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Pers Ubiquit Comput (2014) 18:2035–2055
DOI 10.1007/s00779-014-0759-2

ORIGINAL ARTICLE

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S. A. M. Offermans · H. A. van Essen · J. H. Eggen

Received: 22 July 2013 / Accepted: 13 January 2014 / Published online: 1 February 2014

Abstract New lighting technologies create new opportunities that may contribute to people's experience of light. These opportunities are a result of the increased variety and freedom in terms of colour, form factor and connectivity of the lights. To allow people to fully benefit from the potential of such novel lighting systems, there is a need for a new user interaction paradigm. To develop this paradigm, we have to better understand the aspects that play a part in the interaction with lighting, paying special attention to people's motivation for interaction. This paper reports on a context-mapping study that was performed to gain insight in these aspects. As result, we present a set of seven themes that regard the interaction with lighting in the current situation and in the future. These themes provide an overview of the relevant aspects in this domain and contain considerations and opportunities for the design of new interfaces for novel lighting systems. We conclude that people have different levels of lighting needs that are highly dependent on context and that also require control at different levels. The context and lighting needs have a large influence on the extent to which people are motivated to adjust their lighting. Moreover, the lighting interface itself has a large effect on this motivation, mainly influenced by the degrees of freedom, the control location and availability, the degree of automation and general interaction qualities.

Keywords Lighting control · User interfaces · Context-mapping study

S. A. M. Offermans (✉) · H. A. van Essen · J. H. Eggen
Industrial Design Department, Eindhoven University of Technology, Postbus 513, 5600 MB Eindhoven, The Netherlands
e-mail: s.a.m.offermans@tue.nl

1 Introduction

Ongoing developments in the area of LED (Light Emitting Diode lighting) are changing the way in which light will manifest itself in our surroundings. In the near future, our environments are likely to contain many LED sources that are embedded in dedicated armatures, but also in furniture and even in our walls and ceilings. This will lead to spaces with a large number of small light sources that will partially disappear into the background of our environments, which can be seen as part of the ongoing shift towards ambient intelligence [1, 2]. Due to the nature of LED control technology, we can also have a high degree of control over various light parameters such as intensity, colour (-temperature), position and focus.

The potential benefits of this trend result from the increased degrees of freedom that are available. This allows people to create more suitable atmospheres and working environments and as such have different settings for different occasions. Moreover, the increasing knowledge about the effects of light on people allows us to use the emotional, psychological, physiological [3] and social [4] effects of light, as well as to use light to convey information in ambient displays [5, 6]. The potential connectivity of the LEDs to each other and other computational devices also allows for behaviour of the environment based on information from sensors or the web.

The combination of the increased amount of individual light sources and the increased degrees of freedom creates a huge amount of parameters to control. This increased control freedom requires us to rethink our current interaction paradigms for lighting control. It is very unlikely that each individual LED (or even worse; each of its parameters) would have its own switch or control slider. This would result in control panels that are not unfamiliar in theatre and club settings and would require the same level of professionalism to use them. On the other hand, setting all light sources simultaneously will lose a large amount of the potential benefits that the LEDs provide. The current control paradigm that is based on the linkage between a switch or a dimmer and a (group of) luminaires stems from a technical history that is no longer relevant and will no longer suffice if we wish to exploit the opportunities of novel lighting technologies.

In order to design interfaces that allow people to benefit from the opportunities of novel lighting systems, while keeping control comprehensible, it is important to have an understanding of peoples' underlying motivations for using their lighting and the interfaces that are used to control it. This paper aims to shed a light on peoples' desires regarding their light and the interaction with it, as well as on their motivations for doing so. The presented insights resulted from a user study that this paper reports on. We look both at current practices and behaviours and also at the usage of possible future systems. We try to capture generic principles and describe design implications and opportunities. Through this, we aim to contribute to the development of a new interaction paradigm that will open up the opportunities of novel lighting systems to people.

In the following section, we will discuss related work; after which we will describe the study setup. The remainder of the paper contains study results, conclusions and design considerations for interactive lighting systems, followed by a discussion of the findings.

2 Related work

Various efforts have been made to allow people to benefit from the new opportunities of modern lighting systems. In this section, we will first discuss several commercially available interfaces that attempt to open up the opportunities of modern LED technology. Second, we will discuss several systems in the research domain. Many of these systems are essentially examples of ubiquitous computing [7] or intelligent environments with lighting as an important component. Finally, we will discuss related work that specifically investigates the relation between user and system control over lighting.

2.1 Commercial lighting interfaces

There is quite a number of examples of innovative lighting interfaces, both commercial and in research laboratories. Although not all of these interfaces are evaluated (or evaluations may not be in the public domain), it is relevant to provide a brief insight in some of the recent trends and more innovative interfaces. As a point of departure, we start beyond what we consider traditional interfaces such as on/off switches (either on the luminaire, wall-mounted or remote), dimmers and variations on the "hold to dim" and "toggle dimming levels" interactions.

To conveniently switch to a light setting that is suitable for a particular activity, many company meeting rooms have wall-mounted preset panels that set the intensity of all lamps simultaneously to a predefined level. One can also find these types of panels in some home environments. A popular system that supports this type of controllers is the Lutron HomeWorks QS system (Lutron HomeWorks QS, www.lutron.com/europe). A wall-mounted version of the preset panel is shown in Fig. 1.

In commercial applications, there is a trend towards coloured LED lighting; both in retrofit bulbs that fit the E27 and E14 standard (Edison screw-in bulb) as well as LED strips. The controls for such products only vary mildly and are usually intended for a single luminaire. Cheaper models are most often controlled using a basic remote control that rely on some twenty colour presets and a dimming option (Fig. 2).

Slightly more expensive models usually rely on a hue–saturation–brightness-based approach (using a colour wheel) that is similar to the remote (Fig. 3) for Philips' Living Colors lamp (Philips Living Colors, www.philips.nl/c/livingcolors/302825/cat).

Although all these remotes allow one to choose the preferred light colour in relatively great detail, it is still a rather technical approach towards lighting control. The user is able to adjust the light parameters of a single luminaire (or sequentially address multiple lamps in case of the Living Colors).

Recently, Philips took a more user-centred approach to this control in the interface for their Hue lamp (Philips Hue, www.meethue.com/). The basis for the interface is a smartphone on which the Hue application can be used. Apart from setting lamps individually, users can create presets for various activities and can use their own photographs to create a colour palette (Fig. 4). It also allows the use of timers for waking up or apparent home presence when one is on holiday.

One of the most innovative and recent examples of interaction with light can be found in the "Fonckel" which is a table lamp that allows users to direct and dim the light by touch gestures on the back of the lamp (Fig. 5). In doing so, they aim to make light tangible (Fonckel One, www.fonckel.com).

2.2 Lighting interfaces in the research domain

Besides the commercial trends, in research, there is quite a number of interfaces that regard ambiance creation as a whole, with lighting as one of its components. Considering

Fig. 1 Lutron Dynamic Keypad, a wall-mounted preset panel for the home environment (image source: http://www.lutron.com/europe/HeroImages/DynamicKeypad_01_hero.png)

Fig. 2 Example of a basic remote control for coloured lighting

Fig. 3 Philips Living Colors remote (image source: http://www.newscenter.philips.com/pwc_nc/main/shared/assets/nl/2008/news/productnews/20081204_livingcolors_floral/livingcolors-floral-remote.jpg)

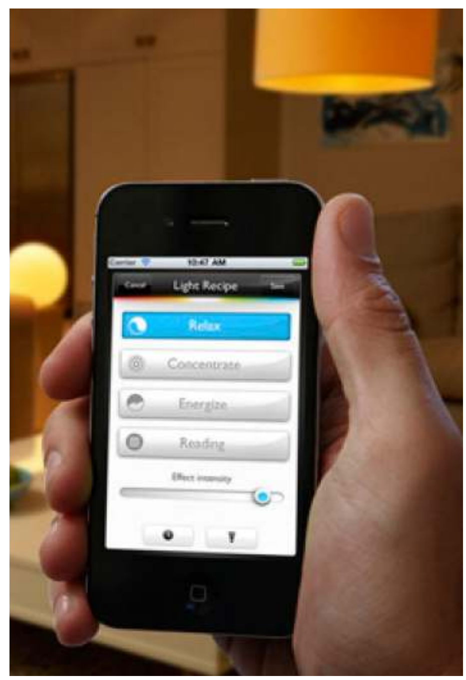

Fig. 4 The Philips Hue wireless control application with presets (image source: http://flic.kr/p/dpaxEj)

the foreseen large amount of connected light sources that will be embedded in our environments, it makes sense to approach novel lighting systems as part of the broader trend of ubiquitous computing [7] and related fields such as ambient intelligence. In the "Views on Ambient Intelligence" [1], two interesting atmospheric concepts are presented. Nebula is an interactive projection for the bedroom that is controlled by placing themed pebbles in bedside pockets and dynamically tuned by analysis of bodily movement (p292). Aurora allows you to draw light patterns on an illuminative wall to create an atmosphere (p296). Ross and Keyson present an expressive tangible interface for ambience creation that allows people to adjust light, sound and projections by manipulating flags on a rotating carousel [8]. Mason and Engelen [9] present Globe UI; a tangible user interface that is focused on lighting control for hotel environments and is based on atmosphere association that people have with various cultures. Westerhoff et al. [10] present M-Beam, a tangible interface that is

