Reactive Light Design in the ‘laboratory of the street’

Esben Skouboe Poulsen, Phd. Candidate, Aalborg University, Studio: Electrotexture Lab.

Hans Jørgen Andersen, Associate Professor, Aalborg University

Abstract

This paper presents and discusses results related to a full-scale responsive urban lighting experiment and introduces a light design methodology inspired by reactive control strategies in robot systems. The experiment investigates how human motion intensities can be used as input to light design in a reactive system. Using video from 3 thermal cameras and computer vision analysis, people’s flow patterns were monitored and sent as input into a reactive light system. Using physical as well as digital models 4 different light scenarios are designed and tested in full-scale. Results show that people in the square did not engage in the changing illumination and often they did not realize that the light changed according to their presence. However, from the edge of the square people observed the light patterns “painted” on the city square, as some people became actors on the urban stage, often without knowing. Furthermore, the experiment showcased power savings up to 90%, depending on the response strategy.

1 Introduction

Illuminating the street, paths, square and parks has been practised from the very dawn of civilisation. In the Ancient Roman Empire lighting primary served the purpose of security, both to protect the wanderer from tripping over something on the path as well as keeping potential robbers at bay (Scott 1904). This historical notion presents two fundamental purposes of the illumination: to illuminate the pavement and to illuminate the people in the space in such a way that potential observers could take action, if needed; a social mechanism also described by Jane Jacobs as passive surveillance (Jacobs 1961), which serves as a central mechanism in the organization of everyday life. Today street lighting is often controlled as binary control logic: On/Off. The system is preprogrammed to turn on according to the time of day and year. This notion of *global control* assumes that people always need evenly distributed light, even when nobody has the need for light. With new light sources, sensors and embedded dimming technologies it is possible to detect changes in occupancy patterns and make simple response patterns in the lighting, thus enabling feedback between light pole and the occupants for a more flexible and site-specific response. The study of feedback between sensors and acting environment can be tracked back to Norbert Wiener’s (Wiener 1948) notion of cybernetics; a marriage of control theory, information science, and biology that seeks to explain the common principles of control and communication in both animals and machines (Wiener 1948). Since then much work has been done in the field of computer/ human interaction. And new research fields such as robotics (Arkin 1998), responsive environments(Negroponte 1975), situated technologies (Shepard, Scholz, and Khan 2010) etc. all contribute to a particular focus within the field of sensing and responding to change related to the environment.

Inspired by the cybernetic notions from Gorden Pask (Pask 1962; 1961), Usman Haque presents experiments that utilize sensor technologies and lighting as part of a larger collective constructed environment, where people and objects collaboratively create social domains as in the case of Sky Ear and Open Burble (Haque 2007, 24-31). In the two cases environmental feedback between weather systems and social actors is essential in the temporary composition of the color and intensity of the light. Another example is the Dune project (Rijk de, Chong, and Roosegaarde 2011) by artist Daan Roosegaarde: a 60 meter long reactive light and sound installation unfolding in the landscape along the Mass river in Rotterdam. The installation consists of thousands of illuminating light straws that react to the occupancy of people. The behavior of the lighting is inspired by natural mechanisms hence it can be scared, excited, and curious. Within the last decade these (and many other) initiatives present cases in the emergence of a new creative discipline that prove to have aesthetic and social potentials in the field of light design. Within the industry of lighting, firms like Echelolon (Echelon 2007) and IBM(IBM 2012) have entered the development of technologies for large-scale control systems of smart city(Batty 2012, 191-193). They contribute to the development of an infrastructure for a new type of responsive and more effective environments. The study in this paper aims to develop prototypes for simple and robust reactive lighting scenarios and test how the changing light might reveal new social behaviors in a full-scale experiment in everyday life situations. As an early hypothesis, we argue that responsive lighting in public space will affect people's behavior in the square and furthermore that by dimming the light when nobody is there we are able to save energy. We test this argument through design of small-scale models and full-scale experiments, realized at Kennedy Square in Aalborg during January 2012. The paper describes and discusses the design methodologies, tools and technologies utilized in the experiment.

The paper is organized as follows: first the experimental site and setup are presented, followed by an introduction to the applied computer vision analysis, the interactive illumination design and observation methodology. The observations of the four different light scenarios are then presented and discussed, and finally the findings are concluded.

