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SENCITY – EVALUATING USERS' EXPERIENCES OF INTELLIGENT LIGHTING FOR WELL-BEING IN SMART CITIES*

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ABSTRACT

This paper presents the evaluation of users' experiences in three intelligent lighting pilots in Finland. Two of the case studies are related to the use of intelligent lighting in different kinds of traffic areas, having emphasis on aspects of visibility, traffic and movement safety, and sense of security. The last case study presents a more complex view to the experience of intelligent lighting in smart city contexts. The evaluation methods, tailored to each pilot context, include questionnaires, an urban dashboard, in-situ interviews and observations, evaluation probes, and system data analyses. The applicability of the selected and tested methods is discussed reflecting the process and achieved results.

Keywords*:* evaluation, intelligent lighting, method, smart lighting, user experience

I. INTRODUCTION

Applications of intelligent or smart lighting will be spreading in the near future to various types of urban context. If designed wisely, smart lighting can, besides energy savings, offer added value for urban environments on various levels of experience [1]. However, as the implementations are still rather rare and recent, there is a lack of knowledge on user's experiences to support design processes. Thus, in our research and development, we aim to increase understanding of user's multifaceted experience of intelligent lighting and of the methods for evaluating it.

1.1. SenCity Project

SenCity – Intelligent Lighting as a Service Platform for Innovative Cities is a national research and development project between Finnish cities, companies and research partners [2]. The project aims at employing lighting infrastructure as a service platform – an IoT (Internet of Things) backbone – for smart lighting solutions and innovative, user-oriented services in urban environments. The project develops intelligent LED lighting pilots in the participating cities, to which the companies involved develop solutions to better respond to the cities' needs. The research partners integrate the project together through the design of pilot contents and realization, user experience evaluation and technical development and testing.

The project pilots smart lighting solutions in six Finnish cities in different kinds of urban environments. The research focus is dual: to study user needs and experiences of smart solutions, and to develop and test technology needed for such solutions. Together, separate pilots in different cities around Finland create a living lab ecosystem for developing and testing innovative solutions. Each pilot has a focus in a different theme or application con-

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text. The themes include interactive and communicative lighting and digital services; traffic safety in a residential area; smart lighting and services for kids and young people; and presence-based lighting in bicycle routes and road environments. The pilots are realized in 2016–2018. As the pilots have varying research focuses and contexts, the SenCity project provides an excellent opportunity to test different kind of evaluation methods in real world contexts.

1.2. Aims and Content

In the paper, three pilot case studies are introduced presenting objectives, contexts, smart lighting applications, and methods that are used in evaluation of users' experiences. The evaluation methods, which are tailored to each pilot context, include questionnaires, in-situ interviews and observations, evaluation probes, and system data analyses. The applicability of the selected and tested methods to each pilot and its specific context, research target, and user group is discussed reflecting the process and achieved results.

2. EVALUATION OF INTELLIGENT LIGHTING IN URBAN CONTEXTS – PREVIOUS RESEACH ON USERS' EXPERIENCES

There has not yet been wide research of the experience of intelligent lighting in real-world urban contexts, as the lighting solutions are internationally still in the process of development and piloting. However, some previous research exists and some examples can be mentioned here. The research concerning experiences of adaptive and intelligent urban lighting has covered aspects of safety [3,4], social experiences [5, 6, 7] meanings, and [6, 7] atmosphere and aesthetic experience [5, 6], participation [6], and communication [7]. Most of those aforementioned aspects have also been relevant in experiences of media architecture and described, for example, in [8] and [9]. The evaluation methods that have been used, include, for example, a psychophysical method based on questionnaires [3], and semi-structured interviews and observation [6].

Our previous research has related to understanding of the multifaceted and emplaced experiences of adaptive and intelligent urban lighting, covering all the aforementioned aspects [1, 10]. In our real-world studies in park and streetscape environments, we have applied qualitative methods inspired by ethnographic research. These include the experience gauging walking interview method, which means in situ participant observations coupled with a semi-structured walking interview [1,10]. Besides this, we have applied semi-structured interviews and questionnaires in electronic and printed form [11].

3. EXPERIENCE EVALUATION IN THE *SENCITY* PILOTS

In this section, we describe the arrangement and evaluation procedures and methods of three pilot projects, and in the next one, the methods are reflected and discussed. Two of the case studies are related to the use of intelligent lighting in different kinds of traffic areas, having emphasis on aspects of visibility, traffic and movement safety, and sense of security. The last case study presents a more complex view to the issue of intelligent lighting in smart city contexts: How lighting can serve citizens on various levels of experience and what kind of digital services can lighting infrastructure provide for the users? The *SenCity* project is still on-going and all of the evaluation processes are not yet finished. Thus, the presentation and discussion of methods is based to some extent still on evaluation plans.

