SenCity - Piloting Intelligent Lighting and User-Oriented Services in Complex Smart City Environments

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New operation frameworks and user-oriented design methods are needed to make better use of new innovative technologies within smart city contexts. This paper addresses the design and research of intelligent lighting and user-oriented services for smart city environments. It presents the problem setting and research and development methods of the SenCity project. The project will pilot smart lighting solutions in six Finnish cities in different kinds of urban environments. In the pilots, the target is to employ lighting infrastructure as a service platform - an Internet of Things backbone - in the intelligent city. Together, separate pilots in different cities around Finland will create a living lab ecosystem for developing and testing innovative solutions. The specific objective of this paper is to present the concept of a platform as defined and applied in SenCity project. The presented framework forms an operational model for creating intelligent lighting and digital services in smart cities by integrating relevant technologies, users' needs, and business into an interactive system. In the paper, the framework is applied to a selection of pilot cases with specific themes to introduce its usability in real world implementations.

Keywords: *smart city, sensing, intelligent lighting, smart lighting, user-oriented design*

INTRODUCTION

The world-wide interest to smart city development as well as impetus to implement intelligent lighting solutions for energy savings is opening up new collaboration patterns between urban development, research and business. New operational frameworks and user-oriented design methods are needed to make better use of new innovative technologies. This paper addresses the design and research of intelligent lighting and user-oriented services for smart city environments. It presents the problem statement and research and development methods of the project "SenCity - Intelligent lighting as a Service Platform for Innovative Cities". The project pilots smart lighting solutions in six Finnish cities in different kinds of urban environments. The research has three focus areas: 1) to study users' needs and experiences of intelligent lighting, 2) to develop and test sensoring, data analysis and communication methods and technologies needed for the user-centric designs, and 3) to generate business opportunities for smart, data-based services. In the pilots, the aim is to employ lighting infrastructure as a service platform - an Internet of Things backbone - in an intelligent city. Together, separate pilots in different cities around Finland will also create a living lab ecosystem for developing and testing innovative solutions in the future. The SenCity project group consisting of research institutions, cities, and companies is presented in Figure 1.

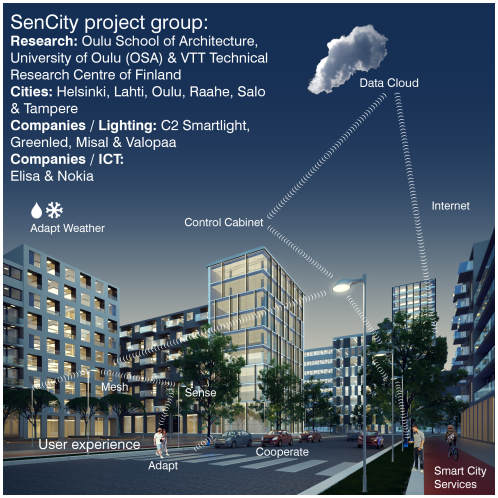


Figure 1
SenCity project pilots intelligent lighting and smart services in different kinds of urban contexts.

Intelligent lighting

Intelligent lighting, or smart lighting, can be defined as a lighting system which gains real-time information of its environment and users through sensors, and adapts its behavior accordingly. The information is analysed and processed in the system into lighting control commands based on pre-defined parametres and rules (Guo 2008). The principle in itself is simple but the complex real world setting, i.e. the city with its inhabitants, renders the design task highly complex. Thus, it is important to reflect upon what the users' needs are in different kinds of environments, what kind of information is relevant for the users' needs, how the information can be analysed and how lighting should behave to best serve users' needs. In order for lighting to be truly intelligent, not only the system should be smart but the overall design should be smart as well: Intelligent lighting can, besides energy savings, offer added value for urban environments on various levels of experience. (Pihlajaniemi 2016.) However, even though almost everything is possible with new technology, it is challenging to find technologically reliable and economically feasible means to operate in complex environments which have many changing factors. How can we strike a balance between the desired simplicity of a system and the complexity of the design task?