Fig. 5 Fonckel one (image source: https://www.fonckel.com/dotAsset/4ecdbd58-2c1f-4215-ba4d-49672d600790.jpg)

based on the concepts of valence and arousal and can be manipulated on these parameters to control lighting and sound in a home environment. In one of Philips' Experience Labs [11], a lighting interface for shops owners is mentioned involving a physical colour picker to create atmospheres that best match the items displayed. Ishii et al. [12] present the ambient room in which various ambient displays that are in some cases based on light, provide information of various sorts. They also present two interfaces to control the available information: a clock to browse through temporal events and a bottle through which information can be "uncorked". Although the interface influences lighting in the environment, it is not intended to provide atmospheric lighting, but rather information.

All of the interfaces mentioned so far are a type of graspable [13, 14] or tangible [15] user interface. This type of interface may be especially suitable for the control of lighting interfaces as they are ready at hand for the users and to some extent form an integrated part of the environment.

When addressing particular lamps, rather than the room as a whole, one of the issues in interaction with multiple luminaries is the definition of the effect; in other words, which lamps should respond to the command? For remotes, the pointing interaction is a popular approach to this problem that has been addressed by several people. Delamare et al. [16] propose the most defined approach that works at two levels of selection detail and use the light of the luminaire itself as a feedback mechanism. An alternative approach is presented by Wiethoff et al. [17], who use an augmented reality approach on a mobile phone to paint on a large media façade; an approach that could similarly be used for lighting actuation. Magielse and Offermans [18] present a system where one can use a tablet PC to "paint" the lights displayed on a topographical map of a room.

The systems presented in this section all rely on different qualities. The diversity of these interfaces show the width of the field and the variety of angles from which the control challenge can be approached. We believe designers will benefit from a more structured understanding of the matter, which is what this paper aims to contribute to.

2.3 Relation user and system control of lighting

With the technological changes, the role of system behaviour in lighting control is increasing. How to approach this (partial) shift from user to system control is an important topic in the aim for increased benefit of novel lighting systems. There is a fair amount of work regarding the influence of user control (vs. automated systems) in office lighting, mainly aiming for a balance between reduced energy consumption and user comfort. Findings suggest that automated systems have the potential to reduce energy consumption [19]. Nevertheless, allowing a user to have control over its lighting has a positive effect on user comfort [20] and may still result in reduced energy consumption, compared to automated systems aiming for legislation standards [21]. The use of smart systems that employ principles of artificial intelligence may further contribute to the balance between user comfort and energy consumption [22].

There are also several studies on the effect of control on the user experience. Some studies are done in a rather controlled environment and for instance show that self-chosen colour appears to induce relaxation [23]. In another study outside the laboratory, Meerbeek et al. [24] studied the use of an automated blind system in an office environment. They suggest that the perception of control rather than the objective control is most important for user comfort.

In general, there are numerous considerations for designers of interactive systems regarding the relation between user and system, and the behaviour of a system in context. Kulkarni [25] discusses behaviour of the intelligent room and poses 6 design principles for intelligent systems. Bellotti et al. [26] pose five questions for designers that aim to support the mutual understanding of user and system. Wensveen [27] proposes the Frogger framework in which he aims to bridge possible gaps between user input and system output using six characteristics of the coupling between input and output. Edwards et al. [28] pose seven challenges for designers of ubiquitous computing environments which provide useful guidelines that can very well be applied to lighting systems.

The increased control freedom (and complexity) in novel lighting systems creates new opportunities for systems to support the user. The balance between user and system control and how they relate are therefore of significant importance. The extensive research on this topic in the area of lighting can be seen as a confirmation of this significance.

The related work presented in this section provides an overview of various efforts to contribute to the increase in benefit from new technologies for lighting (both lighting technologies and intelligent environments). What we aim to add with the work presented in this paper is an understanding of what should be considered when designing for novel interactive lighting systems. To gain this understanding, a user study was conducted which will be presented in the following section.

3 Study setup

3.1 Aims

We have conducted a user study to identify what is important in the interaction with light in terms of light effect and control. We are looking for underlying motivations for using and adapting light in an environment in order to identify generic principles that can be used in the design of light control interfaces. We wish to explore the interaction design space by learning both from current everyday practice and evaluating novel interface concepts. Eventually, we aim to provide the reader with an insight in the important aspects in the interaction with lighting, especially to support the design of lighting interfaces that open up the opportunities of novel lighting systems.

3.2 General methodology

The general approach for the study is an adaptation of the context-mapping [29] method in which one aims to identify (latent) needs of users in a particular context. This method first consists of a sensitizing phase in the form of a sort of cultural probes study [30]. In a probes study, people perform small exercises provided by the researcher during their daily routines. The sensitizing phase is primarily intended to prepare participants for a second phase by making them more sensitive to the specific topic at hand (in this case the interaction with light). The second phase is a (group) workshop in which participants usually discuss their probes, but most of all participate in a generative session in which they design something based on their experiences during the sensitizing phase.

This approach was largely adopted with the addition of an "experience" session. After discussing the probes in the sensitizing session and before the creative session, participants were invited to try out several novel interfaces that were designed to support the possibilities of novel lighting systems. The addition of the experience session is intended to allow participants to include the opportunities of future lighting solutions in their thought process during the creative phase. Simultaneously, they can use their gained sensitivity in the previous phase to position these novel solutions in a day-to-day context and reflect on the qualities and shortcomings of such lighting systems and their controls.

3.3 Participants

Thirteen people took part in the study. Participants were selected based on three criteria. First, we aimed to have a broad spectrum of lighting environments and usage and therefore looked for participants with varying living and working environments. Second, we aimed to have a variation in the extent to which participants were conscious and caring about the lighting in their environment. Finally, people had to live in close proximity to the university in order to be able to participate in the workshop phase. Participants were also chosen such that age (mean = 35, stdev = 18) and gender (female = 6) varied across the participants. Recruitment was done by word of mouth which allowed us to insure the selection criteria were met.

3.4 Phase 1: sensitizing

The sensitizing phase involved a type of probes study [30]. In this study, participants were asked to complete several assignments in which they had to pay attention to their usage of and interaction with light and document this in various forms in a booklet (Fig. 6). Each day of the sensitizing phase, which lasted for 1 week, they were asked to do one assignment which each focussed on different aspects of their interaction with light.

This phase serves two purposes. First, it is used to gain a broad insight in how people interact with light in their daily environment. This aims to address questions such as: When, how and why do people control light in their environment? What aspects of the interaction are considered important? The second purpose regards the actual "sensitizing". For the workshop phase, it is essential that participants have a certain degree of awareness and sensitivity with regard to the usage, control and possibilities of light in their environment. The sensitizing phase was conducted in the week prior to the workshop.

We will now briefly describe the assignments that the participants got with a short motivation.