2 Experimental site and setup

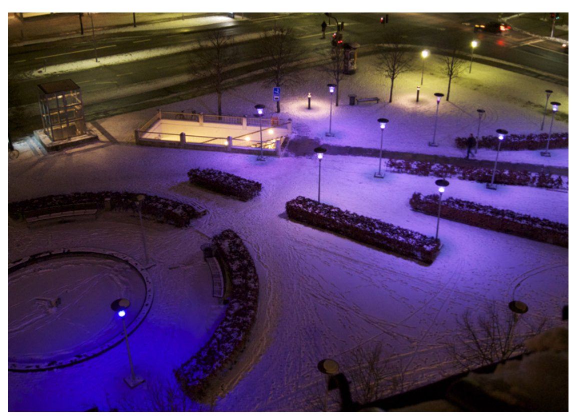


Figure 1 (a) Overview of Kennedy square with 16 lamps.

(b) Night time Overview of the square seen from the position of the thermal cameras .

During January the authors of this paper presented a 1:1 experiment at Kennedy Square in the city of Aalborg in Denmark. The square is located between the main train and bus station and the city center, and serves primarily as a transit space between these two locations, see figure 1(a) for an overview. To monitor the square three thermal cameras type Axis Q-1921-E, with a 19mm lens were mounted at the height of 15 meters at one of the buildings facing the square. The cameras covered the area from the exit of a subway to where people leave the square on their way to the city center, as illustrated in figure 1(b). Along this pathway the 16 RGB LED lamps were placed, figure 1(b). The street lamp is composed of a Riegens Ray light fixture, figure 2(a), a 3,5m tall light post, a 60x60 cm sidewalk tile as foundation. As light source a LED module containing 18 1W LED is mounted at the bottom of the light fixture. The LED module is connected to a DMX module that enables a 0-255 step brightness control of each led color as well as a unique address of each lamp.

Figure 2 (a) Lamp Housing **(b) LED module.**

2.1 Computer vision analysis

Detecting and tracking people is a large research area in computer vision, with most approaches using normal visual cameras. But due to falling prices on thermal cameras new approaches using these sensors have been developed lately. Thermal cameras measure the amount of thermal radiation that lies in the long-wavelength infrared spectrum (8-15 μm). Since thermal cameras only measure radiation and not visible light, they have a clear advantage over visual cameras especially in night conditions. Figure 4(a) shows an example of the input image from one of the camera views. Real-time information about the position and velocity of people in the square is being transmitted to the Light control interface (Figure 3b).

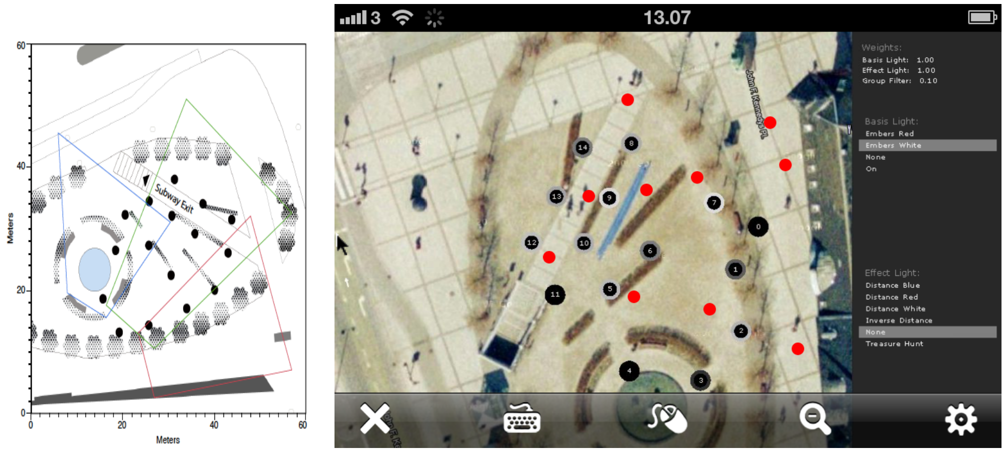
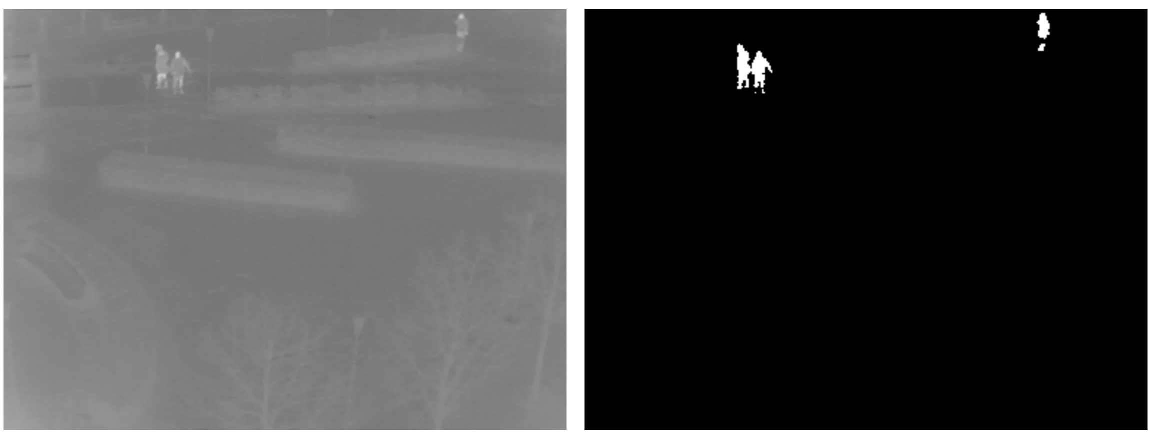


