Exploring In-Air Gestural Interaction with Home Lighting

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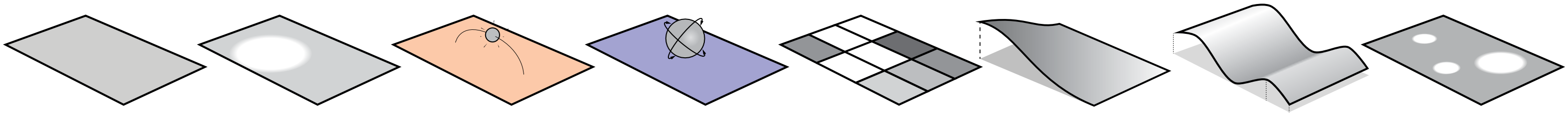

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PREFACE

This thesis is prepared at the Department of Computer Science at Aarhus University, Denmark, in fulfilment of the requirements for the MSc degree in IT Product Development. The thesis work is equal to 30 ECTS points.

The interest in lighting comes from our initial experiences with the Philips Hue smart bulb system - a lighting system, which provides homes with all imaginable colours, imitates a sunrise in the morning, and autonomously changes colour to visualise the weather outside. And… controlled by the smartphone(!) We found ourselves, standing, right in front of our new and beautiful smart bulbs in a state of despair, as we could not interact with all these features without digging down into our phones.

Although we respect the practical potential of smartphone integration, we agreed, "*there must be a more delightful way to interact with these beautiful lighting features*". Inspired by the foci on interaction design and user experience inherited from the researchers associated with our education, we set off on a journey.

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Project supervisor: Tim Merritt

All figures and photos in this thesis are made by the authors unless stated otherwise.

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ABSTRACT

Lighting is a key aspect of the design of interior spaces, which serves functional purposes of illuminating tasks, accentuating the objects and materials in the room, and setting the atmosphere experienced by the occupants. More recently, the commercially available, controllable, multi-coloured light emitting diodes (LEDs) have been introduced in the home domain, providing new possibilities when using and interacting with light.

While much research has focused on tangible lighting interfaces embedded in physical objects and smartphones as remote control, there has not been sufficient attention on how the expressivity of bodily movement can be used when designing interactions with home lighting. Therefore, we investigate interaction with lighting technology beyond the smartphone and physical controllers, and examine the potential of the emerging in-air gestural interaction style for lighting control.

Based on literature and empirical studies, we frame the design space of in-air gestural interaction with home lighting. This knowledge is synthesised into an initial framework with five dimensions including: acceptable interaction effort, contextual lighting needs, lighting features available, mapping schemes, and required interaction effort. We then pose two research questions, which ask how we can design in-air gestural interaction with home lighting, driven by key aspects identified, and further explore related implications and concepts.

We take a research through design approach in order to explore the uncharted area of interactive home lighting coupled with the in-air gestural interaction style. To focus our research, we create the *Gestural Lighting Platform* for prototyping in-air gestural interaction at the dining table to support functional and emotional lighting needs. Using this platform, eight prototypes are systematically developed to explore the dimensions of the initial framework.

Based on the exploration of prototypes, we make the following contributions. First, we extend the initial framework into what we define as the extended framework for in-air gestural interaction with home lighting. This extension adds two dimensions: number of individual lights and whether individual lights are movable. The extended framework can be used analytically and as inspiration for future in-air gestural lighting applications in the home. Second, through three field studies and two expert evaluations of the prototypes, we present a number of contextual implications and promising concepts that emerge, which can inform designers of future in-air gestural lighting in the home. We finish this thesis by discussing future perspectives of our work, including the potentials seen in other domains.

ACKNOWLEDGEMENTS

We would like to thank everyone, who has devoted time and effort to help us with this thesis.

First and foremost, we could not have asked for a better project supervisor. Tim Merritt, you have spent countless hours helping us out, and have continuously been providing highly relevant feedback and guidance. We sincerely appreciate your effort – thank you! Marianne Graves Petersen, we thank you for your valuable guidance as supervisor throughout the project. Your expertise in interaction design has been of utmost importance at all stages of the process.