Technologically, intelligent lighting can be seen as part of a larger Internet of Things (IoT) development. IoT can be defined as an intelligent and interoperable node interconnected in a dynamic global infrastructure network. IoT means connecting everything around us, such as household devices, mobile phones, cars, even cities and roads, to the Internet and/or to each other. As such, IoT seeks to implement the connectivity concept of anything from anywhere at any time (Ali et al. 2015). This leads us to our broader research context: smart cities.

Smart City development - From technology towards better urban living

According to the large number of varying definitions found in literature, a smart city is a combination of modern ICT technology, economic ambitions, and social and communal objectives in urban environments. Due to increasing environmental awareness and economic and social importance of cities, more and more focus has shifted from technology to people and community. Besides conserving natural resources, the opportunities for increasing the quality of urban living, regarding city administration, education, healthcare, public safety, real estate, or transportation for example, have been recognized. Also, sustainable economic growth more related to modern technology and services is considered important in the current smart city environment. (Albino et al. 2015.)

The interest on smart city development is global. For example, India has a grand project of developing 100 smart cities, while Masdar City in United Arab Emirates and Songdo in South Korea have launched projects of their own. Also, South Africa has a smart city project in Modderfontein. In Europe, the development towards smart cities is active, and several European cities, like Amsterdam in Netherlands, Santander in Spain, Lyon in France, and Morgenstadt in Germany are investing to develop into smart cities. (Frost & Sullivan 2015) Amsterdam with dozens of smart city related projects is an interesting example of European activities. Somewhat similar to our project, in Amsterdam, smart lighting is implemented with sensors to control street lighting and the lighting infrastructure is also used for services beyond the lighting functionality. For example, traffic flows are controlled with help of coloured lighting. In addition, a smart lamp post has been sketched with functions like sensing various data such as pedestrian count or environmental data, communication, assisting in navigation, and delivering notifications, alerts and advertising. [1] An energy provider, Alliander, has an "Open Smart Grid Platform" which allows using and managing of different objects independent of the different suppliers. The Alliander's system has been employed on lighting control in Amsterdam. [2], [3] Also in Santander, there are over 25,000 wireless devices over the town monitoring the environment. The sensors help in lighting control, planning of garbage collection, tracking traffic, and monitoring air quality [4]. The project has reduced energy costs by 25% and garbage pickup costs 20% [5].

The smart city development already carried out around the world sets good reference to our objectives in the SenCity project. In addition to the smart city definitions and actual implementations discussed above, there is also a literature which examines smart cities in a more critical light. When examining this literature, the crux of the issue seems to be the lack of participation and democracy in the field of smart city development, both on the level of viewpoints and practices. (Kitchin 2014, Hollands 2008) To surmount these issues, the operational framework that is utilized in the SenCity project, is introduced.

OBJECTIVES AND METHODS

The general objective of the SenCity project is to pilot intelligent lighting solutions and to employ lighting infrastructure as a platform for user-oriented services in different kinds of smart city environments. The pilots vary in complexity level concerning both design and research targets. The specific objective of this paper is to present the concept of a platform as defined and applied in the SenCity project. The presented framework forms an operational model for creating intelligent lighting and digital services in smart cities by integrating relevant technologies, users' needs, stakeholders, and business into an interactive system. In the article, the general framework of the platform is presented. In addition, the framework is applied to a selection of pilot cases with specific themes to introduce its usability in real world implementations.

The pilot cases are presented discussing design and research aims and methods to be applied. The relevant users' needs and users' experience aspects, technological needs, stakeholders and service related business potential are presented. The pilot projects will be realized and evaluated between summer 2016 and autumn 2017. Those results will be published in the future.

Methodologically, the basis of our research can be found in traditions of research-by-design, qualitative research and technological research. Our research can be defined as transdisciplinary research, referring to Gibbons et al. (1994). The research subject concerns various research disciplines such as research of lighting design and experience, architectural research, engineering and HCI. Typical to all of these disciplines is that their research problems are not usually set within a one singular disciplinary framework. In addition, the research problem and knowledge production operates within a context of practice. In the research process, the framework of methods is being developed and modified throughout the process to respond to the needs of research and to the clarified research questions. The research follows a mixed-method or combined strategies approach, where multiple methods from diverse traditions are applied in a single research endeavour. This approach is suitable for researching complex phenomena, as in this case intelligent lighting solutions and digital services in smart city contexts. Each method brings with its particular strengths and weaknesses and "combining methods provides appropriate checks against the weak points in each, while simultaneously enabling the benefits to complement each other." (Groat and Wang 2013)