Figure 3

(a) Overview map of Kennedy square with the areas covered by the three cameras.

(b) Snapshot of the iPhone application by which it was possible in real-time to see the result of the computer vision tracking and control light settings of lamps.



(a) Thermal image

(b) Binary image.

Figure 4 Example of the thermal input image and resulting binary image from one camera view.

In outdoor environments the temperature naturally changes, which gives a slowly changing background image. Therefore, a running average background subtraction is performed, as the first step in detecting people (Piccardi 2004, 3099-3104). The background will be updated with selectivity, meaning that only if the pixel is segmented as background it will contribute to the new background. As the experiments take place in an urban space with limited car access, it is assumed that all activity detected is human activity of interest. The different images produced by background subtraction show the area of interest. The detected objects must be mapped to real world coordinates at the square in order to correspond to the positions of the lamps. The mapping is calculated using a homography matrix (Criminisi 1997)(Figure 3a).

This matrix can be calculated using at least four corresponding points in image and world coordinates. Since the camera views are not aligned, a mapping must be calculated for each individual view. Figure 5a illustrates the mapping from image to world plane. For this purpose of illumination control from tracking data, groups of people should be considered as one object.

The individual objects detected are grouped using single linkage clustering(Hartigan 1975) with a distance threshold of 3 meters. In order to determine stable positions and velocity of the groups, a Kalman filter is applied to track the groups (Welch and Bishop 2001, 1-16). Splits and merging of groups are handled based on the distance between predictions of group tracks.

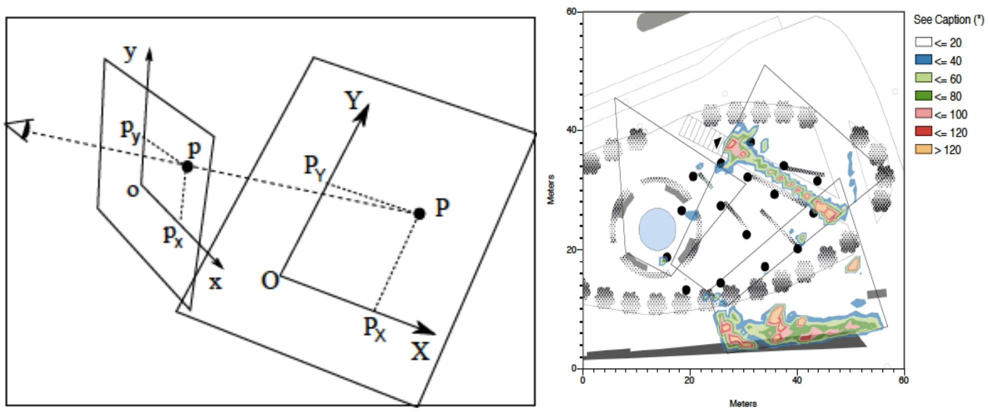
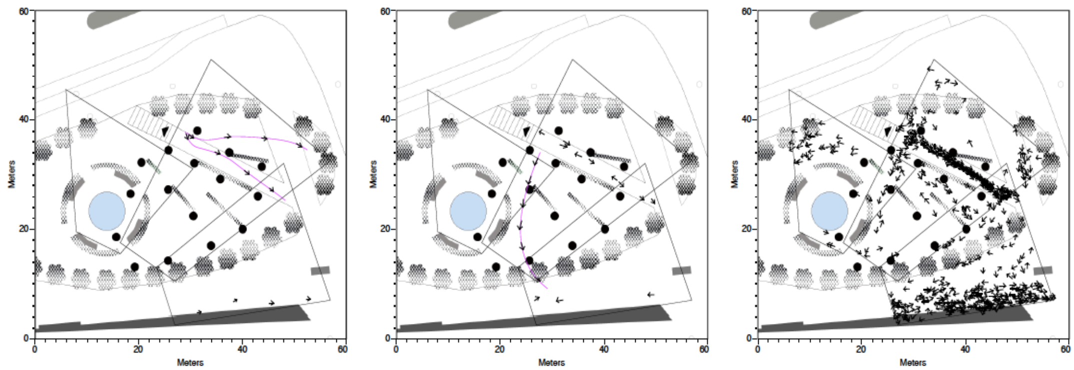


