Responsive Lighting: "The city becomes alive"

Esben Skouboe Poulsen, Ann Morrison, Hans Jørgen Andersen, Ole B. Jensen
Department of Architecture, Design & Media Technology,
Aalborg University, Denmark
{espo, morrison, hja, obje}@create.aau.dk

ABSTRACT
We distributed fourteen controllable street lamps in a city square and recorded three comparative and one 'usual' condition, operating the public lighting as if it were an interactive stage. First tested was adaptive lighting that responded to people's occupancy patterns. Second was a mobile phone application that allowed people to customise color and responsive behaviours in the overhead lighting system. Third was ambient lighting, responding to wind velocity. The study extends the discussion on multiuser interaction design in public lighting by asking: how can interactions using mobile phones, thermal tracking and wind inputs afford new social behaviors, without disturbing the usual public functions of street lighting? This research lays foundational work on the affordances of mobile phones for engagement and interaction with public lighting. The study indicates the use of personal phones as a tool for interaction in this setting has potential to provide a stronger ownership to urban place.

Keywords
Experiment, responsive lighting, urban lighting, public space, interaction design, mobile interaction, experience.

ACM Classification Keywords
H.5.m. Information interfaces and presentation, HCI.

INTRODUCTION
A new understanding of the city as one that is 'overlain' with technology [4, 11, 14, 18, 29] affords a different understanding of networks and datascapes. Gathered data can in turn inform urban public lighting allowing light designers to create light strategies that adapt to every-day situations. Obviously, street lighting is part of a functional infrastructure sustaining a 24-hour operation for safety and orientation. Even so, design strategies associated with these light systems may offer new potentials, if we start exploring their aesthetic and social capacities. These adaptive and responsive capacities add to the classic understanding of cities as sites of civilized engagement [14, 16, 30] and we introduce a new concept, that of *responsive urban lighting*. New responsive urban lighting strategies may offer novel stimulating experiences, which afford different types of exchange and participation between social groups within contemporary public spaces.

An earlier responsive lighting study on controlling urban lighting [26] employed the one condition—thermal camera input—and demonstrated that adaptive public light did not affect the overall use of a city square. However, the study was conducted in winter with average temperatures of -10C, which may account for the low rate of direct participation. To address more interactive dimensions in the study we report on here, we added a multilayered and flexible design methodology that brings mobile phone, computer vision and environmental sensing inputs into the contemporary responsive urban lighting arena.

Little work has been undertaken to understand how people in everyday situations experience responsive public lighting. However, work from corresponding communities examining social and creative potentials in public spaces with researchers working with large displays [9, 17], and mobile solutions [13, 19] feeds sympathetically into the larger concerns surrounding this research.

As such, these studies point towards a contribution to the field of interactive architecture [1, 7, 20, 23, 29] and motivate a more sensitive approach to context and sensor data, which are both captured from devices in the buildings and from personal applications. These inputs have the potentials to inform design patterns in public lighting, affording better more adaptable, social and effective lightings. This research offers findings from a full-scale public lighting experiment initiated in downtown Aalborg, Denmark. The experiment is comprised of three light designs: adaptive lighting; mobile phone interaction; wind phenomena and one base condition of usual use for comparison. The base condition was recorded for two weekdays between 20.00-22.00, in usual Scandinavian late-summer climate (10C, cloudy). The three responsive light scenarios were recorded for five weekdays each between 20.00-22.00, in 10-15C with partly cloudy climate. The results are based on 122 interviews, 126 uploads using the mobile application, observations and computer vision flow maps of more then thousand passersby use of the square during the total 17 days of the experiment held in September 2012.

MobileHCI '13, August 27 - 30 2013, Munich, Germany

1 (a) Gl. Torv 1 (b) Thermal cameras

Figure 1. a) Picture of Gl. Torv taken from Budolfi Church, the thermal cameras was mounted at the corner of the Yellow building as marked on figure 1a.

RELATED BACKGROUND

Exploring the field of responsive control systems began in the early 1960s with pioneers such as Norbert Wiener [34], Gorden Pask [24] and Heinz Von Forster [5] leading cybernetics research as a theoretical and experimental research field. Since then and expanding upon this early work, many art installations have been produced. Examples include Lorenzo Hemmer's light installations: Homographies, [21] Pulse Room and Body Movies [1]. These interactive art installations have found their way into the contemporary art scene, and present alternative solutions for a new performative art form, that holds unique performative capacities [31]. In contemporary art there lies a wide performative potential, however the installations often favor a temporal event-oriented context, and the qualities are not part of everyday life situations, as we find with public lighting scenarios.

In the field of public lighting much research has been done with crime prevention strategies [3], color temperature [6] and sustainable intelligent light solutions [22]. In the field of urban screen and interaction design Schroester's work [28] with citizen engagement and Wiethoff & Blöckner's exploration of the impact of coloured light [33] demonstrate how media screens can work as central drivers for social interactions. Few studies address everyday life scenarios using the mobile phone and a Human Computer Interaction (HCI) perspective with adaptive urban lighting in public spaces.