Next up is our dear friends. Thank you for participating during our initial workshop. This was the key to get started. A special thank you goes to the friends, who agreed to have our prototypes integrated as part of their daily lives. We hope it was as fun for you as it was for us!

We would further like to thank you, Kätte Bønløkke Andersen, for sharing your lighting expertise with us early in the process, and for setting up the design workshop with your students. Ted Selker, we thank you for your qualified feedback during your visit at the department. The people who invited us into their homes for interviews, and those who visited us in our lab and engaged with our prototypes over the past months… Thank you!

Finally, we thank you, Pusheen the cat, for always being here when we need you the most. You make us smile.

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1 INTRODUCTION

This first chapter introduces this thesis by outlining the domain of home and lighting, in which our work takes place, followed by the state-of-the-art lighting technologies and the current approach of the research. We introduce in-air gestural interaction as a potential interaction style for interactive lighting. Next, before stating our contributions, we briefly state our research approach, and pose our two research questions. Lastly, the structure of this thesis is provided.

Outlining the domain

In the home, lighting is a key aspect of the design of interior spaces, which serves functional and emotional purposes of general illumination, supporting tasks and activities, accentuating objects and materials in the room, and contributing to the atmosphere experienced by the occupants. Ever since domestic environments started to get equipped with electricity, the home has been subject to commercial tools that assist humans in their daily lives, e.g. the vacuum cleaner, food processors, and sewing machines. Later, technology developed to not only be a tool in activities, but to contribute to the activity in the home, e.g. television and personal computers (Harper, 2003, p. 20).

The world today

Recently, the commercially available, multi-coloured light emitting diodes (LEDs), which are controllable from a computer, power saving and with 20 years lifespans have been introduced to the market as an alternative to traditional light sources. In Europe, the incandescent light bulb was banished for sale in 2012 by the European Union (EU Commision, 2010), as these light sources were declared too inefficient after 100 years of service. In line, IKEA, the global furniture retailer, has announced to discontinue selling incandescent and fluorescent lights entirely and will sell only LED lights by 2016 as one of the first large retailers in the world (IKEA Group, 2012, p. 18). Further, IKEA also plans to substitute all store lighting with the energy saving LED, thus phasing out all other lighting sources. These initiatives push consumers to consider the LED alternative, despite the currently added costs and colour reproduction limitations.

On the other hand, this new technology provides new possibilities with home lighting. Modern LEDs allow for 16.8 million unique colour combinations of red, green and blue along with 256 levels of brightness (Philips, 2012a). This new combination of lighting and technology is put into our daily lives, and we are given the control.

Commercially, we have started to see interconnected smart bulbs for the home, e.g. LIFX, Philips Hue, and Stack Alba (LIFX Labs, 2013; Philips, 2012a; Stack Labs Inc, 2014). These commercial trends tend to hide the interaction of features in the user's smartphone, but do these market trends really represent what the user needs, or is there more to this? We see several practical benefits in utilizing the smartphone as a central platform for interaction, e.g. dynamic interface, 'always' with you, remote access and control without dedicated remote controllers. However, this direction comes with a list of shortcomings: smartphones can be displaced from the user, other residents and guests cannot interact without connecting to the wireless infrastructure, and interacting users are not necessarily situated in the lighting environment they are controlling (Magielse, Hengeveld, and Frens, 2013). Socially, the action of physically switching the lights on/off or adjusting the brightness provides immediate, visible clues to other people in the context.

Towards new interfaces for lighting control

We wish to challenge this trend, and investigate how the emerging LED technology can be used in new interfaces for interaction with lighting. In research, this has been recognised by Aliakseyeu and colleagues who set up lighting workshops on the international conferences INTERACT 2011, AmI 2011, DIS 2012, CHI 2013, and NordiCHI 2014 (Aliakseyeu, Mason, Meerbeek, Essen, and Offermans, 2011; Aliakseyeu et al., 2012, 2013, 2014; Aliakseyeu, Mason, Meerbeek, Essen, Offermans, et al., 2011). Here topics included ambient intelligence, interaction design, user interfaces, user studies, evaluation methodologies, connectivity with other systems, degree of autonomous behaviour, and embedded lights in daily objects. Additionally, Offermans et al. (2014) recently explored the initial design space of interactive lighting interfaces and present important aspects regarding the interaction in a relational model.