SENCITY PLATFORM: GENERAL FAMEWORK FOR USER EXPERIENCES, INNOVATIONS AND BUSINESS

In the cityscape, lighting is always utilized along routes, where people move, and within areas, where people spend time and act. With intelligent lighting this will mean that, in the cities, a relatively evenly distributed network of electricity supply as well as communication exists near people. These networks can be employed for integrating different kinds of sensors which gain and analyze data in real-time for smart city services. This forms the starting point for the SenCity project and the technological core of the platform concept (see Figure 2). The **Technology node** of the framework consists of both the hardware and software, which form the smart infrastructure of the cities, enabling lighting control, gathering sensor and other type of data, communication as well as data analysis and fusion. This infrastructure is partly lighting control related, but can serve other purposes, too.

Smart technology offers endless potential. However, it is useless if it does not meet users' needs. Thus, in the framework, we have situated users' needs and experiences as a **User node** parallel to Technology node. The pilots are designed applying user-oriented and participatory design methods, such as scenario working, workshops with users, and cultural probes. Networking with relevant stakeholders as well as communication are part of understanding the users' needs and anticipated users' experiences of piloted lighting and services. Evaluation of users' experiences of each pilot is a central part of our process, as it provides feedback applicable in further design iterations and has value as such from research perspectives.

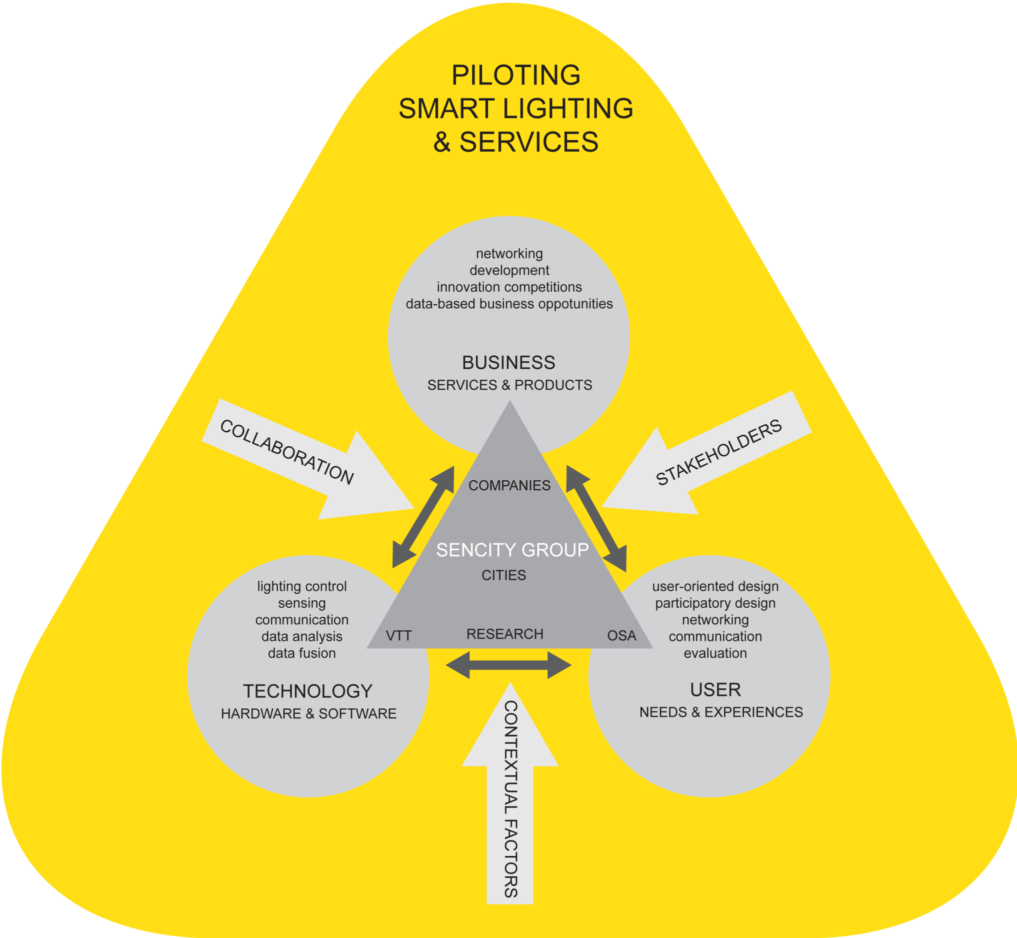
A deep understanding of users' needs helps companies develop smart technology to serve cities' aims about better urban living and sustainable service and maintenance processes. Boosting economy in the pilot regions by providing new types of business opportunities based on data is one of the focus areas in piloting, thus forming the third node, i.e. **Business**, in the framework. The methods for this are connecting developers with their customers, supporting development projects and providing test and piloting opportunities for new products and services, arranging innovation competitions, and generating data for data-based business opportunities.

