ABSTRACT

Historically light has been a catalyst for social life to emerge. In recent years of lighting research the social effect of light has been underexposed. The environments we occupy on a daily basis are used for a wider variety of activities. Consequently, lighting conditions need to become sensitive to adapt to the variety of activities being performed. We argue that the effect of light on the social relations between people needs to be considered in order to make adaptive lighting environments viable. To design a socially adaptive lighting environment an approach needs to be used that is iterative, experiential and involves multiple users in an actual context. The design process is described in three stages (Interactive Sketching, a Design Experiment and Socially Situated Adaptive Experience); for each stage the aims, the setup, results and lessons learned are provided. In this process an experimental environment is used, named Incubation environment, which is set up as a dining environment and equipped with computer controllable lighting armatures. In the final design stage the Socially Situated Adaptive Experience technique is described and is found a suitable technique to design socially adaptive lighting environments.

Categories and Subject Descriptors
H.5.2 [Information Interfaces and Presentation]: User Interfaces – Evaluation/methodology, Theory and methods, User-centered design.

General Terms
Design, Human Factors

Keywords

1. INTRODUCTION

A new era in lighting technologies is emerging with the development of Solid State Lighting (SSL) technologies such as LED and OLED. The low power consumption, flexible form factor, high durability and long lifetime provide a basis for new paradigms of lighting. Light sources can now be embedded into everyday objects and environments, and be controlled easily and in an advanced way through microprocessors. These microprocessors can be given sensing capabilities by equipping them with sensors interweaving lighting solutions into the complexity of human life [22][1].

Our everyday environments are turning into highly dynamic spaces; e.g. the boundaries between home and work are blurring through the adoption of new (communication) technologies [18]. Spaces that have traditionally been the domain of family life become workplaces and vice versa. It therefore seems impossible to design a priori a lighting scheme that is applicable to each of these activities. E.g. different lighting conditions are preferred for office work than for a family dinner, while they might occur in a similar environment. We believe the new capabilities of lighting technologies provide opportunities to adapt environments to the dynamics and flexibility of everyday life. Only when technologies become sensitive to contextual and social situations, system can truly become adaptive, personalized and anticipatory [1].

In this work we present our approach and initial explorations regarding the design and implications of socially adaptive lighting environments. We propose the design of environments, where lighting conditions are not static and set by the (lighting) designer. Instead, we propose lighting systems that behave, adapt to people and activities through implicit and/or explicit interaction. Additionally, we argue there is a need to take into account the implications this has on the social relations and social behaviour of people occupying these spaces.

In section 2 the social dimension of light is discussed. In section 3 an approach towards designing intelligent environments is presented as well as our experimental environment. Section 4 discusses three stages in our design process to come to a technique to design socially adaptive lighting environments. Section 5 reflects on the approach and design process.

2. The social dimension of light

Throughout history mankind has been struggling to increase control over (artificial) light conditions. Bowers [6] provides a well-illustrated overview of the many lighting technologies and lighting devices mankind has developed in approximately 2000 years. We are now entering a new phase in the evolution of lighting, where we can gain even greater control over the lighting in our environments and light can become embedded into our surroundings; one of the key characteristics of ambient intelligent environments.

Bitner [5] presents three ways in which environments affect our behaviour. Knoop [12] uses a similar division to discuss the effect of light on people (Figure 1, left); firstly visually, it allows people
to see. A significant body of research has focused on studying this effect of light (e.g. research towards visual performance etc.). Secondly, the emotional influence of light. This knowledge is applied in theater and stage lighting to strengthen the play by enhancing our emotional experience. In retail lighting sales are influenced by lighting conditions [15]. Products such as ‘ambient experience’ [21] exemplify how light can be used to reduce emotions of stress and excitement for children in hospital environments. Thirdly, studies on the biological effect of light have emerged. Light is, for example, used to stimulate our circadian rhythm during office work [7]; it helps to activate our body. Light has significant biological influence on us and can be used to enhance our activities. E.g. it is suggested that children’s concentration at schools can be enhanced through light [4]. A product such as the Philips WakeUp Light [19] integrates the biological effect of light in the ritual of waking up.