Research has also developed various lighting interfaces embedded in physical objects, which allow for personal, direct, and expressive lighting control (Cheng et al., 2012; Magielse and Offermans, 2013; Ross and Keyson, 2007; Ross, 2008). Further, research has examined social aspects of lighting control (Magielse et al., 2013). Looking beyond smartphones and physical controllers, and into the field of natural user interfaces (NUIs), we find the in-air gestural interaction style. Research has found that interactions relying on bodily movement possess unique interaction qualities in terms of expressivity and supporting the capabilities of the body (Jacob et al., 2008; Leithinger, Lakatos, DeVincenzi, Blackshaw, and Ishii, 2011). In-air gestures as an input style effectively allow for communication of your intentions to other participants through interaction (Klemmer, Hartmann, and Takayama, 2006) and allow for the possibility of engaging multiple users simultaneously (Wigdor and Wixon, 2011, pp. 37–41). Further, in-air gestures allow for remote control from where the user is situated (Juhlin and Önnevall, 2013; Wigdor and Wixon, 2011, p. 97; Zoric, Engström, Bark Huus, Ruiz Hidalgo, and Kochale, 2013).

Research approach and research questions

Thus far, the in-air gestural interaction style has been combined with home lighting to a limited extent. Although a number of technical solutions exist in this area, the qualities of the user interaction have not been deeply explored. Therefore, we set forward to explore this area from an interaction design perspective using a research through design approach inspired by Zimmerman, Forlizzi, and Evenson (2007). This approach has its roots in design research and has proven useful in practice, when working with “wicked problems”, which cannot be easily defined and addressed using traditional approaches.

Based on our empirical studies and review of the literature, we frame the design space for in-air gestural interaction with home lighting. This knowledge is synthesised into an initial framework with five dimensions including: acceptable interaction effort, contextual lighting needs, lighting features available, mapping schemes, and required interaction effort. From here, we pose our two research questions

How can we design in-air gestural interaction with home lighting driven by lighting needs, features, and mapping schemes?

What implications and promising concepts does in-air gestural interaction hold for home lighting?

To address our research questions, we have iteratively been creating research artefacts, based on implications related to lighting needs and the proposed mapping schemes between gesture and system functionality. These research artefacts take the form of prototypes (which will be the term we use in this thesis), where each prototype holds design knowledge and is a specific framing of our research problem.

Contributions

Following our approach to addressing the research questions, we provide a summary of our contributions. First, we develop an extended framework from our initial framework for in-air gestural interaction with home lighting, which can be used to analyse examples of interactive lighting systems and as inspiration for future in-air gestural lighting applications in the home. Second, we discuss and present a number of contextual implications and promising concepts that emerge from field studies and expert evaluations, which can inform and inspire designers of future in-air gestural lighting in the home.

Video material and included paper

Accompanying this thesis is a short video (length 01:40), which provides an overview of eight prototypes developed as part of our exploration. The video presents the interaction in each of the eight prototypes, and can be viewed on Vimeo (Andersen and Sørensen, 2014a).

Additionally, the last prototype, which we have named Tangible Lights, was accepted as a work-in-progress paper for the 9th international conference on Tangible, Embedded and Embodied Interaction, *TEI'15* (Sørensen, Andersen, and Merritt, 2014). The paper can be viewed in Appendix 1. A video walk-through (length 01:23) of the Tangible Lights prototype can be viewed on Vimeo (Andersen and Sørensen, 2014b).

STRUCTURE OF THIS THESIS

In the next chapter, we present and frame the domain of lighting in the home, including three empirical studies. These provide empirical knowledge, which is necessary in order to understand people's lighting routines in daily life. Following this, we present the perspective of home lighting for this thesis. In chapter 3, we review related work on lighting control today and in-air gestural interaction, where key qualities and challenges are outlined.