In the framework, the SenCity group with its partner cities, companies, and research units, connect three focus nodes with interactive collaboration, creating new links between technology, users, and business. The project collaborates with other relating research projects and negotiates with relevant stakeholders, for example, city and business organizations and communities. Contextual factors of each pilot areas, such as environmental conditions, regulations and social and cultural patterns, set requirements for pilots as well as offer possibilities.

PILOTING IN SMART CITY CONTEXTS

In the SenCity project, each pilot project has a focus on a different theme or application context. The themes and contexts include: presence-based bicycle route lighting, traffic safety of pedestrians in crossings and housing areas, data harvesting and ap-

Figure 2
General framework of the SenCity platform concept.



plication, educational outdoor environment, as well as guiding and informative route lighting. The pilots vary in complexity level concerning both design and research targets. In this section, three pilot contexts are scrutinized through the aforementioned framework. The themes are Traffic environment and safety, Big data in road environments, and Smart lighting and services for educational outdoor environment.

Case 1: Smart applications for safe traffic environment

This case presentation (see Figure 3) combines features of three pilot projects, which will be conducted in different kinds of traffic environments in three cities. From a users' experience perspective, the focus in all the pilots is enhancing traffic safety and enabling safe and comfortable moving by foot or by

Figure 3
Framework of SenCity platform application with the Case 1: Safety in traffic environments.

bike. At the moment, energy savings are sought in outdoor lighting by intelligent control and presence-sensing and this should not affect safety or sense of security negatively.

A pilot in Helsinki will approach intelligent lighting on the simplest level, setting a singular research or development target: What kind of a detailed lighting behavior is suitable for presence-based lighting on bicycle routes? The aim is to design and test optimal lighting behavior which saves substantial amounts of energy without lessening cycling safety or the sense of security of the route users during the dark. Two well-designed lighting behaviors will be tested: the one will be perceptible by route users and the other imperceptible. Feedback of the real world pilot will be collected from cyclists and walkers as well as from people living near-by with interviews and questionnaires. Technically, the pilot will develop and test the ability to detect direction of the movement. Otherwise, already existing lighting control products and technology will be applied.

Another pilot, in the city of Salo, will be carried out on a collector road of a housing area. In this case, presence data will not be used to adjust illumination for every road user individually. However, the presence data will be averaged over a certain timeslot and used to dynamically control illumination instead of a fixed dimming schedule currently applied in Finnish cities. Similar to previous example, feedback will be collected from the area inhabitants and the technical implementation will be based on commercially available components.

Due to several recent accidents, the issue of traffic safety in pedestrian crossings is unfortunately very topical in Finland at the moment. Alerting lighting behavior could be used to enhance safety in crossroads or in housing areas with lots of kids playing in the neighbourhood. This requires that the lighting system recognizes the presence of pedestrians and even profiles the risk group - young children. In the pilot implementation in Raahe, we will study different scenarios of intelligent lighting behavior in such context. Even though in our research, the focus is in real world testing, in this case, virtual modelling could be applied for safety reasons in researching users' experiences of different kind of alerting lighting behavior. Traffic environment has many bright objects, illuminated elements, and signal lights already presently. Thus, it is important to study the visual load and legibility of this kind of a new informative lighting layer. In real world implementation, the research will focus on technical aspect of how to identify different road users, vehicles, and pedestrians for example.

