in order to present a 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 II discusses the use of sensors for data collection. Section III discusses how analytics can be applied as input for participatory planning, and Section IV presents the outline of a research design, using the Smart City framework of [12]. Section V presents the results of a pilot study applying our research design. The pilot study led to a successful application for funding to take the research further. In Section VI, we present our final research design, based on the Chourabi et al. framework [12], experiences from the case, and user centered design principles. Finally, we provide implications and conclusions in Section VII.

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 Fig. 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 [14]. According to Abdelhamid et al. [15] 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 [16]. 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 grassroot sensing network could reduce costs dramatically, and also engage citizens in environmental monitoring and regulation. Bröring et al. [17] 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 types of infrastructure. Today, low cost devices (e.g., Raspberry Pi, Intel Edison, Arduino and NodeMCU), have both processing and communication capabilities. Such devices can easily be connected to different types of sensors [18] [19], 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 Intel Edison have built-in wireless communication capabilities, which make connection to citywide Wi-Fi networks even easier. Separate components are available to connect such devices to mobile networks.

The most obvious examples can be found within the following fields:

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

A. *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. The Norwegian company Lyse, originally an electrical utility company, has developed *Smartly* (http://www.smartly.no), an integrated solution for controlling temperature and lighting, house alarms and surveillance, in-house entertainment and fire detection. Fire and house alarms are connected to operators who will check what happens in case of an alarm.

B. 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 prevent blackouts and brownouts by adjusting the price of electrical power. Fregonara and Curto [20] suggests developing a tool that incorporates data from real estate, environmental technology, architecture and materials science, which would make new buildings a lot more energy efficient than they currently are. Other researchers have developed frameworks for comprehensive monitoring aimed at increased energy efficiency. Most of the needed data is available through various sources, but is not yet linked so that it provides a holistic picture [21].

C. 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. While it may be necessary to build new and expanded infrastructures (i.e., In public transport), much can be done by increased information and access to information about what choice to make. This could lead to citizens being more aware of their environmental footprint, and thus to citizens making better choices [22]. In Stockholm, a pilot study of «smart urban metabolism» applied data from various sources to analyze relevant data and intervene where necessary. As with [21], this study also found that much of the data was already available, but not yet linked and utilized for environmental purposes [23].

D. Health

Older citizens 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. Boulos and Al-Shorbaji [24] discuss how IoT sensors coupled with data analytics can contribute to a healthier population, and point to the World Health Organization's (WHO) healthy cities project, and the UK's objective to spend £45 million on IoT and related technologies. Another study discusses how technology can be used to alleviate the consequences of flu outbreaks, by spreading information to people in infected areas [25].

E. 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. Legal and privacy issues will of course vary between different countries, but most countries will have laws governing what we can and cannot do.

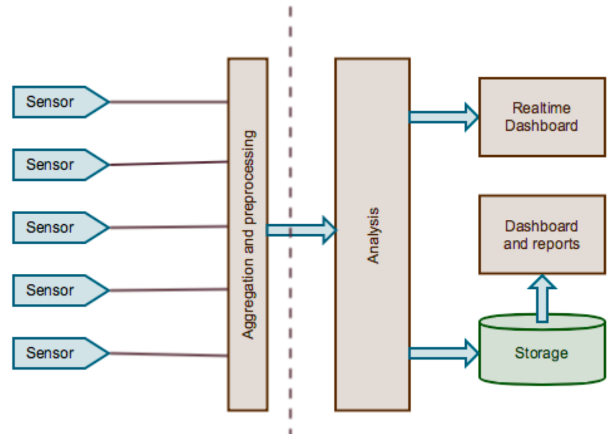

Figure 1. Sensor network, analyzing and visualization architecture

III. APPLYING ANALYTICS AND VISUALISATION 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 world wide web and the large amounts of data generated from the web [26].

A review of data mining literature between 2000 and 2011 reveals that a number of different areas have been developed, which can all be used for various types of analysis [26]:

- 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 [27]. 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 [28]. A similar study mines data from the location-based social network FourSquare to identify under-developed neighborhoods [29].

De Amicis et al. [30] 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 [31]. Another study uses sensor data to model traffic noise and predict the areas that were most likely to experience noise on a given day [32].

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 [33].

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 Fig. 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 [34] 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. [12] presents a framework for smart city initiatives, which is separated into internal and external factors (Fig. 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.