Figure 5 (a) Example of the thermal *Camera input from one camera.*

(b) Occupancy map of the square counting the number of observed persons in 1x1 meter cells sampled per 10 second.

From the analysis it is now possible to estimate trajectories of persons in the square. Figure 6 shows the results of such trajectories in (a) for one minute, (b) two minutes, and in (c) the velocities vectors for persons walking in the square for a period of one hour. This information may also be illustrated by how the square is occupied, which means 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 5b sampled for every 10th second. In this way it is possible to both get information about the instant motion of people in the square and accumulated motion over time. The first information may be used for instant control of the illumination, whereas the later representation can be used for placement of lamps, that is the physical design of the illumination setup for a given urban environment, and to design basic illumination according to how the area is being used.



(a) One minute trajectory (b) Two minute trajectory (c) One hour velocity map

Figure 6: Estimated velocities vectors for people in the square.

2.2 Observations methodology

During the experiment, observations of body language, gestures and behavior of the occupants in the square were made. The observation methodology was based on ethnographic studies and fieldwork techniques, as they are articulated by sociologists such as Erving Goffman and Edward T. Hall (Goffman 1980; Hall 1973) and utilized by architects such as Jan Gehl, William Whyte (Gehl 2004). By observing the interactions from the edge of the street, we were able to describe "space routines" in the transit space (Jensen 2010) and evaluate if people were immersed in or affected by the different light scenarios. By observing the interactions from the edge of the street we were able to describe "space routines" (Gehl 2004; Whyte 1988). When observing people’s gestures, behavior, and non-verbal signals according to the different illuminations we have material to compare the involvement and interaction between people supporting the findings from the flow maps.

3 Layered response model

To approach a reactive light design of an urban square calls for a creative process similar to that needed in the development of architecture. We are interested in novel design tools and methodologies that allow designers to intuitively sketch interactive scenarios and evaluated response patterns through digital and physical models. As a fundamental question we would ask what is the internal performance goal of one light pole? Firstly to shower the pavement with light, protecting the wanderer from tripping over, and secondly to illuminate people's bodies/faces to uncover non-verbal body language. However this notion assumes that a person is occupying the space, and does not describe the need for light when nobody is occupying the space. Because of distributed motion sensors we are now able to address individual lamps, hence presenting the potential to introduce conditional statements, for example ' if movement then dim up ; else set light intensity to fade slowly between 5% & 10%.' Under the assumption that lamps can perform dimming and sensors can provide information about occupancy, this paper suggests a two layered reactive light model, that firstly addresses a minimum lighting that treats situations without occupancy (*ambient light*) and secondly a layer that addresses situations with occupancy (*effect light*), the two layers are summarized in a resulting lighting which is the one experienced on the street.

3.1 Ambient lighting

Basis lighting is the illumination enabled when no occupants are immersed in the lighting. The concept focuses design attention on the empty square. However, this notion does not exclude the possibility that observers from a distance would appreciate an illuminated square. Typically the square would be observed from a distance, a balcony, a living room, café etc. Dark places could lead to an avoidance of the square. In the experiment, we worked with two ambient light scenarios:

- A global minimum; all lamps are dimmed down equally to 10% of the full intensity.
- Ember; the light slowly fades up and down between 0 to 20% in a random pattern.