Within computer science, social signal processing [3, 7, 25] has become an established research field pushing the boundaries of computer vision analysis. In this domain new knowledge has produced automated systems for detection of occupancy patterns [27], speed, and gestures [28], which enriches knowledge about activities in places. Combining these tendencies with cloud computing, enables bypassing data structures to enrich the local protocol with situated data. Additionally, these datascapes can inform lighting systems, enabling highly responsive public lighting. We note a gap between the knowledge produced in artistic performative light installations, market driven innovations and everyday life needs.

Full-scale experiments, such as; Responsive Urban Lighting [26] indicate that everyday life situations on the city square are largely dominated by space routines [2, 10] and that responsive lighting held special aesthetic and social qualities for the everyday users and long term users of the square. This research continues and extends these earlier studies [26] by adding mobile phone interactions, occupancy patterns displayed in intensity of white light around people and wind sensitive lighting strategies. Additionally, the temperature rose from -10 C to +10 C, so testing conditions for the use of public spaces changed from the early study. This study contributes to the field of mobile human computer interactions by addressing three different responsive light strategies in the same public space, allowing for a comparison of three different response strategies. The first, are focused on environmental and ambient inputs, second occupancy adaptive lighting and third; using mobile phone interaction to allow by-passers to design "their own" interactive light design using position data from the thermal camera tracking and input from mobile interfaces.

EXPERIMENTAL ENVIRONMENT

The experiment was located at Gl. Torv Square (see Figure 1a) in the city of Aalborg in Denmark. During the 17-day experiment the temperature fluctuated between 10 and 15 degrees Celsius. The sky was mostly overcast with occasional showers. However, as this weather is typical of a Danish late summer, this did not deter residents from stepping outside. The square is located in the historical center of the city, surrounded by buildings, such as: Budolfi Church (1300 AC.), the City council (1762 AC.) and the Student house (see Figure 2). The square primarily serves as a transit space between these sites and as a thoroughfare to the main streets. The topography of the square is slightly inclined, such that people standing on the top plateau are looking down on the people moving over the square, much like an urban theater setting.

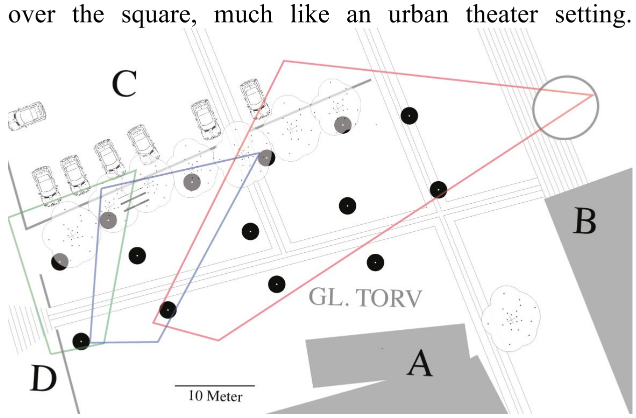


Figure 2. Map of Gl. Torv the coloured lines shows the area covered by the 3 cameras. Black dots indicate placement of lamps. A: School of Architecture, B: Student house, C: Parking, D: access to the center.

Figure 3. (a) Lamp fixture and (b) LED RGB Diode light source.

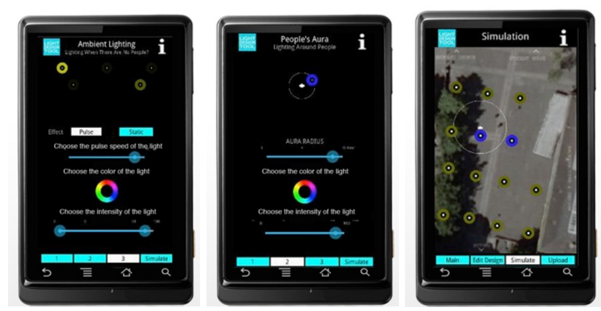
SYSTEM DESCRIPTION

Along this movement-through pathway, we placed 14 RGB LED lamps in three rows (see Figure 2). The street lamp is composed of a 70 cm tall Riegens Ray light fixture, (see Figure 3a), a 3.5meter tall light post and a 60x60 cm concrete tile foundation. An LED module containing 18 1W LEDs, six in each color (RGB) was mounted in the bottom of the light fixture (see Figure 3b). The LED module is connected to a DMX module and power convert installed inside the lamppost. This module enables a 0-5 step brightness control of each led color as well as a unique address for each lamp. To monitor the activity on the square three thermal cameras type Axis Q-1921-E, with a 19mm lens, was mounted at 12 meters height on one of the buildings facing the square. The cameras covered the main transit area connecting the main shopping street with parking places (see Figure 2). In addition, we employed a 2-axis ultra sonic wind sensor (Wind sonic SDI-12) placed at the center of the square. These hardware initiatives support the collection of situated wind and movement data on the square. To capture a person's own design and allow for direct user interaction with the lighting a android mobile application was developed. (see Figure 5).