3.4.1 Day 1: my light is…

As warm-up exercise, people were asked to say something about what they generally thought about the lighting in

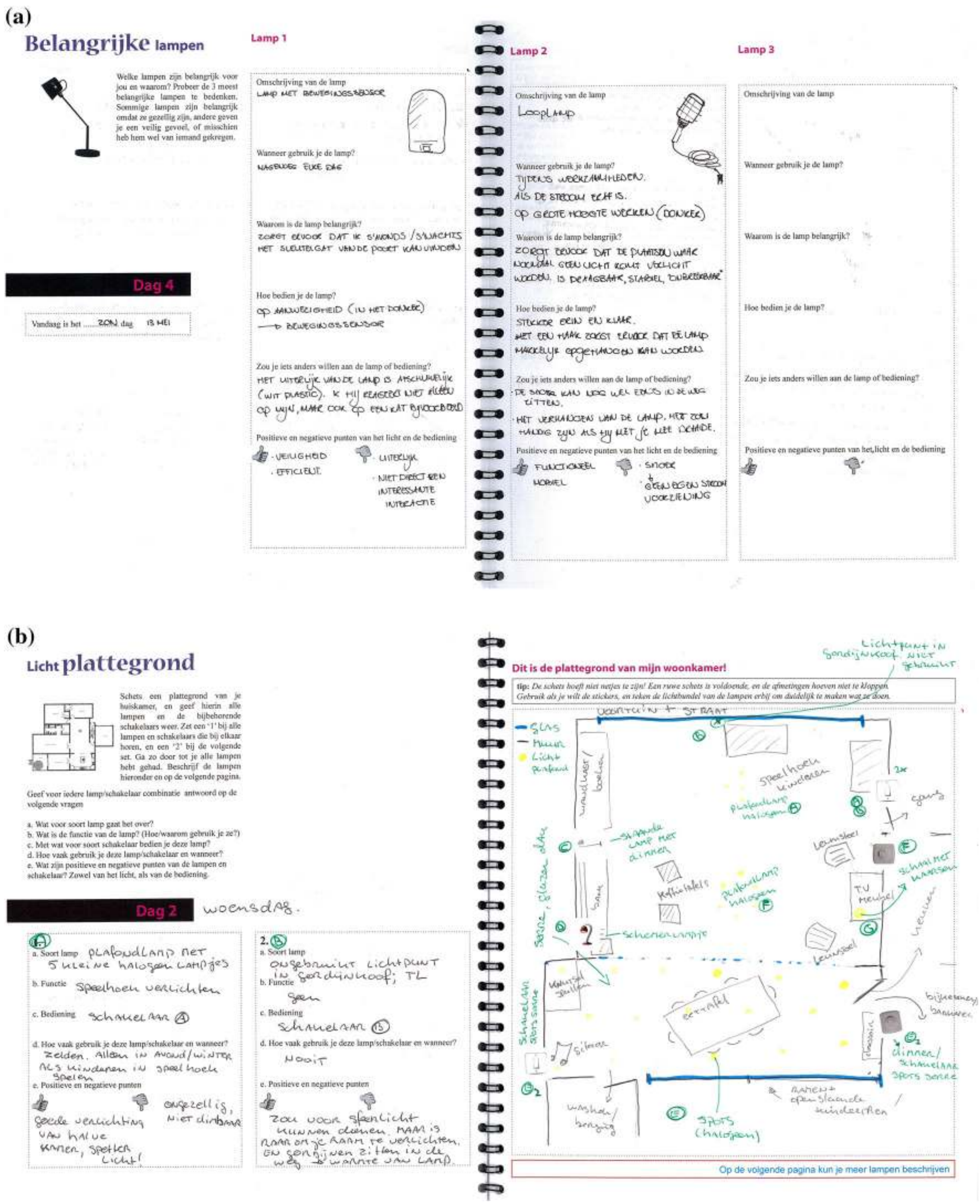

Fig. 6 Two filled-in pages from the booklet used in the sensitizing phase. **a** The assignment for day four: "Important lamps" (*top*) and **b** assignment for day two: "Map your house" (*bottom*)

their home environment. This was intended as to get people thinking about their lighting in the first place in a low-threshold fashion.

3.4.2 Day 2: map your house

In this assignment, participants were asked to make a map of all lights and light controllers in their living room and to draw connections between them. Additionally, they were asked to tell something about the most annoying and the best control/lamp combination. Through this exercise, we aimed to provide participants with some situational awareness about the lighting in their own living environment and reflect on their daily use. It also aimed to provide a large amount of data regarding usage of various lights and controls, along with their positive and negative aspects.

3.4.3 Day 3: light in your environment

For 1 day, people were prompted at three times during the day through a text message. They were asked to look around the environment and denote a light-related effect which may be objective (e.g. flickering fluorescent tube) or subjective (e.g. emotional effect). Through this assignment especially effects of light and the ubiquity of it were addressed. Also, it aimed to provide some insights in desirable aspects of light effects in various situations.

3.4.4 Day 4: important lamps

Participants were asked to reflect on three of the lamps that were most important to them. This exercise aimed to elicit reflection on the underlying qualities of light which increased awareness with the participants and aimed to provide us with insights in these qualities.

3.4.5 Day 5: post-it night

For one evening, participants registered all their interactions with light by placing a post-it note in near the controller with every interaction. After one night, participants were asked to reflect on the interactions, in particular looking at recurring patterns, often used controls and the ones that they felt were interesting for some reason. Through this assignment, we aimed to learn about the frequency of use (and nonuse) of different lighting controls and the underlying motivations.

3.4.6 Day 6: being together

Participants were asked for 1 h not to control any lighting, but ask someone else instead (e.g. the partner). After this hour, they were asked to reflect on the particular ways in which they communicated about the light. This-rather odd-assignment was intended to elicit explicit formulations of lighting desires. These formulations are interesting as they are essentially what needs to be communicated to a lighting system.

3.5 Phase 2: workshop

The aim of the workshop phase in context mapping is to obtain the latent needs of the user. The primary means to achieve this is a generative session in which users create something which will express these latent needs. The sensitivity gained during the first phase regarding the interaction with light allows them to do so. As we are aiming to get a broad overview of all that plays a part in the interaction with light, we were also interested in the more explicit needs and therefore looking for interesting and recurring topics in both explicit and latent needs. The workshop was also an opportunity to confront the participants with possible future systems and let them reflect on these systems based on their gained sensitivity which also exposes additional needs and desires.

The workshop was performed in four separate groups of three (in one case four) participants and lasted approximately 2 h per workshop. Each workshop consisted of three main parts: first a *discussion session* about the experiences during the sensitizing phase. Second, an *experience session* in which participants were invited to a living laboratory (Fig. 7), where they interacted with a novel lighting system through various specially developed interfaces which we will describe later on. Third, a *generative session* in which the participants designed their own ideal lighting environment for their house and a controller for that environment. The workshops were video-recorded for analysis purposes.

3.5.1 Discussion session: sharing experiences from the sensitizing phase

In an open discussion, participants discussed their experiences during the sensitizing phase regarding interaction with light by going through their assignment booklets. The experimenter asked one person to tell about his/her experiences during an assignment, specifically looking for the most interesting and most typical aspects of these experiences. Other participants were encouraged to add their experiences to the discussion. This process was repeated for all assignments, with a different participant starting the discussion each time.

This discussion was primarily intended to identify recurring themes in the interactions that people had, specifically allowing them to reflect on the experiences of others. This was important as it provided an opportunity for people to state their opinion on matters that they had not explicitly discussed in their own booklets. The discussion was also intended as a warm-up for participants' thoughts on the topic.

3.5.2 Experience session: interacting with novel lighting interfaces

During this session, participants were asked to interact with a novel lighting system and several concepts for future lighting interfaces (Fig. 8). This was intended to broaden the participants' view of what can be achieved with light and what other possibilities there are in terms of control interfaces. It also served the purposed of getting to know which aspects of this type of novel lighting and interfaces were appreciated and why.

Fig. 7 The living laboratory in which the experience sessions took place

Fig. 8 Stills taken during two of the experience sessions

The experience session took place in a laboratory that is decorated with couches and lounge chairs to support small informal meetings and personal retreat in the working environment. The laboratory contains a lighting system that connects numerous dimmable warm white lights and coloured wall-washing (Fig. 7). All lighting can be controlled through various interfaces (seven in total) that were designed to vary on potentially relevant parameters of the interaction such as the level of control, the degree of "tangibility" and the amount of system "intelligence". Some interfaces control light parameters of individual lamps, while others control the room's atmosphere as a whole. A more elaborate description of the living laboratory infrastructure can be found in [31]. The interfaces will be described in detail below.

The participants each used two of the available interfaces and were asked to first explore the interface's workings while thinking out loud. This was done in order to elicit initial reactions to the system and to get an idea of their understanding of the system. Secondly, the participants were asked to provide a review for the other two participants in the session, pointing out advantages and disadvantages of the interface, where they to have it at their home. The other participants were stimulated to contribute to a discussion and question the reviewer. This review process was intended to trigger critical reflection and the development of (an explicit description of) a rationale to back their initial opinions.

Fig. 9 LightCube

Overview of the interfaces that were used during the experience session:

1. *Light cube* A $7 \times 7 \times 7$ cm cube with abstract atmospheric images on each side (Fig. 9). On rotation of the cube, the lighting in the environment will change such that it reflects the atmosphere of the upward facing side of the cube.
2. *Smartphone application*: *individual lamp control* A smartphone application that can be used to determine

Fig. 10 Individual lamp control

Fig. 11 Room control application

the settings for each individual lamp through a colour wheel and brightness bar (Fig. 10).