3.2 Effect lighting

Effect lighting is the action triggered by an event (a person, a vehicle or an animal) perceived by the perceptual organ of the light system. One can design a range of different complicated, banal or playful scenarios depending on the level of occupancy, velocity, climate, time of day etc. In this initial experiment, we tested the following two effects:

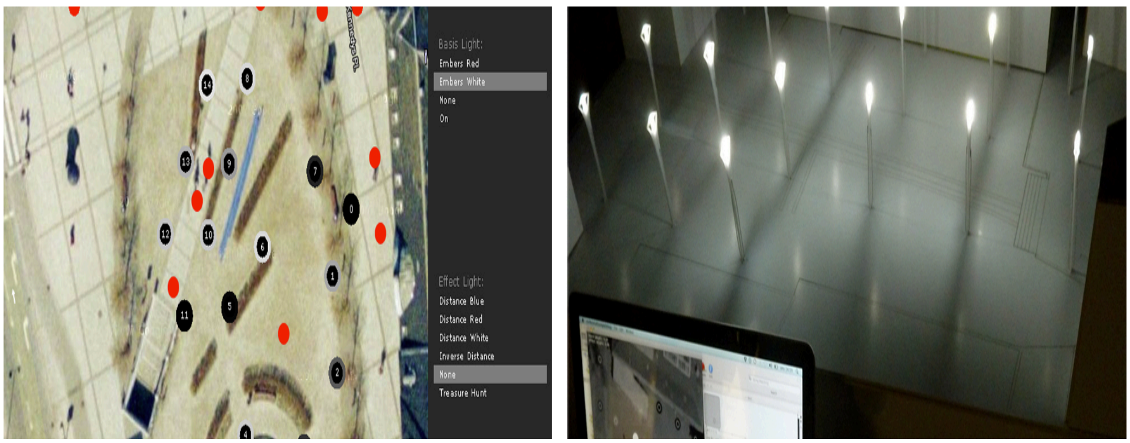
- Light circle; as an illuminated aura around the occupants the localized light would secure an illuminated circle of a minimum of 10 meters in diameter. This would allow the occupants to perceive variations in pavement and the face of people passing by, which in turn facilitates secure navigation and travel across the square.
- Light wave; as a playful illumination scenario we designed a treasure hunt scenario where two of the lights on the square indicate (blue light) the position of a trigger causing a wave of white light to travel across the square. After 10 seconds, a new blue light will emerge in another location. The hypothesis was to make a playful illumination that engaged people in playful and creative situations.

3.3 Resulting lighting

Summarizing the intensities from the *basis* and *effect* lighting gives the light intensity for each lamp. The resulting lighting presents a light performance that has low intensity in scenarios without people, while offering more social and interesting light configurations during times of occupancy, still fulfilling the functional requirements.

Responsive Light scenarios and design methodology

The layered model described above only describes the logical organization of the design methodology approaching a responsive light design of an urban square, and also calls attention to a creative process similar to that needed in the development of architectural space. In addition, we need to develop tools to provide creative techniques where interactive scenarios can be sketched and evaluated in a creative and intuitive design process. To approach the design challenge, a physical 1:50 model of the square was developed, figure 7b. Simple white LEDs were used to represent the lamps, and, by using video input recorded on-site, we were able to test how different response designs would unfold in the square. In this way, we could simulate the light design using real life video feeds and evaluate response times, rhythms, placement and in relation to the scale of the urban space. Figure 7a shows a snapshot of the screen, where the red dots represent groups on the square and the black circles are the lamps. The diode models were good as sketching tools but to fine-tune the response patterns on site, a smart phone app. was developed. Hence the architect could monitor activity in the square and adjust light response and color intensities on site.



(a) Snapshot of the Light design software. **(b) Illustration of the model**

Figure 7: Light design Software and physical model 1:50

4 Experiment

The experiment was conducted during the last week of January 2012 from late afternoon and into the early evening. At this time the sun sets at 5 pm., therefore collection of data and observations took place from 5 pm. until 8 pm. During that period the weather was very cold for Danish standards, ranging from -5 to -10 degrees Celsius and very windy. Data was collected by observations and by logging of the results of the computer vision analysis.

5 Results

During the experiment the experience and effect of the four different light scenarios were investigated: Ambient, Glowing light, White aura & Red treasure hunt. The normal illumination of the square was turned off during the experimental period.