Figure 4. Light design software, the red dots is people, the black, lamps.

Light Design Software

The light design tool is the backbone of the light control. From here the light behaviors are defined and initiated. The program is developed using Open Frame Works, which allows administrators to view and select different predesigned light behaviors for ambient and effect illumination. The software receives positions, groupings and splitting from the computer vision software via the Open Sound Control protocol (OSC). These are indicated with red dots (see Figure 4), it is possible for the technician to place the lamps on a top-view of the square. Black dots indicate the lamp positions, the numbers indicate their address and the surrounding white circle shows the intensity and color of the light. The Light design tool output opens DMX, via an Ethernet Artnet DMX controller. The software are uses a layered response strategy to overlay different patterns, allowing interaction designers to address situations without people with ambient/default illumination strategies and effect lightings that triggers in relation to people's occupancy patterns. This strategy is further described in section Responsive light strategy and this is available for mobile phone users, using the Android Light Application.



a) Ambient lighting b) Peoples aura c) Simulation

Figure 5. Three step user interface for designing public lighting. The interface allowed people to configure a) Ambient lighting: colour, intensity and pulse speed b) Peoples aura: radius, color and intensity of the light around people c) Simulation: shows how the light would behave when a person goes over the square.

Light application for Android phones

The Light Design application is a tool developed for Android Smart phones that allows users to adjust the color, intensity and behaviors of the ambient and the effect lighting on the square (see Figure 5 for interface). Users were guided through the design process in four steps: ambient lighting design, design people's aura, simulate and submit (See figure 5). First the user had to configure the ambient light; the light experienced on an empty square. At the top of the display, a simulation of lighting displayed color, intensity and pulse speed, changing as the parameters were adjusted in the menus.

Next, the light around the people who enter the square needed to be configured. Using the same procedure; color, intensity and radius of aura could be adjusted and displayed. Then, a simulation showed the user how the light would behave. Once s/he was satisfied with the settings, s/he could submit the design. The settings were uploaded to an xml database that controlled the light scenarios via the light design tool. After one minute the uploaded light scenario (your show time) would control the overhead lighting in two minutes. Figure 8 shows snapshots of user settings during the initial two day test period and Figure 5, the interface.

Wind setup,

We used the wind sensor Wind sonic SDI-12. This sensor recorded velocity and wind speed data, which was then mapped into a Sinus wave shaped pixelshader. The distance between the light waves is controlled by the speed of the wind: In a high wind speed, the waves would be closer together, with more distance between the waves in low wind intensity. Further, as the wind speed drove the speed of the light waves, this caused the wavelength and speed to be controlled by the wind speed intensity. Additionally, the direction of the wind also controlled the direction of the light waves, in this way wave like patterns of light traveling over the square related directly to the actual characteristics of the wind.

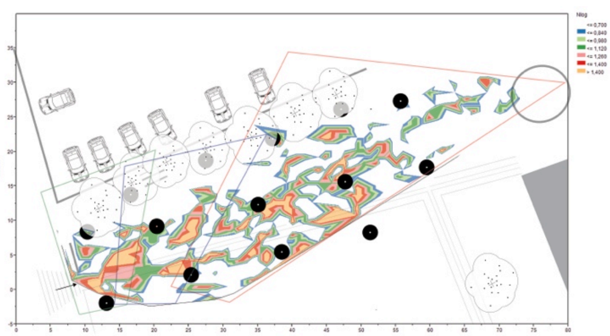


Figure 6. Occupancy map of the square, counted number of observed persons in 1x1 meter cells, sampled in 10 second intervals.

Adaptive lighting

The Adaptive lighting scenarios were developed as a feature for the ambient lighting. The lighting adapted red color intensity to in order to display the recorded use of the square from the day before. Figure 6 shows the occupancy patterns from one day. These then drive the intensity of red light in the ambient lighting of the square, presenting differentiated lighting and indicating long-term use patterns. Further, the tracking was used to drive a white light illuminating the pavement in a radius of 5 meter around any tracked person on the square.

DATA COLLECTION

During the 17 days of the experiment, three responsive light scenarios and one base condition were tested. The tests were done for each responsive light scenario during 5 weekdays and the base condition was tested 2 weekdays prior. We employed three different assessment methodologies (qualitative and quantitative) to gather data; interviews, observation and computer vision analysis from captured motion. Over the duration, 122 interviews were conducted with passers-by. The demographic of the study varied from 12-70 years in age, with relatively evenly distributed gender. 126 participated via the mobile phone app, and more than one thousand passers-by were captured moving on the square.