3. *Smartphone application*: *room control* A similar application to the previous interface, except this variant controls all lamps in the room simultaneously. Additionally, one can set "dynamics" of the light which results in a continuous colour changing effect with adjustable speed and colour variation (Fig. 11).
4. *Smartphone application: cosy/lively parameter grid* Through this application, one can set the lighting through a simple atmospheric description on two parameters: cosiness and liveliness. These parameters are suitable to describe a particular atmosphere [32]. By selecting a position in a two-dimensional grid that represents these parameters, the lighting is adjusted to match the requested atmosphere (Fig. 12).
5. *Phone application*: *activity control* A smartphone application that can be used to indicate the type of activity people are going to do, active/relax and alone/in a group (Fig. 13). The system uses this information

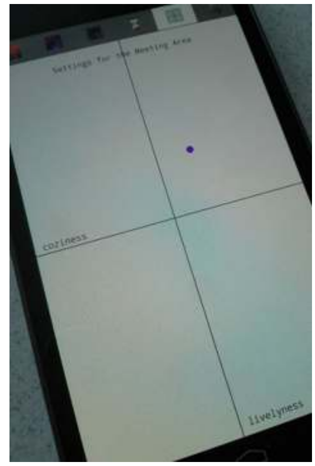

Fig. 12 Cosiness—liveliness atmosphere control

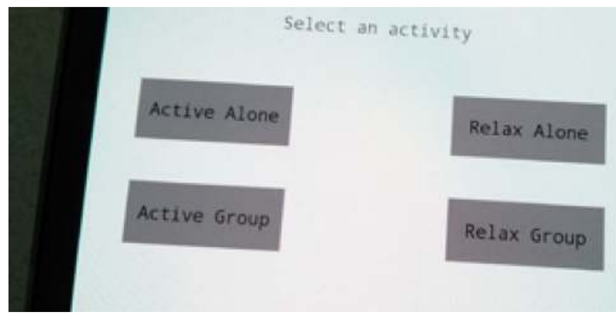

Fig. 13 The activity selection application

Fig. 14 LightPad

along with sensorial information such as the amount of outside light, the noisiness in the area and the time of day, to predict and actuate the most suitable lighting. The system chooses from eight presets, based on a learning algorithm that was "trained" prior to the study. People are able to select a different preset if they were dissatisfied with the proposed lighting, which could in turn be used by the system to improve future predictions.

6. *Light pad* A soft pad on the wall that can be used as a light toggle switch (Fig. 14). Touching the pad once

Fig. 15 Illuminating touch table

turns the light on, once more turns the light off. When touching to turn the light on, the expression of the touch determines the resulting light. The pressure and duration of the touch are mapped, respectively, to light intensity (harder is brighter) and colour temperature (longer is warmer).

7. *Illuminating Touch Table* (*LeCube*, Le et al. [33]) A small coffee table that is a luminaire itself (Fig. 15). By pressing the top of the table, one can toggle between four different behaviours of light in the table, which sets the environment lighting to match the light of the table.

3.5.3 Generative session: designing your ideal lighting and controllers

The aim of the closing generative session was to let participants to express their latent needs based on their experiences during both the sensitizing phase and the discussion and experience sessions (Fig. 16). People were asked to first design their *ideal lighting environment* and second to design the *lighting controller* for that environment. The design of the lighting environment was done by drawing a quick map of their living room and adding lighting features in there. People had approximately 10 min to do this. The aim of this exercise was mainly to identify the desires regarding light when virtually everything is possible. The next step was to design the controller for this particular environment. To do this, people were provided with set of basic tinkering tools and asked to create a physical representation of what the controller would look like. This method was chosen over drawing, as participants' drawing skills could be too limited to quickly communicate ideas or desires and tinkering may more easily promote exploration of different ideas for people with limited drawing experience. People had approximately 20 min for this assignment. Afterwards, the designs were plenary motivated and discussed with the group.

3.6 Analysis process

To prepare the data for analysis, we transcribed all remarks regarding light and interaction in the booklets from the sensitizing phase, as well as the remarks made during the workshop phase that was video-recorded. This yielded a total of 830 quotes which were printed on cards. In various iterations, these quotes were clustered based on the practices of interpretative phenomenological analysis (IPA) [34] and affinity diagramming [35] (Fig. 17). The aim of such methods is to organize qualitative data into related groups. These clusters are labelled afterwards to identify the relevant themes, of which the content is interpreted and generalized conclusions are drawn. As the eventual aim of our efforts is to inform the design of interactive lighting systems, the clustering and conclusions formed the basis for an additional step in which considerations and opportunities for design were identified. This process took place in 5 steps as follows:

1. Initial open clustering to determine the basic structure (using ca. 200 of 830 quotes). This session was performed by the first author and a colleague that was not involved in the project (facilitating an initial clustering that was not primarily formed by prior knowledge on the topic).
2. Fitting quotes in existing clusters, creation of sub-clusters and refining existing structure (using ca. 200 additional quotes).
3. Looking for recurring patterns within the clusters to identify general consensus' regarding the cluster's topic (e.g. a cluster may regard the location of light controls, while a general consensus may be that people prefer to have their light switch near the door when arriving at home). This step also involved the creation of a final cluster structure (and fitting all quotes). This structure was the basis for a set of relevant *themes* in the interaction with light that is an important part of the results of this study and will be discussed in the next section. Steps 2 and 3 were performed by two of the authors.
4. Drawing high-level generalized conclusions from the clusters and its consensus'. These conclusions are the derivative of the content of the various clusters, but also regard the relation between them. All authors performed this step together.
5. Identifying design considerations and opportunities from high-level conclusions and the themes. Here, we translated the drawn conclusions into opportunities for the design of future lighting systems and their interfaces. This has been a process of several weeks and was performed by the first author, also having frequent discussions on the status quo with the co-authors.

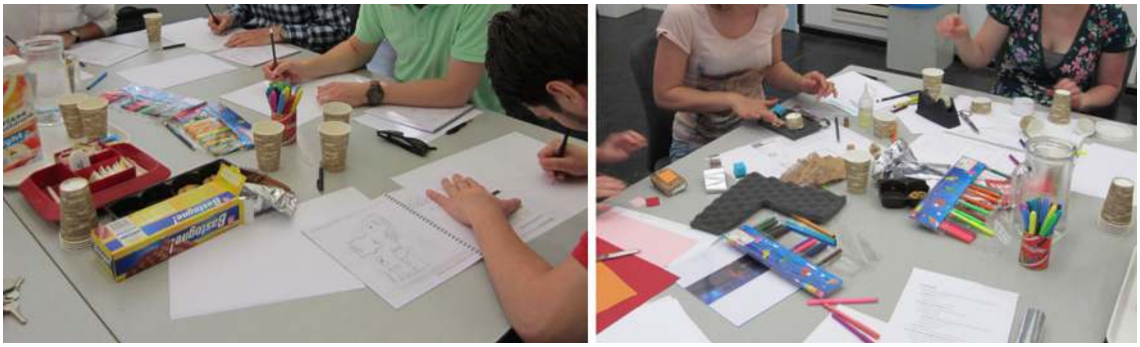

Fig. 16 Stills taken during two of the generative sessions; designing the lighting environment (*left*) and the controller (*right*)

Fig. 17 One of the affinity diagramming sessions

In the following sections, we will discuss the findings including results, conclusions, design considerations and opportunities. The findings are split into two sections: one with themes regarding the user and its context and the second addressing the themes that regard the user interfaces for light in particular.

4 Findings 1: user in context

The main aim for the study was to gain an understanding into what aspects are considered important by people when interacting with light and more specifically to identify motivations for interaction. These insights are intended to inform the design of future lighting systems and their controls. We will describe the findings by means of seven general themes (Fig. 18). We will introduce each theme based on the results from the study and discuss the aspects of this theme that were considered important by the participants. This will be illustrated with quotes from the participants' remarks that were made during study. Finally, we will draw conclusions and pose considerations and opportunities for design.

In this section about the *User in Context*, we will describe three themes of findings that are related to the user and the context. In the next section, we discuss the remaining four themes which regard the *Lighting User Interface*.

4.1 Light; importance, usage and needs

Although in general light is considered important by the participants, their needs for light vary largely depending on the environment and their activities. Lighting is used primarily for illumination and atmospheric purposes and in some cases as a carrier of information. In this section, we will discuss the important aspects of the lighting needs and usage that emerged from the data.