![Figure 1: Left: The effects of light as specified by Knoop. Right: Our vision regarding the effects of light. A fourth component is added, namely the social component of light.](image)

We believe these studies have overlooked or underemphasized the influence light has on social behaviour. E.g. full moon, providing light in the darkness of night, has been a catalyst for extending public social life into the night [6], or the introduction of public street lighting lengthened the time people could walk the streets feeling safe. Considering the historically profound effect of light on our social lives, we believe there is an additionally important component, not mentioned by Knoop: a social effect of light (Figure 1, right). Light has always shaped our lives as social beings; social life emerges around light. Related work investigating the effects of light on social behaviour show that higher levels of illumination can decrease conversational sound energy levels [20], and increase intimate communication in given conditions [8]. Lower levels of illumination tend to make people cheat more [23]. Lighting conditions can also be used to affect the movement patterns within public buildings, although social cues tend to have a stronger effect [2]. In order for lighting environments to become adaptive and anticipatory, the social component of light needs to be considered and investigated.

3. APPROACH

With the aforementioned vision we set out to explore how to design socially intelligent adaptive lighting environments. Our research is unique in that we combine the social component of lighting design with adaptive lighting. This poses challenges for our design process.

In comparison to empirical research towards the social effects of lighting, such as [8] and [20], our work is not concerned with investigating light in pre-specified static conditions. The approach we take should be capable of dealing with unforeseen conditions and behaviours and respond to these. This makes it possible to investigate the effect of adaptive lighting environments as opposed to static lighting conditions. There are studies that have investigated adaptive lighting conditions in an actual context [7]. These studies typically offer little interaction possibilities for users. Such studies can run for longer periods of time, while the expected results of such studies are based on a hypothesis of the researcher. The time, money and effort spent might not lead to significant results, as is the case in [7].

From these observations requirements for the design approach were deduced. Firstly, there is only a small amount of literature available regarding the social component of lighting. It is therefore not known what can be achieved using socially adaptive lighting and there is a need to explore the scope of this domain. There can be several viable options that need to be considered. A suitable design process should thus allow exploring different possibilities in a (A) short time span. Additionally, design and evaluation criteria for socially adaptive lighting environments are unknown. These should be learned during the design process. The design process should be (B) iterative, allowing the designer to incorporate knowledge from earlier iterations. Since interaction only exists at the interplay of people and products, interaction should be (C) experienced [16]. Also to investigate the effect of light on people, people should be able to experience light. Since we are interested in the social influence of light, designs should take into account (D) multiple users. To generate knowledge for design, the design process should allow for (E) evaluation with people in a context resembling the (F) actual context as closely as possible (while maintaining a certain level of control). Using realistic scenarios in evaluations can lead to unforeseen or unexpected situations, which uncovers the limitations of a design.

With these conditions in mind an iterative, experiential design process was adopted; the Growth Plan [17]. The Growth Plan describes three phases, namely Incubation, Nursery, and Adoption, in which highly innovative and complex technologies are designed, explored and evaluated. Each of the phases increases in complexity of the system and realism of the context. In the initial phase (Incubation phase) the design domain is explored. Attention can be paid to areas of interest, and one can investigate multiple areas to gain an understanding of the design domain. The remainder of this paper describes our approach to the phase of Incubation. We wish to investigate the influence of light in a social setting that is as realistic as possible but still easily accessible. For this we selected a situation of eating together. It is a context where social aspects and lighting aspects are important.

3.1 Equipment and Infrastructure

We created an environment in which ideas and concepts can be prototyped and experienced. Using commercially available light sources controlled by a DMX-protocol, the environment can be set up with a variety of light settings. In our environment, light sources are controlled through programming environments such as Cycling ‘74’s MAX/MSP [13] and the open-source programming environment Processing [14]. Using programming software to control the light sources provides freedom over the light sources. We have, for example, created custom-made lighting control boards (which we refer to as lightboards), tailored toward the installed light infrastructure (see Figure 2). This was achieved by connecting an Arduino Duemilanove [3] microcontroller to linear and rotation potentiometers, and push buttons. The freedom to ‘program’ light behavior and incorporate data from sensor boards allows for the design of intelligent and adaptive lighting environments; one can experiment with various sensors, sensor arrangements, and intelligent algorithms and is not bound by the constraints of existing soft- or hardware.
Figure 2: Example of a light control board (lightboard). 1: Rotation knobs control the intensity of the light source. 2: Slider controls the colour of all connected light sources. 3: Time of the transition to the new settings (1-30s). 4: Activation button starts the transition.