Chapter 4 frames the design space of in-air gestural interaction with home lighting. This is done by reviewing the existing design space of interactive lighting, before discussing it against our empirical studies. Next, the areas of interactive home lighting and in-air gestural interaction are combined, before synthesising the knowledge into an initial framework for in-air gestural interaction with lighting. From here, we discuss the identified opportunities for blending the areas, before posing two research questions and the scope of this thesis.

In chapter 5 we develop the *Gestural Lighting Platform*, on which we systematically explore the dimensions of our initial framework through prototyping. As a result of discussing this exploration, chapter 6 presents an extended framework, which can be used analytically and as a generative tool. Moving on to chapter 7, three field studies and two expert evaluations are presented, conducted, and discussed. Finally, chapter 8 presents the identified potentials of the in-air gestural interaction style in combination with home lighting in terms of implications, concepts and future directions.

To strengthen the overview of key parts in this thesis, it is worthwhile to note that the research questions presented in chapter 4 are addressed and presented with the following structure. The first research question is addressed throughout section 5, before the answer is presented in chapter 6. Similarly, chapter 7 addresses the second research question, before presenting the answer in chapter 8.

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FRAMING THE DOMAIN OF HOME LIGHTING

This chapter serves to provide insights into the domain of home lighting that this thesis is concerned with, along with clarification of terminologies. Next, to obtain empirical knowledge on home and lighting, this chapter reports on three empirical studies, including a contextmapping study, interviews with long-term Philips Hue users, and a lighting expert. Finally, all sections are combined into our perspective on home lighting, which this thesis builds upon.

LIGHT

Light in a human perspective forms the basis for our visual perception of dimensions, materials, texture, details, colours etc. (Bønløkke Andersen, 2012). Humans are dependent on the visual perception to navigate and make decisions based on visual input. Light affects our behaviour and perception of space (Flynn, Hendrick, Spencer, and Martyniuk, 1979; Zhong, Bohns, and Gino, 2010). The types of light sources affect not only our visual perception, but also our emotions (Bitner, 1992; Knoop, 2006) and social behaviour (Magielse and Ross, 2011; L. H. Taylor and Socov, 1974). For instance, picture candlelights in the windowsill, a warm fireplace, or bright warm sunlight striking the skin. Research has also found that the psychological influence of light can improve performance and renew mental capabilities (K.C.H.J. Smolders, de Kort, and Cluitmans, 2012; Karin C H J Smolders, de Kort, Tenner, and Kaiser, 2012).

In a historical perspective, we, as humans, have been seeking to lengthen the day by creating light, as we strongly depend on our visual perception. In history, combustion has been the main source for emitting light in the darkness, until the introduction of the electrical light in the 19th century. The control of light has been under development since the dawn of man, from the less controllable bonfire to the more controllable torch. The revolutionary electricity and the pursuit of the incandescent light bulb have changed our way of life, and light sources have transformed as fast as the industry of electronics we see today (Bowers, 1998).

The articulation of light and its properties vary between disciplines. Here we distinguish between science and arts. In the perspective of physics, light can be described as electromagnetic waves or photons according to the wave-particle duality ("Wave–particle duality," 2014). Photons are emitted from a light source and particles in space reflect the photons. When wavelengths fall in the approximated range of 400 to 700 nanometres, the human eye perceives the electromagnetic waves as colours as seen in Figure 1 (Stark, 2014). Therefore, the perceived colour of an object is related to the wavelengths being reflected by the material of the object. The object consumes the rest of the wavelengths and transforms it to heat.

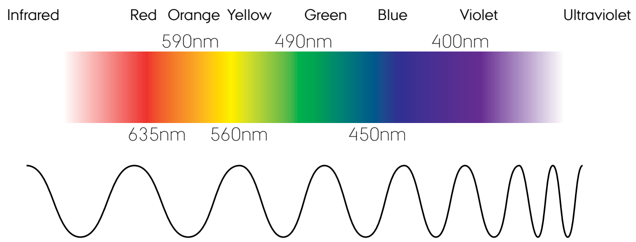


Figure 1. Wavelengths visible to the human eye

In another area of science, engineers focus on the technicalities of light emitting technologies, creating the most efficient artificial light sources with the highest colour rendering index as possible. Technologies have been developed to enable digital manipulation of light for visual perception and as a communication tool for computers. This includes displays, projections, fibre optics, Morse systems, etc.