Interviews

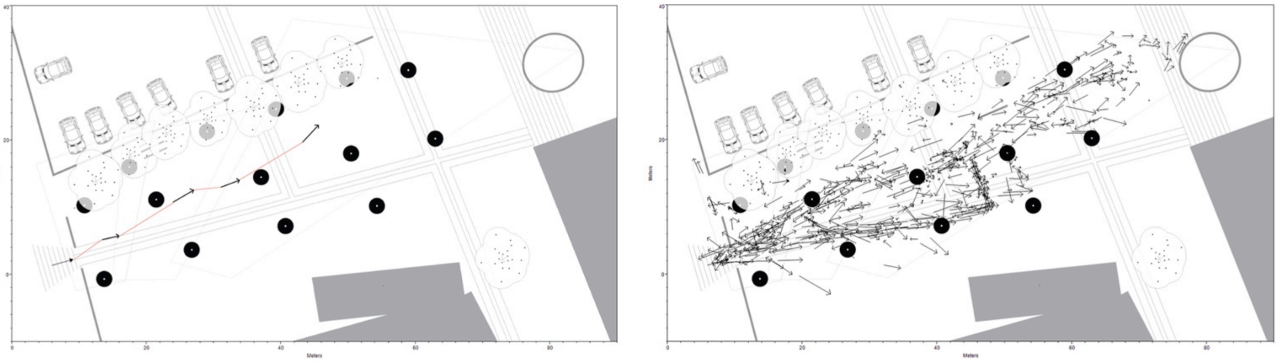
To get people talking about their experience and obtain first hand reports semi-structured interviews were conducted with some structured and some open questions. We first spent time observing the activities and 'interaction rituals' of participants on the square before approaching them. We took this two-step approach so that we could easily devise open-ended questions that could directly address behaviour we had noted and in this way obtain a more in-depth understanding of the motivations for the interviewed participants. First the occupants were asked: *Did you notice the lighting, while moving over the square?* Followed by an open-ended question, such as: *Do you have any comments?*

Observations

During the experiment, we observed body language, gestures and behavior of the occupants on the square. The observation methodologies we employed were based on ethnographic studies and fieldwork techniques employed in HCI [17] coupled with those of sociologist Erving Goffman and anthropologist Edward T. Hall [9, 15] and employed by architects, Jan Gehl and William Whyte [8, 32]. By observing the interactions from the edge of the square we could describe "space routines" in the transit space [10] and subsequently evaluate if and to what degree, people where affected by the lighting scenarios.

Computer vision analysis

Using computer vision tracking techniques allowed us to collect large amounts of data about position of people, duration of stay and speed of movement. We summarised these by depicting results in flow maps that display the occupancy patterns on the square. By comparing these we could see if the lighting produced a differentiated motion pattern on the square.



(a) A half minute trajectory of one person moving over the square **(b) One hour velocity map of multiple people moving on the square**

Figure 7. Estimated velocities vectors for people on the square.

Three thermal cameras operating in the long-wavelength infrared spectrum (8-15 μm), (see Figure 1b) as presented in [26], detected and tracked people's movement in the square. We use thermal cameras in this research for two reasons; night conditions and privacy. As thermal cameras do not measure visible light, they have a clear advantage over traditional cameras in night conditions. Also, it is illegal to film public places with cameras in Denmark, but since people cannot be identified from thermal images, we can circumvent the issue.

From the analysis it is now possible to estimate the trajectories of people on the square. This information was used to drive the *Effect* lighting and to generate vector maps for evaluations and analysis of flow behavior patterns. Figure 7 shows the results of trajectories in (a) 30 seconds and (b) the velocity vectors for persons walking on the square for one hour. The velocity vectors are calculated comparing the present position of each blob ID and the position for the same ID after 5 seconds. Hence we can calculate the speed of the tracked ID over the square. The position data also illustrates how the square was occupied, not taking the motion of the persons into account. Such an occupancy map with a resolution of 1x1 meter for 24 hours is illustrated in figure 6 sampled at 10-second intervals. The real time information is used for instant control of the illumination whereas the occupancy maps could be used as input to city planning and design of future light scenarios.

RESPONSIVE LIGHT DESIGN STRATEGY

Experimenting with responsive light design for an urban square demands a systematic strategy for how inputs from the various hardware will fulfill the overall demands. The design system utilises three levels of illumination functionalities: Ambient, Effect, and Resulting illumination.

Ambient illumination (default) addresses scenarios where people are not physically present on the square. *Effect* illumination addresses events when occupants enter the square. *Resulting* illumination summarizes the normalised values from ambient and effect illumination together. These strategies allow designers to tune light behaviors, customising colors, intensity and rhythms of reactive city lighting.

Through three new responsive light scenarios this experiment expands the knowledge and models of responsive urban lighting [26]. First; a downloadable mobile application, that allows pedestrians to design their own time-based lighting scenario. Second: adaptive lighting that utilises occupancy patterns to drive the intensity of white light around people on the square. Third was a wind sensitive illumination where the velocity, direction and speed of the wind drives corresponding patterns in the light. As wind movement affects the water surface, so too does it affect light patterns on the square.