3.1. Case Study 1: Intelligent Road Lighting in a Housing Area, Salo

The first case study concerns an intelligent lighting pilot in a housing area in Salo, where presence sensitive roadway lighting, adapting both to the motor vehicles using the road and to the measured traffic density along it, was tested. Users' experiences of the lighting have been collected with the help of questionnaires from the community of about 1000 households using the road in their daily traffic as well as from other interested inhabitants of the city. The evaluation was accomplished in three parts. These were connected with different phases in the development of the lighting system, the publicity of the project, and how much information was published about it.

In the first phase (23.1.–5.2.2017), the new lighting was controlled in a very basic way (*Daylight level based control*): during the bright period of the day, lights were turned off, and during the dark period, they were on at 100 % control level. The sensor detected the threshold illuminance level and turned lights on and off automatically. During the second phase (6.2.–26.2.), this basic control continued but a *presence-based dynamic control* was added. The lighting was controlled dynamically so that it was always brightened around a car to the maximum control level of 100 %, and in those parts of the road where the traffic was absent, it was dimmed down to 20 % control level. The dimming and brightening was done softly using 3 seconds ramp. The bright area around a car consisted of five streetlights: the one which detected the car with PIR (passive infrared) sensor and two forward and two backward. In the third phase (lighting control from 6.3. onward, questionnaire 19.6.–2.7.), a third control method was introduced along the two former ones, based on the *measurement of traffic density*. Now the lower control level of lighting was adapting to the amount of traffic detected along the route. When the traffic was dense, for example, during the commutation periods in the morning and in the evening, the control level of lighting was dropped to 70 % on those parts of the road were there was no traffic. With the moderate traffic, the level was 40 %, and with the lowest traffic during the night, it was 20 %.

In the first and in the second phase, the questionnaires used were almost identical. Before answering to the questions, the participants were asked to drive the road with test lighting on during the dark period of the day. There was no sidewalk on the side of the collector road, so we were not able to gain feedback from walkers and cyclists. We asked about the answerers' use of the road and conditions on it during the driving when they evaluated lighting, as the background information. Other questions concerned overall impression of lighting; colour of lighting; amount of lighting on the road surface and on the environment; evenness of lighting; and glare. The participants were also asked how well they could see the roadway and other people moving on the road or in the environment. They could also comment what good was in the lighting, and whether there was something that bothered them in it. In addition, they were asked if they had noticed any changes in the lighting during different times of the day or during driving the test route. The people answering to the second questionnaire were asked whether they had noticed any change in lighting after the first questionnaire. Most of the questions were based on rating on a scale of 0 to 5 and with a possibility to comment freely the subject in question.

During the first two phases, the participants were not given any information about the new lighting in the area except that it was realized with LEDs and that the control of lighting was developed during the winter and spring. In the first two phases, we wanted to gain feedback of the genuine experiences on site, unaffected by any previous knowledge. In the third phase, our approach was totally different: the participants were given detailed information of the three different control methods of lighting that had been tested. At this phase, we were more interested in the participants' *attitudes* towards lighting in general and especially towards intelligent lighting and the three tested control methods. The influence of the shared information on users' experiences, attitudes, and values was also interesting to us. At this phase, the participants were not specifically asked to visit and observe the lighting on site. During the third questionnaire, outdoor lights were completely turned off except for a couple of hours in the dead of night, because of the long daylit periods in northern latitudes during the summer months.

For information sharing needs we had designed and developed a test version of an urban dashboard – the City Monitor for Salo [12]. In the dashboard web page, dynamic visualization of the lighting behaviour, scalable charts illustrating the average lighting and energy consumption levels, and textual descriptions of each lighting control type were presented (http://sencity.cloudapp.net:8888/). The visualization of adaptive lighting behaviour was realized in the form of a dynamic light map, presented on the aerial photograph of the housing area with dynamically altering illustrations of light distribution along the routes. The interface was interactive so that the users could themselves change between different control methods and zoom to different time spans of the chosen date. The PIR sensor data of a single date (8.2.) was used for simulating lighting behaviour with the three different control methods, allowing comparison of the energy consumption [12]. The third questionnaire, both in a electronic version and a printed one, contained the same information but in picture and textual mode, without interactive and dynamic simulations.