In an artistic perspective, architects are concerned with how light can support a liveable environment and shape space by creating three-dimensional spaces perceived through light. They consider how light changes space throughout the day and year. Architects as Poul Henningsen (lived 1894-1967) designed with a focus on how light can be perceived and articulated through architecture without blinding the user (Figure 2). Today, other designers, e.g. Jan Bjarnhoff (2014), work with light as part of the interior in the home to create desirable homes, hiding the lighting fixtures away (Figure 3).

Also relating to the artistic perspective, in theatres, light has been used for centuries to set the stage and focus of a scene (Figure 4). Light is also used in musical concerts as in theatres to emphasise and augment the performance (Figure 5). Artists use light as a factor or means of creating art, provoking our perception of light (e.g. optical illusions) or letting light shift our focus or mood accordingly, as a theatrical scene. Light can embrace and change the perception of space using colours (Figure 6) or by considering the location of the viewer (see Figure 7), as seen in the work of artist James Turrell (2014).

Figure 3. Light fixtures are hidden in this manor. Lighting design by Jan Bjarnhoff

Figure 2. Koglen, 1957, by Poul Henningsen. A design icon of his work

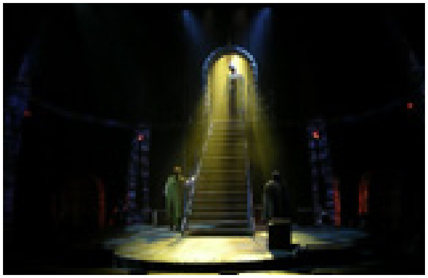


Figure 4. Theatre. Staging the mood with the light in the scene, creating a dramatic effect -


Figure 5. Concert. Light augments the sound of the band


Figure 6. Shanta Pink,1968, James Turrell


Figure 7. Roden Crater, East Portal, 2010, James Turrell

THE HOME

Home is a dwelling place where its inhabitants can relax and enjoy their spare time. It is the geographical place where a person lives. The home constitutes the feeling of belonging somewhere and has different physiological influences on its inhabitants, and it can influence their emotions, behaviour and mental health (Boutruche, Bourgeois, and Lyamouri-Bajja, 2008), e.g. the way we behave behind closed doors.

Historically, the home has been divided between dwelling place and work, even though farmers have maintained the interrelation of co-located family life and work. Today, the home office is getting popular in Denmark, but people still tend to distinguish between home and office, as they possess different psychological meanings (Lynggaard, 2012, pp. 18–33). This duality is also recognised within research on interactive lighting and it provides, *"... opportunities to adapt environments to the dynamics and flexibility of everyday life"* (Magielse and Ross, 2011).

Varying activities

Every home is different due to architectural and subjective values. These aspects coupled with the ethnographic properties of age, stage of life, income, gender, sexuality, culture etc. affect the way people organize their homes (Crabtree and Rodden, 2004). Within homes, the authors outline domestic routines, which relate to a sequence of reoccurring, practical actions, e.g. *"getting out the door, feeding themselves, putting the children to bed"* (Crabtree and Rodden, 2004, p. 7). These domestic routines are often intertwined with technology due to interest in smart home environments, where researchers are trying to infiltrate and understand users in their dwelling places, to support needs and desires.

A way to articulate the variety of activities taking place in the context of the home, is Goffman's notions of occasions, situations and encounters (Goffman, 1959). Each activity is a social construct of a gathering (*occasion*), and is affected by prior knowledge from the participants or drawing on knowledge from similar occasions. Each particular occasion can be viewed as a *situation* and contains its own set of socio-cultural boundaries and rules. Within such situation we experience *encounters*. Encounters cover the engagements and relationships concerning the people present in the situation, e.g. face-to-face engagement. An example of occasion, situation and encounter is the concept of a funeral. By narrowing down, we can picture a particular funeral in a particular family that inherits certain cultural traditions. This thus constitutes a unique situation. Within this exact situation, people engage with each other according to a general set of unwritten, social and cultural rules.