FIELD EXPERIMENT

During the experiment three different responsive light scenarios were tested: (1) Mobile light application, (2) Adaptive lighting, (3) Wind sensitive light. As a comparative study a base condition scenario with static lighting were conducted. Over 17 days we conducted 122 interviews with passers-by in the time frame 20:00 to 22:00. During the 17 days we witnessed a vast array of

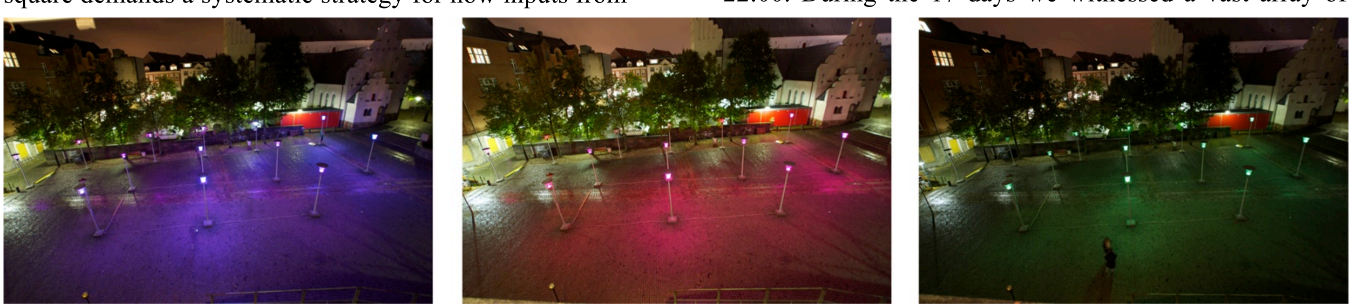


Figure 8. During the experiment people changed the color, intensity as well as behavior.

use, users and behaviors in the public space. Unsurprisingly, people quickened their pace when it was raining and exhibited a more leisurely speed on clear nights, especially on Friday evenings.

Because of the nature of the public space and the diversity of people, we experienced a broad demographic, varying from 12-70 years in age, with evenly distributed gender. Between 20:00 to 22:00, teenagers (from 13-17 years) used a public bench placed on the edge of the square to meet, pass time and observe other people passing by. This was also the time when the elderly people mainly used the square as transit space for cross-town movement. Over half of the 122 people interviewed were between 20-35 years. This may be because of the nearby Student house (a local concert venue). The majority of these were international students or tourists, walking around and exploring the city.

A secondary, but equally important user group, were the people living around the square. Because of high rents in this area, this group was largely comprised of university educated, professionals in their late 40s. They performed as everyday observers and long-term users of the square. We observed how this group returned to discuss the different light scenarios and were generally curious.

RESULTS

During the experiment, four different light scenarios were investigated, using the described qualitative and quantitative methods. Standard lamp illumination was turned off throughout the period of the experiment.

Base condition lighting

The base condition was a static lighting of the square that illustrates the everyday movement patterns over the square. This is used as a the reference point to compare the three responsive light scenarios too.

Mobile Light application

The mobile phone application offered pedestrians a new tool to control the streetlight, enabling exploration of multiuser interaction strategies for city lighting.

During the five day experiment for this stage, we observed that the majority of passers-by did not have/make time to stop and engage with the lighting on the city square. They did not appear to notice the 8-meter long illuminated poster fixed to the façade of a building facing the square, nor the hundreds of flyers that were pasted to proximate power poles and distributed to nearby cafés. We found that people did not take/have/make time and/or motivation to stop and download the application. Because of this, we stopped people and invited them to design the lighting under supervision. We found that it was often necessary to explain for new users what the software was capable of doing, how to download and general smart phone user application issues.

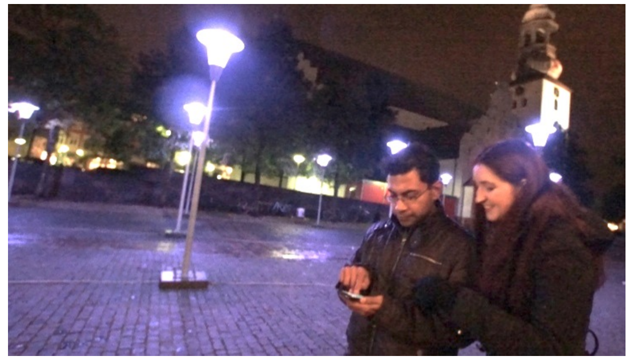


Figure 9. Couple customizing their light design.