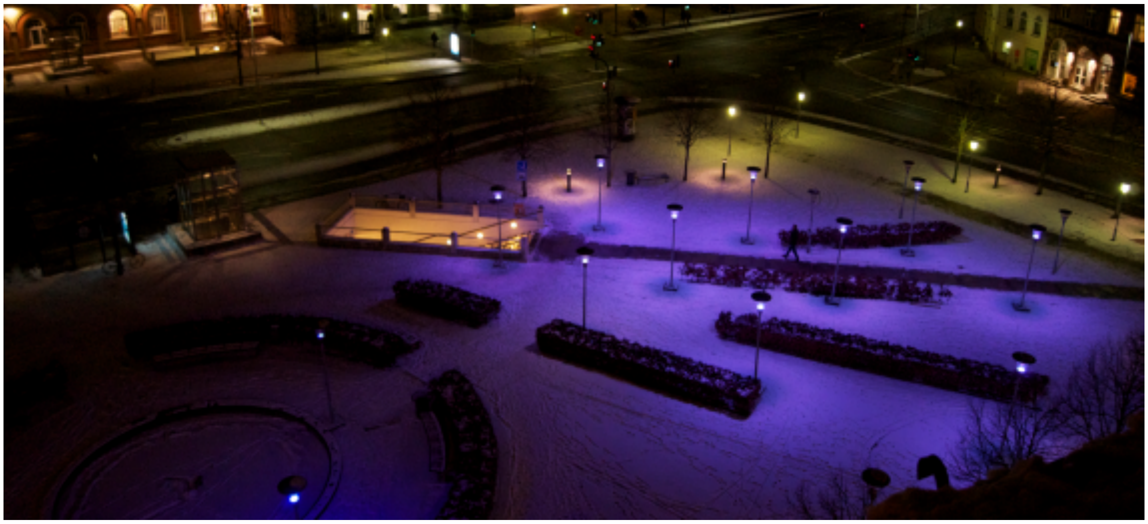


Figure 8: Illustration shows "Ambient Illumination"

5.1 Scenario 1, "Ambient Illumination"

The first scenario is a homogeneous illumination of the square. The 16 lamps had a static intensity of 80% white light and no effect was added. This light scenario was similar to what could have been a traditional static illumination of the square, and was motivated by a need to compare the change of flow and social behavior in the square in different light scenarios. It seemed that people did not see the changed illumination and acted like nothing was different from everyday life. When people were asked about the illumination, only a few recognized the changed lighting, even though the lighting before was very limited.

5.2 Scenario 2, "Glowing Light"

The intention of the slowly fading white illumination was to make a lighting that would illuminate the square in an aperiodic way, leaving the square half lit but always in a process of fading down or up, providing a feeling of overview of the square and supporting the feeling of security (Figure 9). Thus the light system chooses a random lamp and then sets the light level to 10% of the maximum level from which it is then decreased. As a playful chance encounter a light wave effect was introduced.

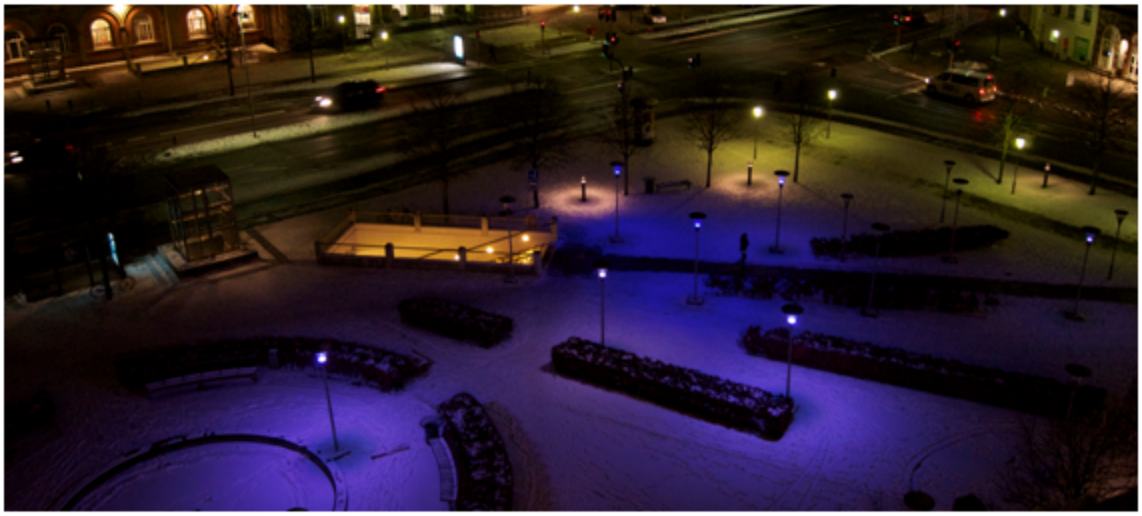


Figure 9: Illustration from the “Glowing light” scenario

A few people became aware of the changing street light and stopped to look at it, some looked like they thought the light fixtures were broken or out of order, one even asked if there was a loose connection and laughed. The majority of the by-passers did not even seem to notice when they triggered the light wave traveling over the square.