The environment we use is a room of 2.8 x 5.8 meters. Light sources and other equipment can be hung on the ceiling or placed on the ground in a cove. The environment is equipped with a dining table and 6 comfortable dining chairs. Ten RGB DMX-controlled light sources are placed in a cove on the floor, directed at the walls (wall-washers). Six 25-watt halogen spotlights are hung on the ceiling, directed at each of the chairs; a 25-watt incandescent lamp is located above the table. Each corner is equipped with a light armature capable of producing light upward or downward (accent lights). All sources are connected to a DMX converter, which is connected to a computer.

Figure 3: Map of the incubation environment setup. Yellow gradients represent the location and direction of the light sources. Green gradients represent the location and direction of the cameras.

4. DESIGN STAGES
The design of socially adaptive lighting environments poses questions often too complex to answer at once. As described in section 3, this poses demands on the design process. In this section, several stages in our design process are highlighted and show an approach that is rapid, iterative, experiential, and involves real people in as realistic contexts as possible.

4.1 Interactive Sketching with Light
Where a ‘traditional’ designer typically starts to explore ideas by sketching, the early interaction designer can initiate the design process with interactive sketching.

4.1.1 Aim
Interactive sketching is a technique in which interactive concepts are explored with minimal use of equipment and time allowing an idea or concept to be experienced as early as possible. The difficulty in designing for socially adaptive lighting systems is how to shape a relation between social behaviour of people and the behaviour of a system. An interactive sketch allows a designer to rapidly design and evaluate the interaction between human social behaviour and behaviour of a system.

4.1.2 Set-up
Figure 4 gives an example of an interactive sketch. The idea of adapting lighting conditions to the social information embedded in body posture is explored. When people lean away from each other, increasing the distance from each other, the environment is lit. This makes the atmosphere feel more public. When they lean towards each other, decreasing the distance, the table and faces are lit and the surroundings are darkened. This gives the environment an private feeling.

Figure 4: Interactive Sketch of a Socially Adaptive Dining Environment. Body posture triggers changes in the lighting conditions.

The equipment used in this sketch is minimal; two RGB light sources are used to light the surroundings. Incandescent and halogen light sources provide light on the table and participants. MAX/MSP was used to connect all light sources to a single virtual slider to slide between public-private lighting. Two force dependant resistors (FSR) at the back of the seats were used to switch between the two states. This sketch was built in a single day.

4.1.3 Results
Just as a sketch makes an idea visible, an interactive sketch can make an interaction ‘experienceable’. When using video footage the results can be communicated and discussed with others. Figure 4 displays our result of an interactive sketch in photographs.

As experienced, changing the lighting conditions can make people move from the background into the foreground and vice-versa. The tempo of the transition can determine the impact of the effect.
A slow transition feels calm, while a rapid transition feels blunt and ‘active’.

4.1.4 Reflection

The most important benefit of this stage is its speed. Concepts can, and should, be built in a matter of hours to days. Based on the skills of the designer, the choice can be made to simulate intelligence of a system, using a wizard-of-oz approach [10], or to implement simple interactions using basic electronic components. E.g. commercially available analog dimmers are well suited for wizard-of-oz purposes.

This technique can provide insights in two forms; (1) the actual implementation of the concept will raise questions the designer can deal with in later stages (see section 4.2). In this sketch the question was raised what should happen when one person leans forward and the other person leans backward. Or what happens when the number of people increases? In general this questions how the interaction between social behaviour of people and behaviour of the system can be designed. (2) Since the concept can be experienced, the designer himself and other people can experience the system and provide feedback.

The technique of Interactive Sketching contains some of the elements outlined in our approach. It is rapid and experiential and can be done iteratively. The scenario however is still acted out, so it does not involve real people in an actual context. The interactions are predefined and any behaviour not pre-programmed is ignored by the system.