3.2. Case Study 2: Presence-Based Lighting on a Light-Traffic Route, Helsinki

The second case study concerns evaluation of presence-based lighting on a light-traffic route in Siltasaari housing area in Helsinki. In this still on-going pilot, the target is to find out what kind of a detailed lighting behaviour is suitable for presence-based lighting on routes used by pedestrians and cyclists. The aim is to design and test an optimal lighting behaviour, which saves substantial amounts of energy without lessening traffic or moving safety, or the sense of security of route users during the dark. The piloted intelligent system has the ability of detecting the direction of movement of route users. Thus, the lighting control can be adapted to this information so that the lighting is brightened further ahead a walker or a cyclist than behind.

In the evaluation, two well-designed presence-based lighting behaviours will be tested and compared. The one will be designed to be perceptible by route users and the other to be imperceptible by them, changing the distance how far ahead the route users the lighting is brightened. Lighting will be dimmed to 20 % control level in those parts of the route, where no-one is moving, and brightened to 100 % control level around the route users. The brightening and dimming is done softly. Feedback of the experiences will be collected on site with the help of a questionnaire and a short, structured interview. In addition, questionnaires will be delivered to the apartments near the route, which have a view towards it, in order to find out how presence-based lighting is experienced from the interiors. For example, can dynamic changes in lighting cause disturbance to the inhabitants?

We conducted a preliminary evaluation in order to test our method, during two nights in the beginning of April 2017. We had invited participants from educational institutions for young adults around the test site. Altogether we had ten participants, two of them being primary school and high school aged children, who came with their parents. The evaluation protocol was arranged so that we had three interviewers with questionnaires, standing in the meeting point that was located in the mid-point of the route. First, we had a short introductory discussion with each participant, where we collected the background information. After that, each participant was asked first to walk to the one end of the test route and back. At this point, the first interview and filling of questionnaire was done. Then a participant walked to the other end of the route and came back for the second part of the interview and questionnaire. Each participant was walking and interviewed alone. The lighting control was designed so, that in the other half of the route, the brightened area in front of a walker was longer than in the second half of the route, and respectively, the first type of lighting behaviour intended to be imperceptible and the second type intended to be perceptible. The evaluation was conducted from 9 pm to 10 pm, when there was not many other users of the route and it was dark enough outdoors.

The questions after each lighting type concerned the general impression of lighting; amount of lighting; possible sensations of glare; visibility of the surface of the route; visibility of other people; and visibility of surrounding environment. There was also two questions regarding safety: one on the safety of movement and the other on the feeling of safety. Most of the questions were asked based on rating on a scale of 0 to 5 and with a possibility to add comments of the subject in question. The participants were also asked what was good about the lighting and whether there was something about the lighting that bothered them. Finally, they were asked if the lighting changed in any way as they were moving along the route, and if it did so in their opinion, they were asked to describe it and tell at which point they noticed something.

3.3. Case Study 3: Intelligent lighting with services in the Harbour Promenade, Lahti

In Lahti, a lake harbour promenade is being developed into an active recreational environment for citizens through introducing there intelligent lighting and new digital services. The 1.5 km long pedestrian route spans from the Sibelius music Hall in the main harbour area towards Sports and Fair Centre in the other end. The area has an interesting history with an important inland harbour, rail traffic, and industry.

The new, intelligent lighting for the area was devised with the help of a user-centric design and development process with city representatives, business partners, researchers, and users of the area. For the process and participatory methods, see [13]. The process is still on-going as the development of the area and its lighting is continuing.

TABLE I. Analysis of Evaluation Case Studies

Case Study	Analysis of Evaluation Case Studies				
	Context & Experience Aspects	**Methods**	**Successes**	**Challenges**	**Development Ideas**
1	**Roadway:** – Visual impression – Lighting quality – Visibility – Perceptibility of lighting behaviour – Traffic safety – Attitudes & values – Acceptance	- Electronic and printed questionnaire – Rating scales and open questions – Driving and observing real-world road with two lighting types – Urban dashboard for information sharing	- Good sample: Phase 1: 130 people Phase 2: 106 people Phase 3: 52 people – Motivated participants – Sharing of information was valued by the participants – Combination of rating scales and comments – Electronic and printed questionnaires	- Comparability of results weather conditions traffic density – Technology barrier with the urban dashboard and simulations	- Weather conditions more easy to control in the autumn – Observation time fixed to low traffic situation – Development of the dashboard according to the feedback
2	**Light traffic route:** – Visual impression – Lighting quality – Visibility – Movement safety – Sense of safety – Disturbance	- Interview with questionnaire on site – Comparison of two lighting types in different parts of the route – Question- naires delivered into nearby apartments	- Combination of rating scales and comments – Motivated participants – Good timing in the late evening	- Attracting enough participants for a good sample, in the test evaluation 10 participants – Influence of a different context on the experience – Real-world challenges of the sensor technology: wind and vegetation – Perceptibility of lighting behaviour	- Co-operation with local schools and senior service centre, different age groups (teachers, pupils, parents, seniors) – The same test route for all lighting types
3	**Harbour Promenade**: – Interaction and participation – Communication and information – Social experience – Atmosphere – Movement safety – Sense of safety	- Semi-structured interview and observation on site, experience gauging – Evaluation probes – System data analysis – Questionnaire for service users	**Participation process and evaluation of history augmentation:** – Motivated participants – Contextual knowledge and ideas	- Complex real-world environment and experiences – Technological challenges of the pilot	- Utilizing urban dashboard in information sharing and evaluation