Our objective is to create a research project where environmental 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. We have already made a mobile platform for environmental monitoring, and the first step will be to use this platform to help decision makers make better decisions on restricting car use when pollution levels are high. With this in mind, the framework of Chourabi et al. [12] can be used for the initial project planning:

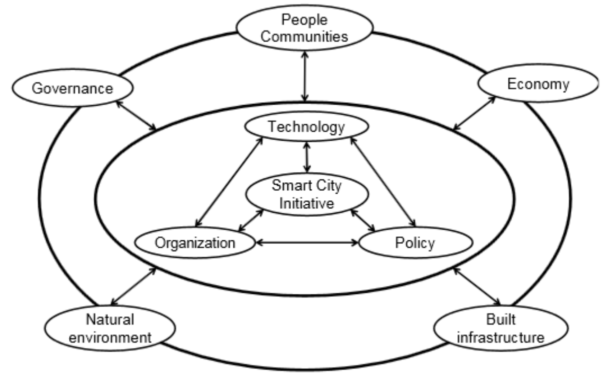

Figure 2. The Smart City Initiatives framework [12].

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. Further, it is a political goal that even if the region becomes more integrated, emissions from transport should not increase. Thus, smart solutions for transport planning and environmental monitoring will be an essential part of the project. 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 Raspberry Pi, Intel Edison, Arduino, NodeMCU 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.

Technological challenges include IT skills of the end users, and issues related to organizational culture [35]. In Norway the population generally has good IT skills, so this challenge is not a major one. Setting up and creating the sensor platforms is another challenge. The project partner from Romania (LBUS) has long experience with embedded systems design, and is responsible for creating the sensor systems. The project partner from Norway (USN) has done several technology projects in collaboration with local cities and municipalities, and has focus on collecting, analyzing and visualizing data.

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 sensor platforms. Local media could also be a partner in recruiting "human sensors" to collect information.

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 [12]. The region where 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 [12]. The cities we are trying to set up our project with 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 and pollution, 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 NO_X 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 Jancic [36].

Participation and collaboration between government, citizens and organizations is seen as essential in the development of smart communities [37]. Many of the activities (parks and recreation, planning and community development) typically involved in smart city projects can benefit greatly from citizen participation [38], and there is a clear correlation between cities' adoption and implementation of sustainability policies and public participation in policy formulation [38].

In addition to smart city benefits, many researchers and political theorists see political participation as essential for democracy [39]. By engaging more citizens in political processes, they will take more responsibility for their own situation, and contribute more to society. Simultaneously, other research [40] has shown that citizens are not that interested in participating. Their main interest is that government provides services in a good way.

This latter view finds support in evaluations of participation studies. There have been many initiatives to utilize electronic communication to improve participation. However, citizens tend to remain passive [41]. Those who report to be active participants in democratic processes only make up a small percentage of the population [42]. Thus, Hibbing and Theiss-Morse [40] argue for so-called "stealth democracy", where citizen input is collected in other ways than through direct and active participation.

While active participation is difficult, people can be willing to contribute in other ways. Decision-makers can implement passive crowdsourcing, which requires less commitment and time than other forms of participation [43]. This can be done by using sensors and smartphones, coupled with analytics software that provides important data for decision-makers as outlined in the previous Sections. Passive crowdsourcing is an important part of the project we report on in Section V.

However, active participation is also necessary in order to create useable applications that will encourage people to become "passive participants". 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 [44]. 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 1. Dimensions and indicators of user involvement

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. Experiences from a Pilot Project: A Mobile Platform for Environmental Monitoring

In this Section, we present experiences from our pilot project to design and develop a mobile platform for environmental monitoring. Many cities have problems related to air quality. In discussions with city administrators and politicians, we found that environmental monitoring is high on their agendas.

The Norwegian cities of Oslo and Bergen experience severe problems with air quality, especially during the winter season. The two cities have implemented regulatory measures to reduce the emission of pollutants. When pollution levels are high, the City of Bergen restricts the use of cars based on the last digit of the number plates. In Oslo, the city will be closed for cars with diesel engines on days with high pollution levels. Romanian cities, in particular Bucharest, experience high pollution levels due to heavy traffic. The problem is global, with most big cities reporting environmental problems.

Air quality is commonly monitored by use of stationary units. Such stationary units are expensive, and provide data with low granularity. The stationary units are located throughout the city, but the number of units is small (e.g., the City of Oslo has 12 such stationary units). This low granularity has led to criticism from motorists, who claim that air quality measurements are not reflecting the actual level of pollution, only the level of pollution in a few selected areas. Thus, having more measurements from more locations can help justify policy measures to reduce emissions on days with high pollution. In addition, people who experience health problems due to pollution can use these numbers to avoid staying in, or travelling to, high pollution areas.

A. *The Pilot Project*

The main objective of the pilot project was to design and develop an inexpensive environmental monitoring unit using off-the-shelf components to be deployed in cars. The cities own a lot of cars, and they are regularly parked throughout the city. One example is the cars used by the home care service. The caregivers park their cars when visiting patients, and moves from one location to the next at regular intervals.