126 people spent their time designing a light scenario and in doing so changed their relation to the square, in that they spent a longer time than the other passers-by. Many reported that they would like to try again and/or recommend it to others. When guided through the design process, the majority seemed to enjoy the five-minute design process and discussed colours and intensities (see Figure 9). One participant stated:

"It is very exciting that you can do something with the city today, so ***it becomes our city,*** *instead of being somebody else's city, which was built a long time ago. '…' I just think that everything else in the city is static and this is not. I like when there is something you can change and something that is new and different, and that it does if all people are allowed to design the lighting – then it is always different."* **Woman, 25 years (translated from Danish)**

We noted that people passing by did not observe other people in the process of designing the light on their mobiles. Based on statements from the interviews we can

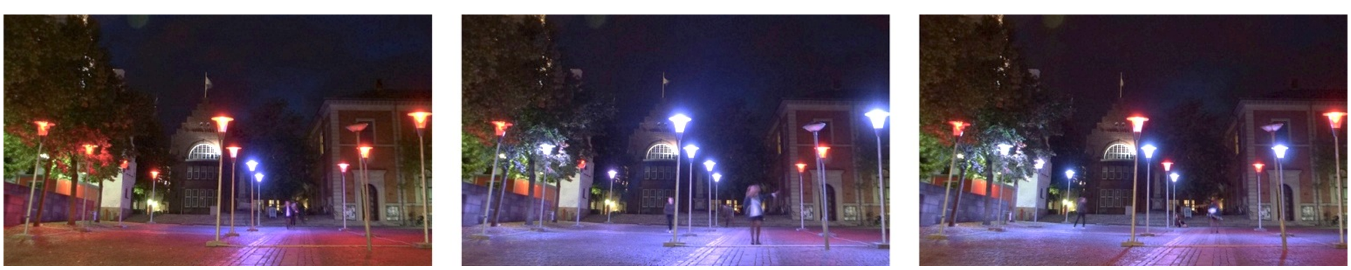


Figure 10. Picture sequence of catwalk behaviors during adaptive lighting scenarios at Gl. Torv.

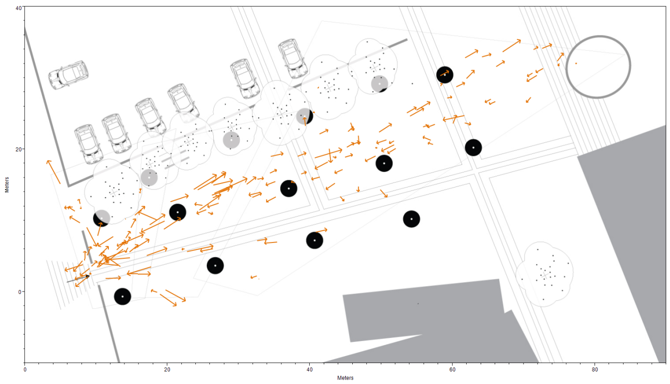


Figure 11. Vector map of people moving over the square during the adaptive light scenario, time: 21.30 – 22.00, 24th September 2013

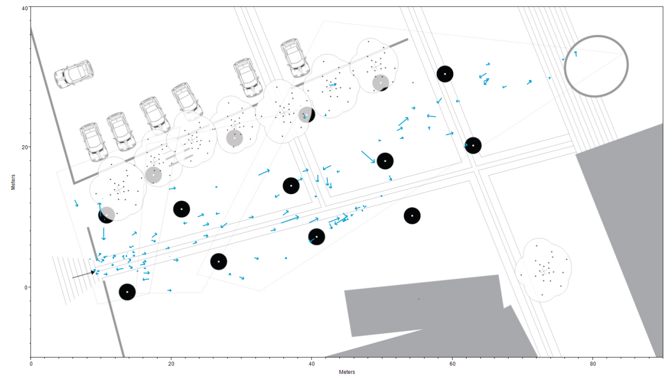


Figure 12. Flow map of people moving over the square during the wind scenario, time: 21.30 – 22.00, 1. October 2013

conclude that people did find the concept very inspiring. We believe that if mobile public light interaction cultures were more developed, interaction between streetlights and people would open new and interesting discussions of ownership, participation and long-term interaction effects. However, here people used and played with the adaptive lighting in an intuitive and creative ways. We can conclude that the learning curve on mobile applications for light design is not obvious to the passers by, and that "just responsive" light is easier for people to understand.

So saying, once involved, most users were generous with their time and followed the steps through to the completion in order to design their lighting display. Design processes often included discussions on favorite colors and behaviors. Most people who had designed a light behavior stopped and waited for their 'show time' to begin. However, some left earlier, and did not have the extra one-minute waiting time to see their lighting displayed. Many expected the lighting to change in a realtime interaction with the phone, so the researcher needed to guide them through the design process.

During the experiment we observed an extreme display of different, even "unexpected" behaviors afforded by the changing light. For example, we noted flying gestures, running, dancing, skating etc. (see Figure 10,13). Based on 5 days observations of people's interaction patterns in both mobile phone controlled lighting and autonomous adaptive lighting confirmed that these unexpected behaviors were not triggered by the mobile phone interactions, rather they resulted from a more direct and embodied interaction with the adaptive light.