4.2 A Design Experiment

After the interactive sketch questions were raised regarding aspects of the concept. A design experiment was set up in order to investigate one of these questions in depth.

4.2.1 Aim

Once the design process advances, the questions the designer has to answer gain more detail. To answer such questions experiments can be performed. Reflecting on the interactive sketch described in section 4.1 the question arose whether it is possible to describe a lighting environment in social-emotional terms. We used for example the terms public and private to describe the lighting conditions in the interactive sketch. However, is there a relation between lighting conditions and social-emotional terms? In the experiment we ask participants to design lighting conditions. These lighting conditions can later be used for analysis.

4.2.2 Set-up

Figure 5 shows an interactive lighting setup in the context of a dining environment. 6 environmental descriptor pairs [11] (e.g. inviting vs. repelling, pleasant vs. unpleasant) were selected for this experiment. Each participant was given 6 environmental descriptors to create using lighting conditions. The final result for each environmental descriptor was stored. This data was used to observe whether there are consistencies between the settings participants created. If so, this would make it possible to describe lighting environments at a socio-emotional level.

The environment was equipped with 10 RGB wall-washers, 4 accent lights in the corner, and 6 spotlights aimed at the seats (as described in section 2). Using control boards (as depicted in Figure 2) the participants could vary the colour and intensity for the RGB sources and the intensity for the other light sources.

4.2.3 Results

Twelve participants, each designing six environmental descriptors, designed in total 72 lighting conditions, 6 for each environmental descriptor. The final results were photographed and the photographs were clustered per environmental descriptor and inspected visually for commonalities and differences.

Visual inspection showed that descriptors with a positive connotation were often created using symmetry, nuanced use of colours and balanced light intensities. Descriptors with a negative connotation were mostly created using a-symmetry, saturated colours and sources fully on or off.

The similarities within descriptors indicate that it seems possible to describe lighting environments at a higher level. However, the social-emotional descriptors used showed overlapping results.

Figure 5: Images of the experiment where participants try to create light settings to express an environmental descriptor.

4.2.4 Reflection

A question raised in an interactive sketch was explored in this technique. Results enhanced the feeling of the designer for qualities of lighting conditions (i.e. symmetry, balance and saturation of colours are factors determining the connotation of a lighting environment), as well as a better understanding of classifying lighting conditions at a socio-emotional level.

The experiment adhered to most of the conditions outlined in section 3. With the dining environment and the control boards created, experiments of this type can be performed rapidly. The context is increasingly realistic, however is still not an environment where people eat. Additionally, we have lost the social dimension of our designs, since we are performing the studies with a single participant.

4.3 Socially Situated Adaptive Experience

Given the shortcomings of the previous two techniques, a third technique was created; the Socially Situated Adaptive Experience (SSAE) technique. Figure 6 shows images of this technique. In this technique two improvements were made: (1) the people were placed in an actual context performing real actions and (2) the events occurred in a real social situation with multiple users.

4.3.1 Aim

The goal of this technique is to explore the implications of adaptive lighting conditions on real people performing real activities. For this a wizard-of-oz method [10] is used. Knowledge
gained in earlier iterations can be used in this technique to investigate the expected effects in realistic situations. The benefit of using this technique is that it is a rapid approach to explore the effect of adaptive lighting in realistic scenarios. Using people to simulate the intelligence of an adaptive system allows us to deal with unexpected situations. To provoke real behaviour it is essential that participants are unaware that other people are controlling the system.

4.3.2 Set-up
Participants are invited for lunch in an intelligent dining environment. The participants are told that the lighting conditions adapt to their behaviour based on an intelligent video analysis algorithm. In reality, a second group of participants (which we named controllers) observe in real-time video footage of the environment in another location. Based on their observations they adjust the lighting conditions. People are used as controllers since people are proficient in ‘reading’ social situations.

We explored two different approaches to this technique. In the first, the controllers received specific assignments to adjust behaviour of the lunching participants; e.g. try to make person X talk, or let all participants lean forward. In the second approach the controllers received similar environmental descriptors to adjust the lighting conditions to. This exemplifies how knowledge gained in one of the earlier phases can be used in later phases. The concept of using body posture as an indicator for intimacy derived from the Interactive Sketch was used (section 4.1). Also the environmental descriptors used in the Design Experiment (section 4.2) were used in this technique.