In the pilot project we built a prototype of the environmental monitoring platform, and secured funding for production of twenty units to be deployed in cars. These twenty units will allow us to demonstrate the practical usefulness of our mobile platform, and also provide a platform for further research and additional funding.

B. *Project Partners and their Expertise*

"Lucian Blaga" University of Sibiu (LBUS) has been working on embedded systems for many years, developing an application that keeps track of people inside a building based on collecting data from sensors [45] and using artificial intelligence tools to model energy consumption in buildings based on alternative data sources, such as the number of vehicles in a parking lot. LBUS experience related to smart buildings concept was materialized in development of a PLC-based embedded system that aims to automate processes and reducing the house energy consumption by optimizing the entire hardware assembly and software algorithms [46].

University College of Southeast Norway (USN) has a research group focusing on "smart cities". Smart cities use technology to improve services and the quality of life for citizens. The smart cities research is well aligned with the embedded systems expertise of LBUS. USN has also collaborated with cities and municipalities on many technology related projects.

C. *Related Work*

The pilot project included a literature search to find related projects and developments. We found examples of mobile environmental monitoring units, and a couple projects related to monitoring by cars:

The Green Watch project [16] distributed 200 smart devices to citizens of Paris. The devices sensed ozone and noise levels as the participants walked the streets of Paris.

CITI-SENSE, a project funded by the European Union, developed LEO (Little Environmental Observatory), a hand-held environmental monitoring unit [48]. This unit monitors three gases (nitrogen dioxide, nitrogen monoxide and ozone), as well as temperature and humidity. CITI-SENSE targeted people living in nine participating cities – Barcelona (Spain), Belgrade (Serbia), Edinburgh (UK), Haifa (Israel), Ljubljana (Slovenia), Ostrava (Czech Republic), Oslo (Norway), Vienna (Austria) and Vitoria (Spain).

A research team from South Korea used a dedicated van containing environmental measurement equipment [47]. The van can be driven to locations where measurements are wanted.

As mentioned before, Bröring et al. demonstrated the use of the OBD-II [17] interface connector to collect information from the car itself (velocity, fuel consumption).

We have not found anyone pursuing the idea of using parked cars as sensor platforms. Such solution will provide more data and better granularity than existing solutions. Further, the similar projects we have identified are all large, well-funded and to varying degrees relying on expensive production processes. We demonstrate that projects such as these can be done in a low-cost way, using off the shelf hardware and a bit of creativity.

D. The Prototype

Our prototype used Intel Edison combined with sensors (air quality, temperature, humidity barometric pressure, noise) and a GPS receiver. The communication with the server was done through an Android phone. The Intel Edison used the built-in Bluetooth to communicate with the phone.

The prototype was tested and evaluated. The feedback made us reconsider the use of an Android phone for communication. It requires the phone owner to install and configure an app, and also pay for the data traffic. A dedicated phone would be expensive, and many city employees would object to use their own mobile phones. It would also exclude iPhone owners. The noise sensor did not provide useful information when sampled at intervals. Noise is contextual. A large truck passing the sensor at the right moment may give a very high reading. The Intel Edison processor is also quite expensive compared to alternatives.

Based on our experiences with the prototype, we have redesigned our environmental monitoring unit. The new version uses a LinkIt Smart 7688 Duo with two processors. The main processor is running the OpenWrt Linux distribution and will handle communication and location data from the GPS receiver. The second processor is compatible with Arduino, and handles the sensors. We also decided to include a GSM mobile data unit to avoid the use of an Android phone. A dust particle sensor replaced the noise sensor. Fig. 3 shows the architecture of the environmental monitoring unit. A total of sixteen units have been produced for field testing.

Whenever the car is parked the environmental monitoring unit will start sending environmental data to a server at regular intervals. This allows us to collect information from many different locations, and thus provide a much better granularity than existing solutions.

E. Platform Design

After launching the software (at boot-up), the platform needs about three minutes for heating and calibrating the air quality sensor. The Arduino compatible processor will then start collecting information from the sensors (air quality, dust particles, temperature, humidity and barometric pressure). The other processor, running Linux, will collect location and time from the GPS, and connect to the server. The Linux application will then collect data from the Arduino part, and send the data to the server.

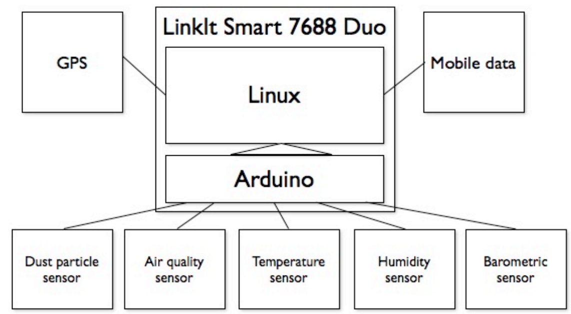

Figure 3. Environmental Monitoring Unit Architecture.