4.1.1 General light usage: functional and atmospheric, central and peripheral

Most participants at some point state that they consider lighting to be important and assume the light to have an effect on them, both in practical and emotional terms. One participant states "The light in my house is important, to be able to see and for the atmosphere". To provide this lighting, several types of light sources are mentioned. Daylight is generally considered most important and pleasant; "On dark days I sometimes feel the lamps are a necessary evil, as daylight is the most pleasant". In terms of artificial light, all participants have one or two large general (living-) room illuminator(s) that provide instant general illumination of the entire space. They are mostly used when entering a room (not for longer durations) or for instance when cleaning or ironing. The switch that controls them is usually near the door which is appreciated; however, the light itself is generally disliked. "I would prefer to get rid of the ceiling lamps, but for practical reasons it is quite nice, for instance that you can see the floor when you are vacuum cleaning". Besides the ceiling lamps, it appears that people like to have lights in their periphery. It is most often dim lighting from small lamps in the corner or

Findings 1 - User in Context

Light; Importance, Usage and Needs
General light usage – Functional and atmospheric, central and peripheral
Lighting needs are latent needs
People have varying levels of lighting needs

Context and routines
Lighting- and interaction desires depend on the environment, user-intention and social context
Light usage can be routine or support routines

Interaction Motivation
Rewarding light from low-effort interaction
Interaction itself can be rewarding
Personal investment can be rewarding

Findings 2 - Lighting User-Interface

Degrees of Freedom in Control
Support varying degrees of freedom
People have fairly fixed lighting scenes
How do we access the degrees of freedom?

Control Location and Availability
Controls are desired where the user is
Interaction should match the flow of the activity

Automation and Autonomous Behaviour
Automation is accepted and appreciated under strict conditions
Smarter systems are desirable and can go beyond reactive systems

Interaction Qualities
Experiences of fun, magic and competence are appreciated
We may leverage off of the existing interaction paradigms and mental models

Fig. 18 Overview of the findings in their more general themes that are split into two sections

coming from a larger light source in an adjacent room. This type of light mainly supports the atmospheric needs. One participant nicely summarizes; "The small lamps are distributed along the sides of the room, and the big light that is hardly used is central". Finally, there are various more dedicated function lamps such as reading lamps and lamps above the dinner table. Reading lamps are in some cases also used to create an atmosphere, while the dinner-table lamps more often function to provide immediate bright light when entering.

4.1.2 Lighting needs are latent needs

When asked, the participants were able to express their needs regarding their lighting, especially by means of current shortcomings. They mention a lack of daylight, dark corners, a broken bulb. However, lighting needs often appear to be latent needs; people seem generally satisfied with their lighting as long as they do not critically think about it. This became especially apparent as all participants initially stated they were satisfied, but would immediately come up with shortcomings and improvements. "I am quite satisfied with the light that I have; except there is one dark corner that is not well lit".

4.1.3 People have varying levels of lighting needs

As stated, people have certain needs regarding their lighting. However, it appears that these needs are not always equally present, known, nor can they always be described in the same way. When entering a room at night, participants often simply described the need as "light". People need basic illumination of the space to orient and feel safe in the environment. "The ceiling lamp in the hallway is the first to turn on when we get home; it is functional and safe as it allows to see where you go". When being somewhere for an extensive period of time or when the lighting is used for a specific activity, the needs seem to shift. They become more detailed but less "demanding". "The ceiling lamp in the bedroom is used for reading and getting dressed. It could be a bit brighter for reading and less bright for getting dressed". This appears to be quite typical and shows that more detailed improvements are imaginable; however, the current situation is also acceptable for both activities. When lighting is used for atmospheric purposes, the descriptions of needs become more "environmental" (i.e. people talk about the room instead of a lamp and a desire for dim light in their periphery) and more integrated (i.e. also regard other elements like music/temperature). Also the needs are described in a less technical fashion; rather than describing for instance directionality, descriptions may regard "warmth".

People thus seem to have different levels of lighting needs. Based on the study results, we define *basic visibility*, *functional* and *emotional* needs or low-, middle- and high-level needs.

Interestingly, there seems to be an inversely proportional relation between the level of lighting need and the willingness to invest effort in it. Low-level visibility needs should be fulfilled with minimal effort, whereas high-level emotional needs may require more interaction effort.

Concluding, people are generally satisfied with their lighting as long as they do not think about it. There exist generalizable patterns of lighting use, involving central and peripheral light, and we are able to distinguish several levels of lighting needs. Being aware of people's lighting needs and the distinguishable levels will allow designers to create lighting interfaces that take these needs into consideration and are in tune with the willingness to interact in relation to particular needs. Which type of interaction is suitable for the various levels of needs requires further exploration and is most likely highly dependent on the context.

4.2 Context and routines

Throughout the study, participants consistently described their experiences and desires regarding light and interaction in relation to a particular context and often in relation to their daily routines. In this section, we will discuss the relation and importance of context to the interaction with light.

4.2.1 Lighting and interaction desires depend on the environment, user intention and social context

Lighting desires as well as the willingness to interact with the light appear to be highly context dependent. Participants desired different lighting in different situations, and the strength of this desire also varied. Moreover, their desire for control and the extent to which they wish to spend time on this varied with context. This context (or situation) in which the interaction takes place can be described by several context parameters. Schmidt et al. provide a working model for context describing the human factors (user, social environment, task) and physical environment (conditions, infrastructure, location) [36]. The relevant context parameters for lighting control that we have deduced from the study concern mainly environment conditions (e.g. darkness), user's task or intention (e.g. get something from the fridge) and social environment (e.g. in a conversation). These context parameters are important for the interaction as they have an influence on its suitability. How specific is the desire for a particular kind of light? How much time would you want to spend on the interaction? How often does this interaction take place? "The light switch in the kitchen is most used, it is important if you quickly want to get something". Such contextual information can support the definition of requirements for the interaction. In the above example, the frequency and rapidity of use should for instance be reflected in the quick availability of the control.

Regarding the light itself and the preference for different kinds of lighting for different situations, it appears that one can only draw very general conclusions regarding these preferences (e.g. dim light is preferred in cosy settings). However, it appears to be important to take the various context parameters into account when determining the amount of freedom that the user will have in relation to the situations that may occur in the particular space. It seems that if too little freedom is offered, the lighting may be unsatisfactory, however, too much freedom in a situation where it is not desired results in cumbersome control. "The control happens with a dimmer, which requires me to look for the right brightness every time; this should be different". Depending on a person's current context, it may be more or less desirable to spend time on setting the light. Apart from time, also the availability of the control should match the context. For instance, while relaxing on the couch, a remote control would be more convenient than a wall-mounted switch which requires you to get up. "If you are on the couch you would have to walk to the wall to change it; you don't want that…". The remote of a coloured lamp (e.g. Philips Living Colors) may be great if you want to set a mood for a cosy evening. However, if you are in a hurry, it is dark and you need to find your keys, a light switch near the door would probably be more convenient.

Lighting also appears to play various parts in the social context. People state they wish to provide illumination (or atmospheres) for others. "I would certainly want the light to change, but I probably won't do it. But I would for special occasions though; when I have friends over". In this sense, the social context can be a motivation for interaction. People also may not wish to disturb others with their light. "The ceiling lamp in the hallway is used by my boyfriend when he gets dressed in the morning; this way he can leave the light in the bedroom off when I'm still in bed". Some participants also mentioned the importance of having the right light depending on the social relation to the person you are with "…for instance with a new boss I would like more [brighter] lighting because you don't know each other".

4.2.2 Light usage can be routine or support routines

Usage of light also appears to be very much related to routines. Many people stated that their usage of lighting is very much the same every day, in some cases almost ritualized. For instance, when dusk sets in, several participants mention walking around the house turning on all small lamps. When going to bed, the sequence of switching on and off the various lamps is always done in the same way. "We have a small ritual when dusk sets in; we make a round through the living room and turn on the lamps (in various ways). Usually the same settings…".

It also appears that activity-related routines (e.g. arriving at home, cooking, going to the bathroom) often require specific lighting that is usually the same over time but differs per activity. Interactions, however, seem to be rarely designed to support the routine and are usually the same for each situation. The interaction as well as the lighting for these routines could benefit from a more dedicated approach. The study shows that one of the most common routines is the "quick-in-and-out" (i.e. getting something from the kitchen, walk through hallway, get something from cupboard). The needs participants describe for lighting in these situations are basic (only visibility is important) but usually immediate. Therefore, the light response should be quick (e.g. waiting for fluorescent lighting is considered annoying), and the interaction effort should be minimal. “The light in the bathroom becomes brighter over time [fluorescent bulb]while I usually only need light for one second”. People indicate the opportunities for automatic lighting as some have in a cupboard or outside. “When lighting is functional, it could be automated” and “The light in the kitchen only needs to be on for a few seconds and should then turn off again; automatic switching when entering the kitchen would be good”. Apart from the routine and usage frequency, this also relates to people forgetting to turn off the lights. “It would be nice if the lamp would turn off automatically, my boyfriend tends to forget to turn it off”.