The smart home

History shows that since domestic environments started to get equipped with electricity, these electrically powered devices have found their places in the home, e.g. the vacuum cleaner, food processors, and sewing machines. Later, technology developed not only be a tool in activities, but to contribute to the activity in the home, e.g. television and personal computers (Harper, 2003, p. 20). Weiser's (1991) vision of ubiquitous computing has brought focus on the enriching of environments with technology, as a means to support the activities within them. The speed of technology development has brought the computers and Internet into our homes, which have created a new important field for research. The notion "smart home" is widely used in relation to domestic ubiquitous computing (Harper, 2003; Lynggaard, Petersen, and Hepworth, 2012; O'Brien, Rodden, Rouncefield, and Hughes, 1999; A. S. Taylor et al., 2006). Researchers have had interest in the smart home for decades, and commercial technology companies have also targeted the field, creating intelligent and smart products for the home (O'Brien et al., 1999). While some researchers focus on investigating the challenges and obstacles of developing and maintaining a smart home, other researchers look into a niche part of the smart home, where extremely wealthy families have the resources to develop custom built smart homes (Lynggaard et al., 2012).

In relation to the notion smart home, Harper (2003, pp. 34–35) considers a home smart when the residence has interconnected technologies that accommodate and responds to the needs of the residents. Harper lists five hierarchical classes of the smart home including: *Homes which contain intelligent objects; Homes which contain intelligent, communicating objects; Connected homes; Learning homes;* and *Attentive homes*. Each class is an increase in functionality from the user's perspective. Ultimately, the home can learn activity patterns of the people and objects to understand and accommodate the residents' needs. Rodden and Benford (2003) divide the devices of the smart home into five different approaches *Information appliances, Interactive Household Objects, Augmented Furniture, New forms of Context Sensing,* and *Embedded Interactive Technologies*.

Examples of commercial products, which provide smart home solutions that learn and attend the home, are Nest by Nest Labs (2014) and Alba by Stack Labs (2014). Nest is a smart thermostat that learns to adjust the temperature of the home according to the activities taking place in the home. Alba is a smart light bulb that adjusts brightness and turns on and off according to activities near the bulb. These smart products respond to the behaviours of the residents. These products can be viewed as ad hoc integrations towards a smart home, as they do not interconnect with other smart products outside their ecosystem. This could be due to either the company strategies of providing all necessary products within their own ecosystem, or a standard for intelligent products not being available.

The smart home is a broad definition. We view the smart home as derived from Weiser's ubiquitous computing vision, which today is more vision than reality. The technology is here, but commercially there is a big step for producers of technology to create ecologies for these types of systems, where everything is interconnected, and actively attends to the residents who live with the technology.

Atmospheres in the home

As the smart home emerges, technology goes beyond use and shifts into a seamless presence in daily life (Ross and Keyson, 2007). As technology has become an integral part of the home and people's daily lives, it plays an important part in the atmosphere experienced in the home context. The notion of atmospheres is known across disciplines such as architecture, product design, theatre and performance art. The German philosopher and scientist Gernot Böhme's (1993) proposed atmosphere as a concept describing a relationship between subject and space. Space relates to the physical context and its qualities, and subject covers multi-sensorial, cognitive aspects such as memory, emotions, and perception. Within human-computer interaction (HCI), Dalsgaard and Kortbek (2009) seek to understand atmospheres in urban interaction design. In this regard the authors argue that Böhme's subject–space relation is not sufficient, and researchers need to further consider the *social, technological,* and *temporal* dimensions in order to stage the atmosphere. Dalsgaard and Kortbek set forward a model of these five dimensions for analysis of the ambiguous atmospheric aspects in interaction design.