Case 2: Big data in road environment

There is already lots of information available about Finnish cities. For example, traffic lights in city centers are known to adapt based on traffic conditions and emergency vehicles. Buses communicate their location through GPS and their routes can be followed in screens and by mobile devices. [6] Besides that, buses can be attached with different kind of sensors, thus, creating a mobile sensoring network system of real-time environmental data in different districts of the city [7]. Beyond the transport examples, also environmental information, such as open weather data, is already available [8]. In our pilots, combining this information to intelligent lighting control is studied. In practice this requires collecting and combining available data, and transforming it as a lighting control message. In Finland, roads can be very slippery at winter time causing significant risk of accidents for both the vehicles and pedestrians. So, an interesting case example is to combine slipperiness data from the bus and/or weather service and to utilize lighting infrastructure to deliver warning to road users. The research combines two aspects: technical aspect of collecting and delivering the data to the correct location in the city, and the user aspect how to communicate the information with acceptable and understandable way.

Today, the typical approach is to monitor in road environments, for example, traffic density, with rather expensive and extensive computing demanding camera or radar based solutions, which are installed only in critical locations of the road network. In our project, the research objective is to study the ubiquitous sensing as an alternative to these kinds of solutions. Sensors will be integrated with the luminaires and use the lighting control system as their communication network. The approach is to use simple, low cost sensors and wide geographical coverage over the pilot installation. In practice, this means that a sensing device will locate at every lamp post, and the data that a single sensor generates is simple enough to be delivered through the lighting control system's communication method. As a result, the installations will generate local data in the road environment to be transferred to the cloud for further analysis and fusion with other information available. The research approach is not to pre-define specific events or circumstances, such as accident, snow, or a traffic density, to be detected. Instead, the pilot installations are designed to sense road environment with versatility, and the generated data is analyzed to study which kinds of events can be identified. The pilot implementations will follow this approach in several locations, for example, in Tampere and Salo, and the research serves to communicate the benefits and opportunities of constantly increasing IoT solutions to different stakeholders in road lighting community with concrete examples.

Besides generating data for the research, the ubiquitous sensing will be used to deliver energy savings to the cities and new services to the end users. The presence data will be used to implement presence-based lighting as described above. Also, it is anticipated that collected data will be useful for city operations, for example, for road maintenance. As a part of our research, we will carry out a survey in city organizations in order to discover needs and identify most potential utilizers of the smart city data that is available with the ubiquitous IoT approach. Finding potential use cases and needs will help to generate new data-based business. The framework of this pilot case concerning big data in road environments is presented in Figure 4.