In general, the participants mostly only adapted light when changing rooms (and sometimes when changing activities) or when the (natural) light changes significantly. “During the evening, not much lighting changes; at dusk the lights go on and we turn them off at night, with some exceptions [like getting something from the kitchen]”. When entering a space, it appears that the participants generally desired basic illumination. The lighting that is used is often considered not to be very pleasant (too bright), but mostly used for its control location next to the door. “The ceiling lamp in the hallway is the first to turn on when we get home; safe, functional, as it allows to see where you go” and “In every room we have a ceiling lamp that serves the purpose of quick light very well; enter the room, and turn it on”. It appears that lighting control is often performed as part of another primary activity, making it a type of peripheral interaction [37, 38]. Interactions that are part of a routine should therefore be designed to be peripheral and being executed together with the primary activity.

There are also routines that involve interactions with multiple lamps that frequently reoccur in the same sequence. A lighting routine that appeared to be common among the participants regard turning on and off the lighting, respectively, at dusk and bedtime. Some of these routines could be seen as activating “lighting presets”, which is an opportunity in terms of interaction design. On the other hand, the way people adopt their lighting rituals may also be used to make interaction with lighting part of the daily life.

Concluding, people’s desire for lighting is for a large part determined by the user’s context (or situation); this context also influences their motivation to interact. The current interaction with light is often based on activity routines, and in some cases, the lighting usage itself can become a routine.

4.3 Interaction motivation

As stated before, lighting is considered important by most of the participants. Nevertheless, they often take the current situation for granted, and the considered importance does not always translate into action to adjust the lighting to their needs and desires. “The study made me realize how boring we actually are (in setting our lights)” and “It is strange that something we find so important, we take for granted”.

Participants state that they do not adapt the lighting because either the current situation is acceptable, adjusting takes too much effort or they cannot significantly improve the situation. “I am very lazy when it comes to tuning the light—often I rather stay seated”.

We will now present study results and conclusions that relate to the effort and reward that people experience when interacting with light.

4.3.1 Rewarding light from low-effort interaction

The change in lighting may be very rewarding comparing to the interaction effort. This may be the case because (a) the current situation is undesirable, (b) the improvement is significant or (c) the effort of the interaction is relatively low. This requires awareness about the current lighting situation and the potential for improvement. It appeared that this awareness was often very low as people did not have a clear idea about the opportunities of the lighting and what they would want. “…sometimes my girlfriend is on the couch with the laptop and it has gone dark completely, and then I ask; why are you in the dark? Then she says; uh yeah I am quite comfortable”.

Raising awareness about the lighting conditions and supporting decisions on it may contribute to the motivation to interact. This could also reduce the mental effort required to make the changes, both in terms of what to change and how, as well as in terms of changing the lighting in the first place. To raise this awareness, there is an opportunity for system designers as the systems could play a more active role in the environment and provide suggestions depending on the situation.

4.3.2 Interaction itself can be rewarding

The interaction itself may also be rewarding. Participants mention the control itself being fun; “…turn it on using a rope; actually kind of fun!”. Interaction may also create a feeling of competence or magic (i.e. relation between user action and system response is not self-evident). “In old movies people do this clapping to turn on the lights. It’s rather cheesy but also magical”. Interaction may also be rewarding from a social perspective (e.g. lighting candles for someone or providing light when needed).

Finally, reward may also not be immediate. In case of learning systems for instance, “training the system” may result in a reward in the longer run. “…if it is really smart, and I know it will learn so that I won’t have to do anything later on, then I am willing to put the effort in training it!" In general, "investment" may result in long term reward.

4.3.3 *Personal investment can be rewarding*

From the discussions with the participants, it seems that a higher personal investment in lighting, either financially, creative, (e.g. choosing lamp, refurbishing, positioning/installing) or emotionally (e.g. heritage) results in higher appreciation of the light and in increased awareness about its current state. As a result, they may also be more inclined to interact with it. This could be a strong and interesting principle that can be applied in the design of lighting interaction.

Concluding, in the current situations, the effort-reward balance for controlling light often tends to lean too much towards effort which means that people often do not control it. The lighting is not rewarding enough, people are not aware of the potential improvements, and the interaction takes too much effort or is not rewarding in itself. It is important to note that the concepts of effort and reward are also highly context dependent. What may be rewarding in one case may be a burden in the other and vice versa. We believe that if we aim to let people interact with the light in order to benefit most from their lighting, the interaction with light should be "worth it". "Worth it" may be seen as an *effort-reward balance* tending towards the reward.

5 Findings 2: lighting user interface

Now that we have discussed the three themes regarding the user and its environment, we will describe the remaining four themes of findings regarding the lighting control interfaces, taking the user and environment into consideration.

5.1 Degrees of freedom in control

There seems to be an inherent trade-off between control freedom and control effort; a large degree of control usually requires more effort in order to exert that control. However, depending on the particular situation/context, both a high degree of control and low effort can be considered important and are mentioned as such. "… the light above the table should be adjustable so I can have a lot of light, but you can also create an easy atmosphere". On the other hand, "I really liked the foot switch; no dimming, but just on off so you can quickly reach it".

5.1.1 *Support varying degrees of freedom*

From the study, we identified two main parameters that determine the degree of control; the detail in which a particular lamp can be attuned (i.e. number of adjustable parameters per lamp) and the amount of lamps that are affected by the interaction (i.e. control one lamp or group of lamps). Setting multiple lamps individually with many degrees of freedom provides a high level of control which requires effort. Alternatively, controlling multiple lamps at once with a single degree of freedom (e.g. intensity) is quick and easy, but results in lighting that is most likely not optimally attuned to the situation.

In the study results, it seems that a low degree of control is sufficient (and often desirable) when it comes to overseeing the environment. For instance, a simple on/off mechanism that allows for bright illumination of the room was mentioned as a desirable feature by almost all participants. However, in many cases, more subtle and detailed control is desired, for instance to create atmospheres. "Lamps that cannot be moved or dimmed are turned off to preserve the atmosphere". Based on these results, we believe that it is important to support the user with varying levels of control, depending on the context of use.

There may also be a potentially interesting inverse relation between the levels of lighting needs discussed before and the desired level of control. It appears that people want quick control if the lighting is "basic", while they are willing to put more time and effort in a creating an atmosphere.

5.1.2 *People have fairly fixed lighting scenes*

Most participants in the study have relatively fixed lighting scenes, light settings that are recreated with recurring situations (e.g. activity, available natural light). "Usually the dimming of the small lamps is basically the same. There is a certain setting that is pleasant". This probably explains why all participants considered "presets" for multiple lamps to be a desirable control concept. This was most often expressed after having seen both the detailed control application on the smartphone and the LightCube with presets in the study. "This is nice, it gives you all the freedom you would like (smartphone application), but I would use it to create presets". It was emphasized that these presets should be defined, adjusted and labelled by the users. "…when I have found a setting that I feel good with, I would like personalized icons to go with the preset". Participants generally wished to control lighting in this holistic fashion. "…we are more interested in one holistic atmosphere (makes round shaped hand gesture). I don't really care about which lamp does it, it's about the result". On the other hand, they also indicated that sometimes they wish to have a higher degree of control to be able to control individual lamps or make adjustments. "I would like the possibility to make small adjustments". Adjusting the current setting is also considered more easy than determining the desired lighting from scratch, which was mostly verbalized when evaluating the LightPad on the wall that did not allow adjustments. "You should have something that allows you to adjust it (the lighting) a little bit, not such that you first have to turn it off".

5.1.3 Mapping the human and technical control parameters

So far we have discussed the level of freedom that is desired in different situations. Through which control parameters this freedom should be provided is another question. In the current interfaces, there are limited degrees of freedom (i.e. mostly intensity) and a direct mapping to the control parameters that are provided to the user (e.g. intensity via dimmer). The interfaces that were provided during the workshop aimed to control more degrees of freedom (e.g. colour), through a limited and comprehensible ("human") set of control parameters (e.g. cosiness/liveliness, activity-based lighting, cube with presets). From the experience sessions, it appeared that people often appreciated this approach. "This (cosiness/liveliness) is very clear!" and "I do like setting an activity or atmosphere. Such a colour wheel (individual lamp control application) I would never use…". However, how to make the mapping between the human and technical parameters is yet unclear (what is "cosy" lighting; and is this the same for everyone in all contexts?). After selecting a relaxing activity, a participant states: "This is quite bright for relaxing light". Which indicates the personal nature of these definitions. Also, the parameters used in the cosiness/liveliness application are not natural to everyone. "It is difficult to predict the outcome of a (cosiness/liveliness) setting, although I start to understand the mapping, and I may need a bit of learning". This study did not provide too many insights on how to approach this mapping problem, but rather confirmed the need for further research if we wish to control more degrees of freedom.