In the area of shape-changing interfaces, Kinch, Grönvall, Petersen and Rasmussen (2013) experimented with a shape-changing bench positioned in different locations, including a concert hall foyer, airport departure hall, and shopping mall. The authors had a hypothesis that a shape-changing bench could alter the atmosphere when users sat on it, and further that the atmosphere of the location, which the bench was positioned in, affected people's interpretations and uses of the bench. Importantly, the authors found that each location provided a different atmosphere, which put people into certain modes, e.g. emotional states. In the airport, for instance, people's emotional states were described by the authors as 'alert', partly due to security checks, and thus moved away from the bench. In contrast, the atmosphere of the concert hall foyer was characterised by less stressful adjectives such as 'enjoyable' and 'exciting'. Here the authors report that people mainly considered the shape-changing bench as fun.

LIGHTING IN THE HOME

This section examines different ways to articulate the functions of light in the home, and clarifies our terminology. Further, we outline the human perceivable properties of light that we use.

The functions of light in the home

Since the incandescent light bulb was introduced in the home domain, the illumination of the home has been possible using electricity. Commercial companies provide the light bulbs, and architects and interior designers craft the lamps and shades to embed the light bulbs into the context of the home. Different light bulbs and lamps have provided new opportunities within the home, e.g. the desk lamp provides an opportunity to have a more close-by and direct illumination of objects on the desk compared to a ceiling lamp, which illuminates the room as a whole.

Light in the home comes with a variety of articulations and serve different functions within the home. To outline a terminology for this thesis regarding the functions of lights and the needs they accommodate, we have interviewed architect and lighting expert Kätte Bønløkke Andersen who contributes to Lysviden.dk (2012), which is a large Danish database covering a broad variety of perspectives on lighting. Further, we have examined the lighting-oriented interior company ERCO (2012) (which uses Richard Kelly's (1910-1977) distinctions), the online community Houzz (2012) on home interior, and light bulb manufacturer Philips (2012b). Bønløkke Andersen and ERCO divide the functions into three similar categories, Philips divides into four, and Houzz lists five categories. Some of the categories cover the same functions, but recall them by different names, e.g. ambient luminescence defined by ERCO is equivalent to general lighting by Bønløkke Andersen (2012). Below we provide an overview (Figure 8) of the different categorisations by origin, which we funnel into our own terminology of the functions of light.

We distinguish between three categories when working with artificial lighting: *general, task* and *decorative* lighting

1. *General* lighting, complements the room and the natural lighting in the room. The ambient luminescence serves to create a setting for more extensive lighting in a room
2. *Task-oriented* lighting, a specific type of light which matches the task, often white and bright light for giving detail and a better detail accuracy
3. *Decorative* lighting, can stage a mood or highlight areas and objects. As experienced in the theatre, decorative stage lighting can promote the visibility, focus, composition, depth and mood of a scene

Figure 8. (Next page). The functions of light according to different lighting experts. The bottom row is the terminology used onwards in this thesis

Philips

General lighting

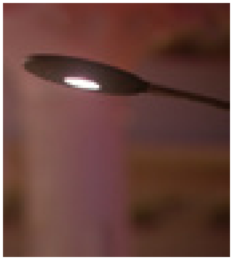
Compensate and complement

Accent lighting

Make the room bigger or smaller

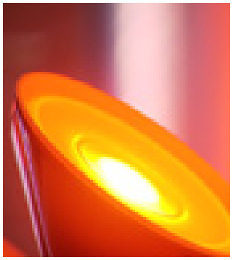
Task light

Bright white light.



Ambient light

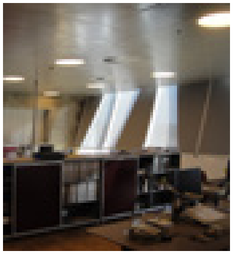
Transform the space according to the mood



Lysviden.dk

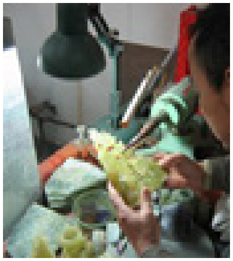
General lighting

.. contributes to an even light level in the room as a whole.



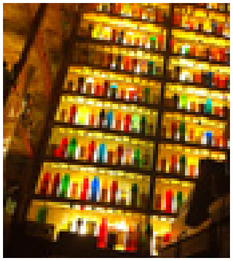
Functional light

.. the lighting, we surround ourselves with have a special feature.