Case 3: Smart lighting and services for educational outdoor environment

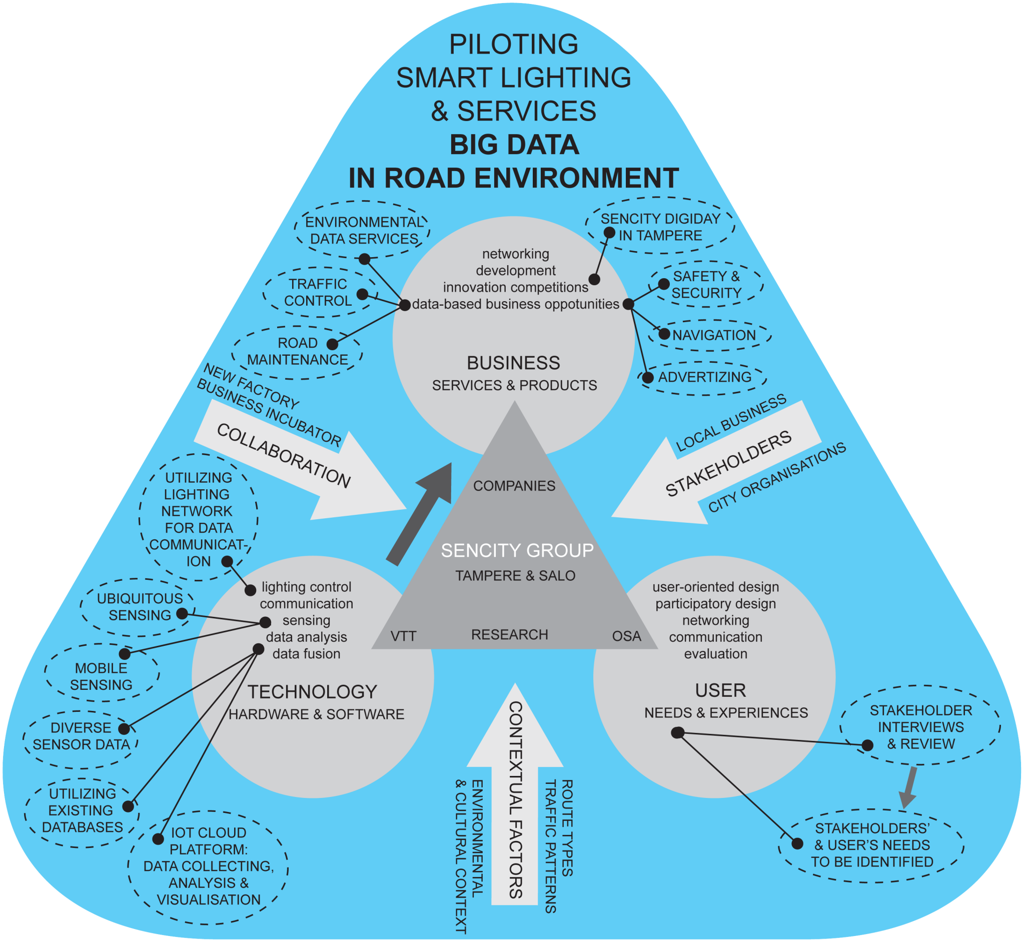
In the city of Oulu, our pilot will concern the outdoor area for Educational, leisure and culture centre in the Metsokangas area. The community centre consists of several buildings containing mainly educational facilities for primary and secondary schools and will eventually host 1500 pupils with all its extensions. Other services, which are located in the buildings, are kindergarten and communal and sports facilities.

The Finnish National Board of Education has confirmed the new core curriculum for basic education and it will be introduced in schools in August 2016. The new core curriculum emphasizes the joy of learning and the pupils´ active role [9]. Smart city solutions can bring sensor data to digital learning environments and school yards can become active learning environments during school days and leisure time.

In the piloting (see Figure 5), understanding the users' needs has had a major role, and during the winter 2015-2016, a participatory design process has been carried out. The phases of the process have been cultural probe tasks (Gaver et al. 1999) for both personnel and pupils, interviews, scenario working (Rosson and Carrol 2002) and an on-line questionnaire. The cultural probes and interviews provided us with teachers' and pupils' analysis of the current situation and activities in the yard and its lighting conditions and development ideas. The scenarios were based on that material, as well as on state-of-the-art research. They describe with short stories and comic strips different ways to implement smart outdoor lighting and digital services as part of the every-day life of the school. In the scenarios, intelligent lighting applications had several motivations in school yards. Besides energy savings, lighting can orchestrate children's actions in the school yard, for example, inform pupils of right routes, game areas, passing of time, and attract them to physical exercise. Lighting connected with digital services can extend educational environment from classroom to the yard and digitally augment the familiar outdoor space adding new educational contents there. Children and teachers can interact with light as well as play and create with coloured light. In addition, the scenarios covered also ideas of digital services related not to lighting but to, for example, maintenance and space management, enhancing security and virtual education. Finally, with the help of on-line questionnaire, we got feedback about the scenarios from parents, teachers, and pupils, which will helps us to develop further the designs for piloting. The participation process will still continue. After realization of the pilot in the summer 2017, we will evaluate the results with qualitative methods to gain feedback from experiences.

Technologically, the pilot implementation requires producing intelligently controlled general lighting and effect lighting using RGBW spotlights.

Figure 4
Framework of SenCity platform application with the Case 2: Big data in road environments.