![Figure 6: Socially Situated Adaptive Experience. Top: actual users occupying the dining environment. Bottom: a group of controllers interacts with the lunch participants through light. The users are unaware of the controllers.](image)

4.3.3 Results
In total three lunches were held. Video footage for each of the lunches was recorded and reviewed afterwards. In addition, the lunch participants were interviewed and the controllers were asked to describe their experiences in writing.

Reviewing the video footage it was observed that perceptual tropism [9], which is the tendency to direct one’s attention to the brightest area in the visual field, seems to apply at a social level. People in brighter locations seemed to be addressed more in the conversation.

Questionnaires held during the interviews seem to indicate that people classify the environment using environmental descriptors from the same valence-arousal domain as the environmental descriptor the controllers used to set the lighting conditions.

4.3.4 Reflection
The approach presented is found suitable for designing socially adaptive lighting environments. It is possible to involve real users with realistic activities into design activities. When asked to what the system responded, participants mostly mentioned conversational sound level or movement. This leads us to believe that people in the environment were convinced that a computer system controlled the environment. The activities of the participants are thus as realistic as one can get in a controlled environment.

Controllers were able to deal with the richness of the social situation and respond directly to events occurring in the dining environment. E.g. a participant started to wave and gesture wildly at the camera probably to attract light to his location. The controllers responded to this and provided him with a spotlight. The described approach is thus capable of dealing with unexpected behaviours.

Using this technique it is possible to investigate the influence of dynamic lighting conditions on social behaviour. As stated in the results, perceptual tropism seems to apply at a social level in dynamic situations. This technique makes it possible to find such results.

In addition, it is not only possible to acquire information from the participants in the intelligent environment, but also from the controllers. This can provide insights into the internal workings of a system. E.g. in our studies the controllers coordinated all their actions such that transitions for all lights started and ended simultaneously. This can be valuable knowledge for the design of a distributed system.

There are improvements to be made. Controllers found it hard to explore options without being provided any guidelines. The technique was intended as a design activity, where the controllers generate ideas and apply them directly. This proved to be difficult for various reasons:

1. The controllers indicated it was difficult to get a feeling for the lighting conditions in the environment. They had experienced the environment before the lunch started, yet it remained difficult.
2. The controllers are often ‘too late’. E.g. It was tried to put a spotlight on the speaker, but the changes in a conversation are too rapid to keep up with. Combining video footage with real time sensor data might reduce this difficulty.
3. Observing changes in behaviour is extremely difficult. Using an observation scheme, or focusing on specific types of behaviour could improve this. Possibly classifications of behaviour from social psychology could be used.

When more ‘handles’ for the controllers were added, such as the environmental descriptors, they found it easier to set the lighting conditions in the environment.

5. CONCLUSIONS
Advances in lighting technologies provide new opportunities for the use of light in everyday life. Given the (historical) social influence of light, the (expected) dynamic use of environments...
and the complexity of networked and socially embedded technologies, design techniques should be able to cope with these complex aspects. In this paper we presented our approach towards the design of socially adaptive lighting environments by the adoption of the ‘Growth Plan’. The main concern in the Incubation phase (as compared to later phases such as Nursery or Adoption) is to explore the design domain in (A) rapid (C) experiential (B) iterations, situated in (F) real social contexts involving (D) multiple users for (E) evaluation.

In comparison to related work the SSAE approach presented is able to meet all of the requirements above. It has been capable to deal with adaptive lighting conditions, as compared to studies investigating the effect of static lighting conditions on social behaviour [8] [20]. It is an approach suitable to develop knowledge in rapid iterative cycles, providing research domains with a better understanding of the problem under investigation. This can make longer-term studies ([7]) more effective in producing results, since it provides the researchers with insights of what the expected results can be.

The requirements A-F are suitable indicators to benchmark design approaches dealing with complex interactive environments. Especially in the early stages of a design process, the presented technique allows the designer to investigate and refine concepts. With the lessons learned the SSAE technique could be improved for future sessions. It is interesting to investigate how the knowledge and technique applies to other domains as well.

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7. REFERENCES