Concluding; the study shows the opportunities for customized presets in lighting interfaces, especially since people already have these fairly fixed lighting scenes. There are interesting opportunities that relate to smart interpretation of rich input to reduce the complexity that traditionally comes with a high degree of control. Two of the interfaces used in the study session, the LightCube (presets) and LightPad (smart interpretation), can be seen as examples of this. The lowest degree of control, no user control or automated lighting, is discussed more elaborately in the paragraph on automation and autonomous behaviour.

5.2 Control location and availability

From the study, it appears that whether or not the control for a desired adjustment in lighting is (immediately) available determines for a large part whether or not people will interact with their lighting. The availability may be even more important than the gained result. "… the small lamps in the corners are less easily used in comparison to the wall switch because you have to go to the lamp which creates a barrier; I often don't use them".

5.2.1 Controls are desired where the user is

From the participants, it appears that control availability is first of all determined by whether the adjustment is available in the lamp itself (e.g. dimming or colour adjustment) and whether there are controllers to support that. This is closely related to the freedom discussed in the previous section. Secondly, the location of the controller seems to be extremely important. Participants indicate that they are often too "lazy" to move to adjust the lighting. "… except when I want to read, than I turn it up. Although I am often too lazy to actually do that. A remote would help". About half of the participants had a remote control for (some of) their lights, and all indicated that they would like to have it because of its immediate availability, which allows them to continue their current activity (or inactivity). Remotes were also liked because they can control multiple lamps from one position and because the position of control is where you will experience the light effect. Nevertheless, there were experienced/foreseen downsides such as having "another remote control" (we already have so many), the lacking aesthetics of the device, and most of all; it may get lost "The size is too big; it is another remote, but if it is smaller I will lose it…". There are currently two primary locations from which people wish to control their light: near the door and at the place where the light is experienced. The latter can almost only be achieved when the lamp itself is at the location from which it will be experienced or using a method to remotely control the light. The switch near the door is a common convention which is appreciated and considered appropriate in nearly all situations.

The use of a mobile phone is also widely considered, both in the interfaces that were used in this study, as well as in commercial applications such as Philips Hue (Philips Hue, www.meethue.com). There is an interesting paradox regarding the availability of the mobile phone interface as it is almost always at hand, however, takes quite some time and effort to actually manipulate the light compared to a tangible and dedicated interface. "That pad (iPad) and phone are practically a part of my body, I won't lose it and always carry it with me", on the other hand: "I like the combination of full control if you want(through the smartphone app), but that is not what you will do if you quickly need light".

5.2.2 Interaction should match the flow of the activity

Another important aspect of availability besides the control location that came forward from the results is the extent to which the control interrupts the current activity. It seems that the feeling of availability increases if the control fits the activity flow. When entering a room, conventions regarding light switch positions allow us to quickly turn on the light. Participants appreciated this a lot. Alternatively, when relaxing on the couch, the activity may be least disrupted if lighting can be controlled using the iPad that is already in use. "… I am playing with my iPad; it would be quite convenient if I could use it to change the lighting". Increasing the availability of the control by fluently integrating it in the ongoing activities and providing it in the right location may increase the willingness to interact and therefore contribute to a better light setting.

Concluding, the control location and availability determine for a large part whether or not the user will adjust the lighting. Having the control where the user is, and fitting the user's current activity will increase the likeliness the user will adjust the lighting.

5.3 Automation and autonomous behaviour

The automatic (or even autonomous) behaviour of lighting systems may become a prevailing feature of lighting systems in the near future as their complexity and context awareness increases. Currently, autonomous system behaviour is mostly limited to automatic on and off switching or dimming of the lights and in some cases control of blinds.

5.3.1 Automation is accepted and appreciated under strict conditions

The automatic switching in the current situation relies mostly on presence detection, dusk detection (light level) and "door-open-detection" (e.g. light turns on when door of a cupboard/refrigerator is open). These forms were all mentioned during the study, and it appears that this form of automation is in some cases accepted and appreciated. It appears to be appreciated if lamp usage is always the same. "All lamps have a separate control; however when it goes dark, you turn them all on anyway; this should be automatic". Another participant expressed the desire for a system's understanding. "I switched the lighting on and off a lot when I did or did not need it. At some point I stopped doing that (because of the hassle). It would be nice if the light would know when I needed it". This is especially the case if the lighting is quickly used "functional" light. "Particularly in the attic or washing area the light could be automated, not in the living room". Automation is also appreciated if manual control is difficult (e.g. dark, hands full). "The lamp in the alley behind the house makes me feel safe, and I can see in the dark. It switches on automatically on movement". Most importantly, it appears to be only appreciated if it works as expected or desired. One of the additional perceived benefits is potential for reduced energy consumption. "The automatic lamp is (energy) efficient".

The appreciation for automatic light, however, is often also outweighed by various dislikes, for instance, if manual control is very easy. "I was discussing that with my boyfriend; would it be convenient if every time I walk through the hallway the light would turn on automatically? And we thought no; if you are near the switch anyway, it is almost no effort". Another participant states "Switching light on and off when entering/leaving the kitchen is not disturbing because it is automatism". There seems to be a contradiction with the aforementioned appreciation of automation in case of frequently used "functional" lighting. This contradiction may be explained by the annoyance that is caused if a system does not function as desired; even if this rarely happens (e.g. slow response, erroneous off switching). "…when we have visitors, I turn the autopilot (timer) off. It is so stupid when you have visitors and the lights suddenly turn off" and "You often see that, Smart Systems, that are just not well enough thought through so that its plain annoying".

Finally, there seems to be a general desire to be in control. "There are light sensors present. Light turns up if it becomes dark or if other tubes turn off. Unfortunately it's not controllable." This is in line with the findings presented by Newsham et al. [20], who stated that allowing a user to have control over its lighting has a positive effect on user comfort. Therefore, even in case of automatic systems, the user should still be enabled to control the system.

5.3.2 Smarter systems are desirable and can go beyond reactive systems

As can be deduced from the comments in the previous paragraph, people would appreciate autonomous lighting if it was smarter. This is also affirmed by the observation that when lighting is controlled by other people (which could be seen as a very smart lighting system), there is generally a high degree of acceptance/appreciation. "Without conversation, turning on and off lights goes well; we have been together for a long time". People (also users) are very much aware of the context and of the state of other people. *You usually ask (if someone can turn on the light) when* *someone is near the light switch, so she knows it is that light that I am talking about.* This sheds a light on an interesting shortcoming of current smart systems which are often ubiquitous and body-less which makes it difficult for people to observe their state and whether the system is observing them.

There are also interesting opportunities that regard a more subtle and supporting role for autonomous behaviour beyond mere automation. During the creative sessions, people came up with concepts that do interpret user input and manipulate the light accordingly, rather than simply switching the light on based on sensor values from the environment. "…a small ball represents your little cocoon, and that you can make less bright light (encloses ball in hands), or more light (opens hands), or disco light (shakes ball heavily)" and "you squeeze it and it allows you to express yourself". Such systems thus require system intelligence to interpret the user input. As it appeared from the experiences with the LightPad, these interactions are not the same for everyone and every situation, so smart systems could learn and adapt mappings between user input and lighting output based on usage of the interfaces. This line of research is part of our ongoing work.

Concluding, automation is accepted and appreciated in situations where light control is frequent, always the same, not so easy to do by yourself and if the automation works as expected. It is, however, disliked if it there is a chance that it does not function properly, while the gain is minimal. There are also interesting opportunities for smarter behaviour by the system that goes beyond simple reactive behaviour, which is especially useful for lighting systems with many degrees of freedom.

5.4 Interaction qualities

Apart from the findings discussed so far, there are other aspects of the interaction that have a large influence on peoples' willingness to interact, as well as on the appreciation of the resulting light. These aspects are interaction qualities that are not related to the inherent functionality of the interaction but regard the user experience of the interface design.

5.4.1 *Experiences of fun, magic and competence are appreciated*

During the study, people gave various examples of interactions that were considered "fun". Among others, participants mentioned a rope switch that is fun to pull, a footswitch that you could step on when walking by the couch and the presented smartphone application. Other positive experiences that were mentioned were feelings of magic, competence/skill and playfulness. "Everyone wants such a magic wand" and "It (LightCube) is nice to play with". Designers can exploit these principles to contribute to the interaction motivation, keeping the suitability for the particular context in mind. That being said, designing for such experiences should be a conscious decision that results in a *possibility* rather than an obligation as for instance playfulness is most likely not always appreciated. "It's a bit hard to control, because I play with it. If you have kids, your house will be a disco".

Participants also seemed to appreciate the diversity in lighting control. This was explicitly mentioned mainly regarding the control experience. "Light is fun because we have various switches. On/off with your foot, dimmer, touch-toggle-dimmer, on/off switches" and "By turning the lamp over (electronic candle) you turn it on or off; nice to have something different than a switch". Moreover, this appreciation exists apart from the control experience which becomes implicitly apparent as different interfaces were considered suitable for different situations.