5.3 Scenario 3, "White Aura"

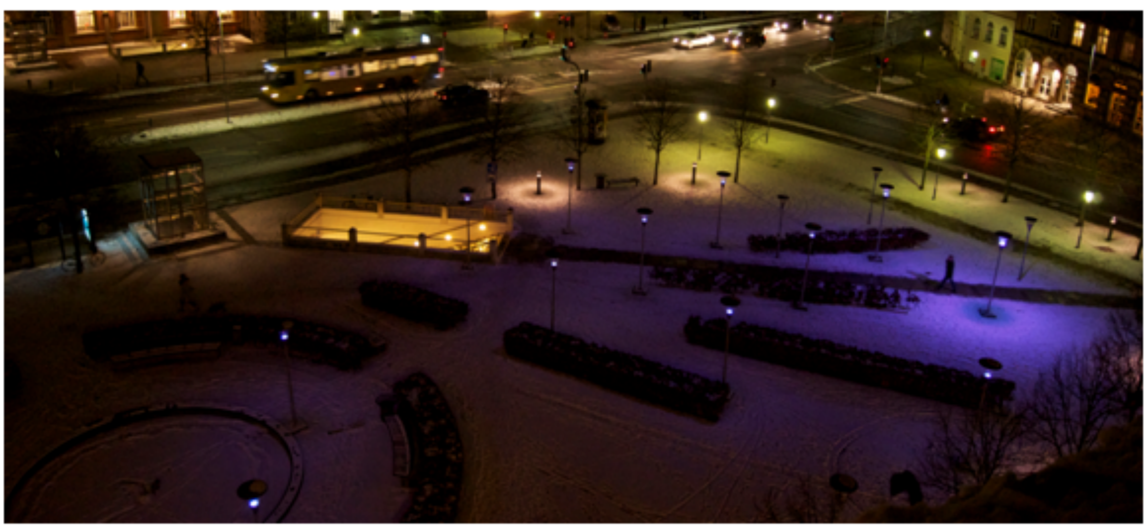


Figure 10: Illustration from the “White Aura” light scenario.

As a simple response pattern, the lamps were set to slowly dim up to 100%, when a person approached the lamp. Because of the relatively big, illuminated area around the people (10 meters) people did not seem to realize the darker square surrounding them. This absolute minimum light scenario allowed the pedestrians to see the ground as well as other people, which were the fundamental functional requirements for lighting, described in section 1. Observed from a distance one could see how people at the edge of the square were making pointing gestures towards the "performing" people, moving across the square. The simple effect and the large contrast between the surrounding darkness and the light “painted” by the moving pedestrians made the persons natural focal points in the square.

5.4 Scenario 4, "Red Treasure Hunt"

Figure 11: Illustration from the perspective of the street

The hypothesis of this scenario was to establish an unusual illumination, which made people stop and confront the lighting in a playful manner. Figure 11 shows a sequence of images visualizing the effect scenario. 1 - A person is approaching the blue "trigger" light. 2 - The person triggered the effect, which sends out a wave of light from the triggered lamp outwards. 3 – The light wave travels through the square. 4 - The light wave has ended and the trigger point is disabled for 10 seconds before it lights up a lamp again and a new person can trigger yet another light wave. A few people noticed who triggered the light wave and when they realized that, the illumination changed based on their presence. Observed from a distance the slowly fading lamps had a calming, inspiring and lively expression, one should look very carefully to notice the wave.