In the final design, smart lighting is employed, besides for creating energy-efficient and safe environment with good visibility, for activating and engaging, artistically communicative and informative purposes. Four sub-areas of design area with different kinds of characters were recognized, and supporting lighting and service concepts for them were designed: an active event promenade by the harbour; a historical rail track promenade in between two lakes; a dangerous crossing area of a busy road; and the backyard-type of area with small-scale industry in the vicinity of the sports and fair centre. The final solution combines evenly distributed neutral white LED lighting, which is dimmed when no one is moving along the route, with an atmospheric play of dynamically controlled light dots on the path, capable of having colours, for example, for communicative purposes or seasonal themes.

The lighting infrastructure will be a combination of intelligent LED route lighting with PIR sensors, and effect lighting by RGBW LED spotlights and DMX control. Additionally, base stations for a free WiFi connection, web-cameras, loudspeakers, and assembly spaces for extra sensors will be integrated in the smart, wooden lighting poles. Thus, the ensemble will form a development platform for smart city services. The first phase of the project will be finished by the autumn 2017 and the rest during the year 2018. The participation process will continue in the autumn 2017 with a questionnaire about the needs and ideas for using the intelligent lighting system for digital services.

A history augmentation application was piloted and evaluated with users in November 2016, as the idea of presenting information about the history of the area through a service came up in the participation process. The evaluation was conducted with a testing session with a semi-structured interview and observation on site. When the lighting design will be realized and applied in services, for example in a light game application and in communicative purposes, further evaluation of experiences will be conducted. A suitable method could be, besides interviewing and observing on site, the *evaluation probes* method [14], which we have developed in our earlier research. It is inspired by *cultural probes* methodology [15], which was already applied in the user-centric design process of the lighting [13].

4. REFLECTION OF THE EVALUATION METHODS

In the Table 1, we have summarized a reflection of evaluation processes of the case studies, from the following viewpoints: 1) perspectives of experience aspects that are of specific interest, 2) evaluation methods, 3) successes we encountered, 4) challenges or problems detected, and 5) further ideas for development of methods.

The case study evaluations, the preliminary and the final ones, have been successful in many ways and provided us with interesting research material. Additionally, the challenges have aided us to develop the methods. In the case 1, *involving a community* with a close contact to the research area helped us to gain an excellent sample of answers from motivated participants. In the case 3 as well, we have already a group of participants who have been involved in user-centric design process. With case 2, we can expect challenges in attracting enough participants for a good sample, especially if we want to interview both walkers and cyclists. Community-oriented approach with co-operation with neighbouring schools and the local senior service centre will be applied.

Real-world studies are challenging due to the *complexity of environments and experiences,* which makes the research environment and situations not easily controllable. According to our experience, qualitative research methods are usually well suited to them as they are robust. Thus, with case 3, the plan is to apply a *combination of qualitative methods.* Evaluation probes [14] let the participants experience the site and give feedback in their own time without a presence of a researcher. On the other hand, interview and observation on site, in a form of experience gauging walking interview [1,10], can as a more interactive method reveal other aspects of experience. However, in the cases 1 and 2, we are also targeting to get some quantifiable data and large enough sample for analysis. For that purpose, the *free-form comments supported well the rating scales* and were essential in some parts in *interpretation of results* as the numbers only could easily have been misinterpreted. This was the situation with the case 2, where we realized from the comments that differences in the two parts of the route were influencing more the answers than the differences in lighting. This notion has led us to adjust our research protocol.

Using both *printed and electronic questionnaire* proved to be a good solution as it enabled participants of *different age and technological abilities* to take part. In the case 1, the *sharing of information* about intelligent lighting solutions was appreciated by many participants and they gave positive feedback of the interesting study and the ability to participate in the development of lighting in their city. Even though the shared information was valued, there was also some critical comments of the dashboard details and some feedback that it did not work. The *risk of technology barrier* and *usability issues* should be solved in further development. Nevertheless, this kind of *bidirectional learning process* is essential in participatory design and research and a good way to engage people in studies and in developing their communities.

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