F. The results and project impact

The pilot shows the possibility of making affordable units based on off-the-shelf technology. Twenty units will be enough to show the feasibility of our proposed solution. The increased granularity of measurements will help decision makers making better decisions, and will be important to identify specific locations with air quality problems.

The "proof of concept" prototypes will be used for experiments, but more important to pave the road for a larger joint project on data analytics and visualization of collected environmental data.

The results will be available on a web site, and citizens can use the results to avoid exposure to high levels of pollution. This is of particular value to citizens suffering medical conditions like asthma. Citizen can put pressure on politicians to reduce pollution levels. Politicians and city administration can use the results to explain the necessity of using regulatory measures to reduce traffic when environmental conditions are bad. The results may also be an instrument to make citizens aware of the need to cut down the car energy consumption and reduce their carbon footprint.

The platform can be used for other purposes. It can be used as an inexpensive stationary unit attached to buildings and other structures. By changing the sensors, it can also be used to measure water pollution, to monitor patients in their homes or to make buildings and houses more safe and secure. In such cases most of the software can be reused. It is our hope that this demonstration and platform can motivate others to follow their own ideas for how sensors can be applied.

VI. DISCUSSION – A USER CENTERED RESEARCH DESIGN

In Section IV, we presented the Chourabi et al. [12] framework for smart cities, and applied it to our project in order to identify challenges that will have to be addressed. Analyzing these challenges, it became apparent that all of them were related to user involvement and stakeholder management in one way or another.

The technologies we use demand a certain set of skills that can be met by involving our project partners from analytics and engineering.

Organizing the project across different municipalities is another challenge, and again user involvement/stakeholders are important for resolving the challenge, as there is an existing partnership between the municipalities, where we have access to key stakeholders.

Addressing the people and communities factors requires citizens who are willing the act as human sensors, by installing the sensor pack in their cars and contributing to a cleaner environment.

Finally, economy and infrastructure challenges include the region's slow growth, and the scattered knowledge hubs located in different cities in the region. Local knowledge about where to find the skills is necessary and it is also essential to set up a regional network of partners in order to fulfil the overall project goal of creating a more integrated and green region.

VII. Conclusion and Implications

In this paper, we propose a research design for smart city projects using sensors 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. [12] 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.

Finally, we present findings from a pilot project that has followed our approach, in order to demonstrate its relevance.

Implications for research: we contribute towards testing the Chourabi et al. framework [12] in a real life setting, verifying that the framework is useful for analyzing smart city projects, and uncovering challenges and obstacles that needs to be overcome in order to create successful smart city projects. Further, we show the need for user involvement in these projects, and present an example of a research design that might be useful for other research projects in the future.

Implications for practice: we show that the factors put forth by Chourabi et al. [12] are indeed important to address, and suggest that the best way of addressing them is by involving key stakeholders, and by utilizing the power of the crowd by having citizens act as "human sensors". Further, we address issues related to the granularity of existing air quality measurements. Current sensors for measuring air quality are few and far between. Most Norwegian cities only have one or two locations. Pollution can be a very localized phenomenon, restricted to certain areas because of buildings, winds, density of traffic and many other reasons. By fitting cars with sensors we are able to get measurements from many different areas, and can therefore create real time pollution maps with a much higher level of detail than those currently being made. This can be of great help to population groups such as parents with small children, asthmatics and people with allergies, as they can access data about polluted areas and make plans to avoid these if necessary.

Finally, and most importantly, we show that sensors can be deployed at low cost. There are other projects similar to ours that use sensors to measure pollution and other variables (see for example the citi-sense project, http://www.citi-sense.eu/), but those are large, EU-funded projects. We demonstrate that by using off-the-shelf technology and some creative assembly, it is possible to reach the same results with fewer resources. For low- and middle-income countries, cost is an important issue.

Limitations and further research: First, while we have finished part of the project and report on this here, this is still but a small piece of the entire project proposal. We need to conduct further research in order to address the entire scope of the project (creating a more integrated and greener region). In the next phase of the project, which is currently underway, we will build and deploy the 20 sensor sets we have received funding to build. After having been deployed for some time, we can experiment with the proper tools and techniques for analyzing the data. Later research articles will present the findings from these phases of the project.

Despite these limitations, our current progress is promising, and demonstrates how smart technology can contribute towards a better future for cities and their inhabitants, in an inexpensive way.

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