When observing the movement patterns over the square during the mobile application scenario (see Figure 13), we can see that the majority of people are still moving in the same pattern as shown earlier in Figure 6. However, we note a higher tendency for greater concentrations of arrows indicating that people have stopped on a single spot. The stopping place is often on top of the stairs, an observation also made by William Whyte when describing the meeting places of people in New York [31]. In this case, 126 people were standing with their mobile phones and their guide designing light scenarios.

Adaptive lighting

During the adaptive lighting scenario, the illumination around the people changed from red to white in a radius of 5 meters, producing white lines of light after people when they moved over the square. "Unexpected" or not usually seen behaviors such as flying gestures, running, performing a cat walk routine, investigating the tracking technology by using the left foot to trigger the color change in the lamps, and dancing were commonly observed during the experiments (see Figures 10, 13).

We observed and recorded a series of "dance-like" behaviors, where people used their bodies to trigger the lamps in sequences they enjoyed. In this way, the light literally became the stage setting for their performances. These "extroverted" behaviors then caused others to stop, point and exchange words, producing a series of 'social chain reactions' for the performers, passers-by and for the neighborhood observers. One of the passers-by described the experience: *"I especially think it is interesting to observe other people, who realised that the light responds to them, they play with the light and it makes you want to engage, but when you don't get the interactivity, then the light is not that funny, but more ordinary light poles. Somehow the lighting provokes a reaction with people and they will change behavior – that is fun".* **Man in his 30's, (translated from Danish).**

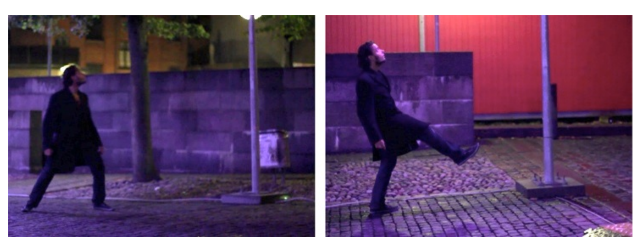


Figure 13. Dance like behaviors observed on the square.

This observation reveals how the illumination has two different properties depending on the user's attitude. First, it functions as space lighting and second it acts as a playful, provocative lighting environment supporting creativity and expansive gestures and behaviors on the square. We can say that for many the lighting became a catalyst for interactions and emergent social exchanges. During the experiment, many neighbors returned, offering comments and opinions on the lighting. Consequently, we experienced a growing awareness of the everyday life surrounding the square. The vector map at Figure 11 indicates that people approaching the square from the staircase (to the left of the picture), have a higher speed then people approaching the square from the top of the square (to the right of the picture). In general people's speed falls when traveling over more difficult terrain and supporting this, we can see that the participants were walking faster downhill than uphill. In addition, we can observe zig-zag movements between the lamps which indicate what we termed the more "abnormal" exhibitionist-type behaviors. Further, the movement patterns in Figure 11 indicate that people's everyday movement patterns are still the most dominant activity types, and that in contrast the less prominent "unusual" behaviors would still be classed as events.

Wind responsive lighting

In times of low wind velocity (0-5 m/s), we observed light waves slowly traveling over the square, dependent on wind direction. With higher wind velocity (8-10 m/s) the light waves were faster and shorter and shorter again, presenting wilder lighting on the square. These four evenings were partly clouded with light rain. From the edge of the square, we could easily observe the waves of light travelling over the square, and based on interviews with 40 people we can say that people generally experienced the changing light (98%). However very few understood that the light changed according to the wind (5%). When people were informed of the relation between the light and the wind they looked surprised, many laughed: "*I like the life it is making and it is fascinating – actually we have walked this way because we saw this strange lighting"* **Woman in her 60s, (translated from Danish).**

Words, such as "beautiful", "calming", "fascinating", "poetic" were common during these interviews and the novel dynamic light attracted people. People were generally very positive to the dynamic light and returning visitors often compared the lighting from different days. These responses indicate the long-term potential for street lighting that interacts with the larger social and ecological elements such as wind, sun, rain, and/or temperature.

When looking at the movement patterns on the square, we can observe that people do not generally change their usual routes for walking over the square, however we noted that their speed across the square was relatively slower, which can also be seen on the flow maps (Figure 11, 12). This indicates that there is a relationship between the perception of the wind sensitive light and the behavior of people. This finding also correlates with those from observations and interviews, where we observed how people moving over the square were looking around and exchanging dialogue with others. During the interviews several people said that they had wondered what caused the changes. This process of reflection, looking around and communicating would impact their everyday movement and increase the amount of time it takes to pass through the square.

DISCUSSION

Our results show that people on the square continued their usual movement pattern through the square, yet a series of unexpected gestures and micro social interactions were observed over the course of 17 days. We observed how the adaptive lighting staged new social interactions and caused "unexpected behavior" patterns to emerge on the square. Our observations indicate that responsive public lighting can engage citizens in new ways and extend the traditional notion of city life in to an event/situation specific lighting strategy. These findings make important contributions in the exploration for social and aesthetical dimensions of contemporary smart city lighting.