5.4.2 *Leverage the existing interaction paradigms and mental models*

Another important aspect of the interface design regard people's understanding of the interface. The mental models (understanding of how something works) that the participants had of existing lighting systems appear to be very simple: a direct relation between in- and output which was almost always correct. In some cases, when the assumed model is incorrect (e.g. left switch for a lamp on the right, or flicking the switch upward to switch it off), it is quickly considered annoying. But in most cases, when mappings are consistent, this is considered intuitive. "Sliding is very intuitive; more, less light".

During the experience session, when people used the novel interfaces, it became apparent that people often used their knowledge of existing interaction paradigms from other domains and applied them to novel lighting interfaces, rather than levering their knowledge of existing lighting controls. For instance, while using the LightPad, one of the participants stated: "Ok, I am going to touch it longer, so I expect to get more light". This is promising as this opens possibilities for the use of richer interaction paradigms. In comparison, in current lighting controls, almost no metaphors are used and the user interface parameters are mostly the same as the technical parameters of the lamp. When discussing the novel interfaces during the workshop, it appeared that people seem to be able to understand the metaphors that were used, once they know how they are intended. "Once it is explained (energy metaphor of the LightPad: what you put in is what you get out) it is easier to remember and do it right". Also in the generative session, one of the participants made an object that would control the light by reflecting the way the device was handled. "…when watching a movie, lighting may reflect the intensity based on how you hold the thing". Such metaphorical mappings may support an intuitive understanding of the relatively complex interaction with a multi-degree of freedom system.

A lack of interaction feedforward and feedback in some of the interfaces that were presented resulted in misunderstanding and quickly in a general disliking of the interface. For instance for the LightPad, "This is not practical. I am too hasty and un-nuanced. It is nothing for me". To compensate, the interaction could also draw from existing interaction paradigms and leverage existing mental models.

The tactile qualities of the interface are also considered important. People indicate that the softness of the LightPad was pleasant for lighting control, although they saw impracticalities in terms of hygiene. Besides the pleasant feel, the softness also supported an understanding of the interaction "There is a kind of soft pad, so it asks me to do something touchy". In other words, the affordances of the interface matched its sensory capabilities (detecting touch).

Concluding, it is clear that apart from the functionality of the system, there are certain qualities to the interaction that may contribute to the interaction motivation by making the interaction more understandable or making it more rewarding in itself. This can largely be done by applying general design principles from the field of interaction design, but should carefully be considered in the context of lighting control.

6 Discussion

In the previous sections, we have presented the results and conclusions of a study that was performed to identify the important aspects of the user interaction with everyday lighting. Additionally, we have highlighted opportunities and considerations for the design of user interfaces for novel lighting systems. In this section, we will first discuss the limitations of this study after which we will make a first step to identify relations between the different findings. Finally, we will discuss the general contributions of this paper to the field of interactive lighting systems.

6.1 Limitations of the study

The experience sessions during the workshop phase took place in a laboratory setting and were therefore not subject to the contextualization of the interaction experience that we found to be so important. We therefore do not know whether the remarks made regarding the novel interfaces would also have been made if the same systems were part of everyday life. For example, during the experience session, the usage of a smartphone as a controller was considered practical as it was always carried around. However, this is most likely not always the case, for instance when taking a shower. Nevertheless, we believe that because the remarks from all phases were combined in the analysis process, such context-naive remarks were counterbalanced by the contextualized remarks from the sensitizing phase and in some cases by participants reflecting on the usage of these novel systems in an actual context.

The data that were gathered in this study are the result of the participants' personal reflections and the discussions in the workshop sessions. Consequently, the topics that have been raised are the result of the participants' experiences during (and also before) the study period. The findings therefore cannot provide a complete and exhaustive overview of all possible relevant themes in the interaction with light, nor do they indicate how important or prevailing each of the identified themes is. Rather the themes provide a starting point for the emerging understanding of and design support for—interfaces for interactive lighting systems.

6.2 Relations in the findings

In the findings, we have presented and discussed the results from the study, clustered by affinity into themes. Although the results are clustered, the resulting themes are discussed in isolation, while naturally they are strongly connected. To gain a coherent understanding of the interaction with light, it is important to also understand the relation between these themes and the ways in which they influence each other. We will now discuss our initial ideas about the relation between these themes.

So far, we have presented the findings in two separate sections, one focussing on user-/context-related themes and the other on user-interface-related themes. This distinction is a result of the way people described their interactions with light, combined with our primary interest in interaction design and our intention to support the interaction with light. An initial relational model could describe the themes is shown in Fig. 19, which highlights the influence of all themes on the interaction motivation and the influence of the user and context on the interface design.

This initial model reflects the results and conclusions of the study. It is, however, not yet a coherent model that describes the interaction with light. In future work, we aim to create such a coherent model, specifically aiming to support the design of lighting control interfaces.

A fundamental assumption that underlies the value of the presented conclusions is that motivating people to interact with their lighting will improve the light experience. The reason for this assumption is that the light that is the result of user interaction will most likely be closer to

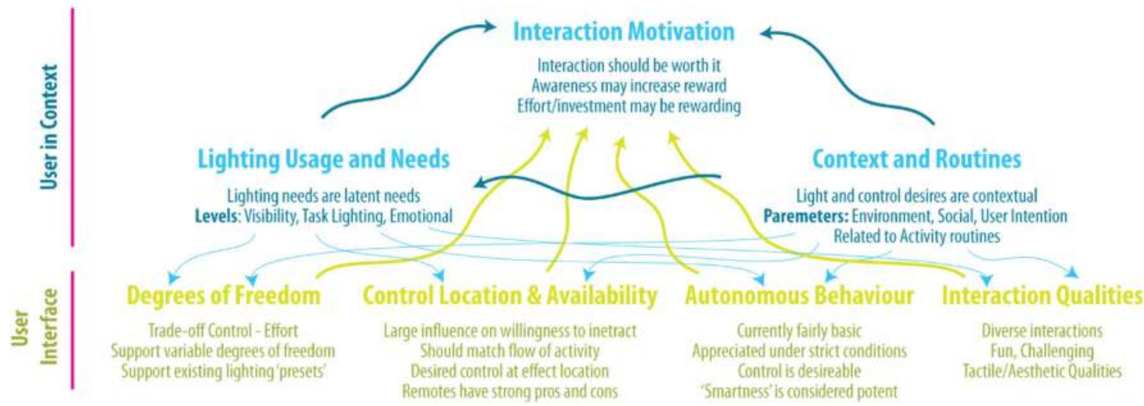

Fig. 19 Initial relational model describing the themes found in the study

the user's preference. Although we have no evidence that interacting with light actually improves the experience, there are strong indicators for this. One important indicator is that people consider lighting to be important, they are able to describe shortcomings, but they are often unable to improve the situation. Furthermore, interacting with lighting more frequently is likely to increase the awareness of the lighting, which in turn may contribute to the appreciation of the light and therefore the experience. In short, as lighting needs are largely latent needs, it is worthwhile to let people explore the effects that different lighting can have on them. Motivating people to interact with their lighting can thus be seen as a goal in itself.

6.3 Contributions of this paper and future work

This paper reports on a study towards the control of current and possible future lighting systems. This can be seen as a domain specific investigation of a class of interactive systems, which means that many of the findings concern general interaction design principles. The main contribution of this paper is the provided focus on the themes that are specifically relevant for lighting control. These themes mainly regard the levels of lighting needs and levels of control freedom, especially in relation to the context of use.

Although we believe every context/situation will benefit from a different interaction, it makes sense to try and develop more general *interaction styles* that describe a general way of interacting with a lighting system. An abstraction from the actual interaction may provide useful handles for the design of lighting interfaces. In traditional human-computer interaction (HCI), various styles have been identified that describe a general way of providing input to a computer (e.g. menus and form fill-in) [39]. Apart from a description, these styles come with their positive and negative aspects in different situations. Similarly, the design of interactive lighting control would benefit from a description of general interaction styles, accompanied by their pros and cons in different contexts. The development of such interaction styles is part of our future work. These interaction styles will have to be identified from a body of work (i.e. interfaces used in context) that can be analysed. We therefore set out to create numerous user interfaces for novel lighting systems in different contexts. The findings presented in this paper provide the basis for the design of these new interfaces.

Concluding, this paper reports on a study on the interaction with everyday lighting. From the results of this study, we have identified seven relevant themes. With these themes, we aim to provide a starting point for the emerging understanding of interfaces for interactive lighting systems, as well as to provide support for the design of this type of interfaces.

Acknowledgments This research is part of the Smart Context-aware Services (SmaCS) project which is funded by the Point-One programme. We would like to thank all participants of the study for their efforts and feedback.

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