Also, there is an interest on testing the pilot implementation infrastructure as an installation site for fast data communication and computing for future digital services, for example, a virtual reality learning aid, which will have many users at the same time. Other technological research aspects, such as user recognition, presence monitoring, and needed IoT cloud solutions, will be clarified during the continuation of the pilot design.

To generate business and interest on smart services development beyond our own project activities, we will arrange an innovation competition for Oulu area ICT start-ups. This is a method to boost local business activity with long tradition in ICT field. The competition will be arranged in collaboration with another project 6Aika which aims at develop-

Figure 5
Framework of SenCity platform application with the Case 3: Educational outdoor environment.

ing an open innovation platform for smart city operations and business. The same approach was taken also in Tampere and Lahti, where our project has already organized similar events with local actors with good results.

DISCUSSION

In general, the SenCity framework of a three node platform has so far proved to be useful and effective in creating collaboration between partners in order to develop intelligent lighting solutions and smart city services and we will expect interesting results from the pilots. The project is challenging, as it has many participating cities and companies with varying interests. Our method in addressing this complexity - the plethora of diverse starting points and interests - has been choosing different focus themes for the pilot areas, which will complement each other in the end. This living lab environment, the testing platform which combines the results of each pilot case, will eventually serve all participating cities and companies and build a coherent picture of a smart city.

Answering to the former critique against smart city concept (Kitchin 2014, Hollands 2008), we have emphasized users' role in the piloting processes and in the platform framework. Understanding the users' needs and experiences forms one of the three nodes in the piloting processes, interacting with technology and business, which are the other two focus areas. With participatory design methods, we have brought the users into the design processes as our partners. Metsokangas school pilot in Oulu is a good example of that kind of process. The community has actively participated in all the phases and is waiting the realization with great expectations. The process has provided us with many good ideas as well as critical viewpoints to be taken care of in further development, concerning, for example, privacy issues. Both industry and city partners are keen on understanding users' experiences and finding ways to serve users' needs.

From our processes so far, we can indicate that the business aspect in relation to genuine user needs is quite crucial in developing smart city solutions. It has partly been challenging to find motivations for investing in smart infrastructure, which goes beyond already used lighting control technologies, due to typically higher purchase costs and lack of practical use cases of smart data-based services. Changing to LED lighting with time-related dimming or presence-sensing, is already saving substantial amount of energy and costs. These functionalities, which are easily justified with energy savings, do not in itself need great capacities of local data communication and computing, which many more developed IoT solutions and smart city applications demand. In our pilot contexts, the critical point seems to be finding those service concepts and business actors which really would find the users, develop scalable and successful business, and pay cities back for building and maintaining the infrastructure - sensor networks and fast communication - necessary for the services.

Reflecting the three case studies presented it can be noted that even though there is always interaction between all the nodes of the framework, there can be seen different main drivers for the pilot development (see the dark grey arrows in Figures 3, 4, and 5). In the case 1, the clear initiator is found in users' needs, which in the selected pilot contexts, obviously are related to safety issues. The framing of the research question as well as methods has been kept relatively simple. The piloting in those sites aims at testing and finding suitable and reliable solutions to support experiences of safety in traffic environments, and the technological research and development clearly follow that driver. Then, the case 2, which concerns big data in road environments, can be considered as technology-driven. Technologically, the complexity level is in that case higher, and that will eventually lead to a bunch of user and business related research questions. However, in that case the main method is to start with implementing a wide range of sensor and data fusion technology to see what new applications and use cases will emerge from analyses of the complex data. The process will be supported with stakeholder interviews to find potential application areas. Thinking about user aspects in the case 3, the context of the case - an educational and community centre - could almost be compared in complexity level to a small scale "smart village" with its functionalities and user groups. Thus, here the main driver for development was chosen to be the understanding of the variety of users' needs whereas technology and business development goals are subordinate to that analysis.

Although the business aspect may seem to lack attention in defining the drivers in our research, it is well understood that in the end the success in business, or in economy in general, is a relevant point of view. After the finalized pilot implementations and evaluation processes, we will be able to analyse the results and reflect the success of chosen drivers for piloting. This will presumably complement the general framework with new clarifying, context-related interaction factors between the three nodes: technology, user and business.

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