People generally noticed the change in the overhead lighting caused by the wind or from peoples movement, however due to time requirements, delays, lack of knowledge and/or awareness, passers-by did not often download the designed smart phone application, despite the presence of an 8-meter illuminated banner fixed to a facing building, nor the hundreds of flyers that were distributed locally. Despite this information, people were not aware of the possibility to download and try the mobile application. Due to the knowledge requirement level needed to navigate the mobile application, we can conclude that everyday users and natural inhabitants of the square might find more value with the mobile interaction, while tourists and passers-by would engage more readily with the adaptive responsive light configurations.

For many of the participants, responsive lighting was a novelty and the idea of user-customised lighting somehow very abstract. However, when guided through the five-minute design process, the majority appeared to be immersed, while discussing colours, light intensities and making several design attempts. Several interviews indicated that this type of user involvement triggered a new type of ownership, because people felt able to update the city lighting according to their interests and aesthetics.

From the edge of the square and from the neighboring apartments, occupants could observe how, pedestrians walked over the square and consequently drawing lines of white light indicating their movement over the square. In special cases the lighting catalysed "unexpected" behaviors such as walking as if on a catwalk, running with arms outstretched as if flying and/or dancing. We could observe how groups of young people ran in circles with their arms over their heads in order to change the light from red to white. People commented that it was like the lighting made the city come alive. The adaptive light scenarios catalysed a range of creative and social behaviors similar to those we have witnessed in the interactive art world over the last decade. We believe that more responsive public lighting solutions would afford better sociability within public spaces and present new types of ownership and creativity for the inhabitants.

During the experiment three different observation techniques were employed; interviews, observation and computing vision tracking of movement represented in flow maps. This triangulation of data proved useful to compare and often reinforce results from the three methods. The vector maps convert large amounts of data into general movement patterns, however it proved difficult to distinguish "unusual" behaviors from regular flow patterns in this format. Nevertheless observation complimented this format, as these social and creative behaviors were easy to spot from the edge of the street. The semi-structured interviews presented insights into how people felt while walking and interacting on the square, indicating more heart-felt and personal values such as a sense of ownership of the space and an appreciation of being able to contribute to the aesthetics of the environment.

In general we did not witness people observe others using their mobile phones as actors on the city square. We observed that the open-ended interaction styles, such as those afforded by the wind and the occupancy dependent interaction strategies had more obvious immediate social impact and effect than those used more privately and less obviously on the mobile phone application. These indications however need to be tested on long-term studies, such that local knowledge about mobile interaction practices are known and used by locals as an integrated part of everyday life and culture.

CONCLUSION AND FUTURE WORK

Situated data types such as those from mobile phone applications, wind sensors and thermal camera tracking, serve as novel information sources for investigating new social dynamics in 'responsive urban lighting'. In this study, we found that many of our participants acted radically differently in the 'responsive urban lighting' scenarios presented. Weather permitting in outdoor settings, occupancy sensitive public lighting can enable novel social interactions between the different users of the square. Further, the lighting interactivity acted as if a stage for people's behaviors, with people acting out roles publically for and to each other. In addition, we observed that people changed their movement trajectories in order to stop and observe each other in action.

By comparing the three response scenarios, we can conclude that using the mobile phone as an instrument for user configured public lighting demands more comprehensive learning from the users then the adaptive lighting scenarios do. While this eliminates the possibility for more casual and immediate interactions to occur, once participants become familiar with the interface and public lighting is more usually available for participation, the potential for action and interaction in sharing ownership and design solutions is wide open. Mobile interaction then compliments the long-term interaction strategies for everyday users.

During the experiments of the wind responsive lighting, the light was experienced as a series of dynamic moving waves synchronously reflecting the movement and dynamics of the wind. As a result of seeing the dynamic lighting from a distance, people changed direction and moved towards the city square to see the lighting close up. Participants were positive about the experience of a wind sensitive 'responsive urban lighting' scenario. Wind sensitive lighting has unique perceptual qualities, which are similar to other elemental experiences such as, the glowing light of burning wood in a fire or the movement of wind on the water surface of a lake. These responses indicate that a sensitive approach to responsive light strategies has aesthetic as well as social qualities, which has much potential that needs to be explored further in future studies.

Using mobile phone applications to configure interactive light scenarios appeared to hold qualities of ownership for long-term users, while adaptive light strategies addressed more easily the casual passers-by. The wind responsive lighting had an ambient and dynamic quality. Future work can utilise data from many different sources to better understand the potential from such situations. Inviting an interdisciplinary design team to work in this space and design meaningful 'responsive urban lighting' for public spaces, provokes a wide potential for productive urban responsive development and research and for more in-depth engagement via mobile applications from the natural inhabitants of public spaces.

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