5.5 Energy consumption

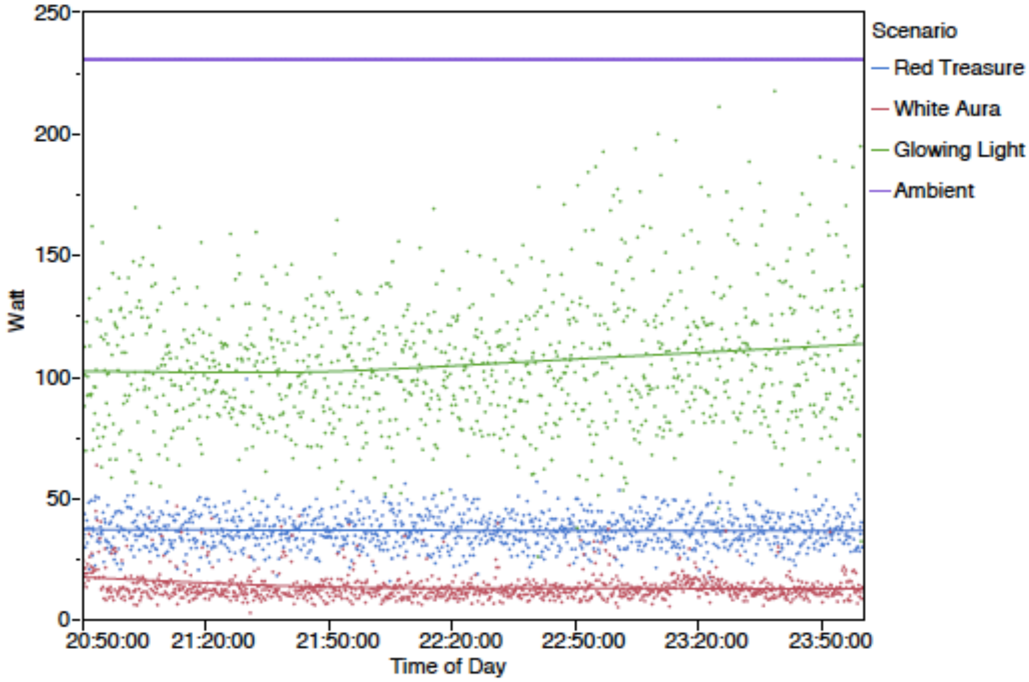


Figure 12 Energy consumption of the four illumination scenarios.

The Ambient Illumination scenario as reference gave an energy consumption of approximately 230 Watt for the sixteen lamps. The other three scenarios are fluctuating in energy consumption due to the deliberate effects and the reactive effects according to the activity in the square. Clearly, the energy consumption of these scenarios are depending on the light design, and especially the choice of ambient light has a significant contribution to the mean value that the scenario fluctuates around. The order of the energy consumption for the scenarios was that the Glowing Light had a consumption of around 100 Watt and this was the scenario with the largest fluctuation that in some cases almost reached the Ambient Illumination level. The fluctuations around the mean are due to the effect light being set according to the activity in the square. White Aura had the overall lowest energy consumption about 20 Watt on average or 11.5% of the Ambient Illumination scenario. This is also the scenario that mainly depends on the activity in the square.

6 CONCLUSION

Street lighting is built to illuminate the square extending the potential use of public space into the dark hours. Because of the recent development in the field of sensor and LED technologies we are now able to modulate the light to any given control paradigm. This study shows new possibilities and design methodologies for applying simple reactive light strategies in a three layered response model, addressing ambient, effect and resulting lighting aspects for an interactive urban lighting. It does this through four experiments using thermal cameras and computer vision analysis that allow designers to detect occupancy and flow patterns in the street. The data is utilized both as input to a real-time light control system and as a mapping of long-term occupancy and flow, allowing researchers and urban planners to access data on the use of urban spaces. In this paper, the evaluation of three interactive light strategies; Glowing Aura, Glowing Light & Red Treasure Hunt, reveal the possibility for reactive lighting to be applied in public spaces and present a significant energy saving up to 90%. This result shows that dramatic light changes would not make people in transit space change behavior. However does the lighting change the relation between the observers on the edge of the square and people moving in the lighting. The responsive lighting amplifies the performance of the occupants who become actors on a stage (Goffman 1959) a person who attracts attention and supports the concepts of passive surveillance by Jane Jacobs (Jacobs 1961). The majority of the visitors did not realize the changing of the light, at the first visit to the square, but after observing other people perform from a distance a new participatory novelty emerged. To uncover the full character of the public space would demand further examinations of space routines across seasons, hence this would allow us to develop deeper knowledge and understanding social potential in situations with long-term occupancy. To address future challenges of response design in the field of reactive, the authors of this paper suggest an interdisciplinary approach, where technologists and architects work close together in search for new robust tools and novel design methods, to be tested in the 'laboratory of the street'.

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