Mood light

.. intends to create a special atmosphere in a room or to provide a special experience.



ERCO.com

Richard Kelly (1910-1977)

Ambient luminescence

.. serves to provide a back ground canvas for a more extensive lighting design.

Focal glow

.. directed light accentuates any eye-catching features and creates hierarchies of perception.

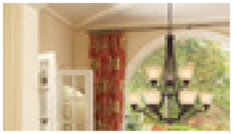
Play of brilliance

.. decorative lighting effects with colours, patterns and dynamic changes to create atmosphere and magic.

Houzz.com

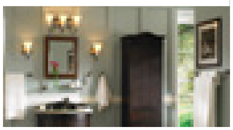
Ambient lighting

the natural light and the light that substitutes



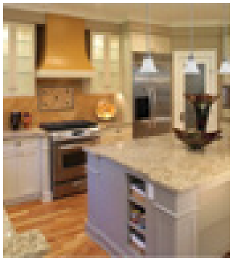
Accent lighting

Used to accent areas, objects, and spaces.



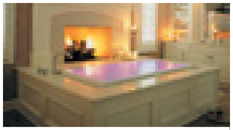
Task lighting

Provides visual clarity.



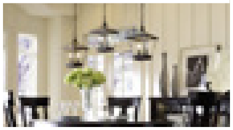
Kinetic lighting

Lighting that is "moving'



Decorative lighting

individual style and affects the mood.



General lighting	Task oriented lighting	Decorative lighting

Functions of light in this thesis

General lighting: Complements the room and the natural lighting in the room. The ambient luminescence serves to create a setting for more extensive lighting in a room.

Task oriented lighting: A specific type of light which matches the task, often white and bright light for giving detail and a better detail accuracy.

Decorative lighting: Decorative lighting, can stage a mood or highlight areas and objects. As experienced in the theatre, decorative stage lighting can promote the visibility, focus, composition, depth and mood of a scene.

Properties of light sources

In radiometry, light is measured in reference to wavelengths, and in photometry in reference to human visual perception. These measurements describe the properties of a light source. In this thesis we are concerned with the measurements as a reference to the human visual perception, as it is a way to quantify illumination in human contexts (Bønløkke Andersen, 2012). Primarily we use three properties of perceived light *brightness, colour rendering,* and *colour temperature* (see Table 1).

Brightness is the perceived amount of light, which correlates to the measurement of luminance, measured in Candela per m^2. This property describes the intensity of a light source. Some light sources allow for adjusting the luminance to a suitable level, e.g. via physical controllers (often sliders are referred to as "dimmers").

Colour rendering is how well a light source emits all wavelengths in the human perceivable spectrum compared to the sun, which emits all human perceivable colours. It is a measured property, which provides an index, the colour rendering index (CRI), ranging from 0 to 100. A light source with CRI of 100 resembles the spectrum of the sun, and a CRI of 0 is no wavelengths emitted. Incandescent bulbs range the highest, with CRI's of nearly 100, while typical LED bulbs range 60-80, depending on the quality.

Colour temperature describes the colour compared to the temperature (measured in Kelvin, K) of a black-body element, which absorbs all colours. When a black-body element is heated, light is emitted (radiant energy) as a cooling mechanism (thermal radiation). The temperature is perceived as a colour, which can be expressed as cold or warm. Warm light is experienced at temperatures below 3300 K and cold light above 5000 K. Temperatures in between is experienced as neutral (Bønløkke Andersen, 2012), as seen in Figure 9.

Figure 9. Colour temperatures are experienced as warm, neutral, or cold

Function	Technical	Comment
Brightness	Luminance (Candela /m^2)	Refers to the intensity of a light source which can adjusted, e.g. via dimmers.
Colour rendering	Colour Rendering Index (CRI, %)	Refers to the ability of a light source to emit wavelengths in the visible spectrum.
Colour temperature	Colour Temperature (Kelvin, K)	Refers to the perception of the colour of a light source, e.g. cold or warm light.

Table 1. Properties of light referred to in this thesis

SUMMARY OF LIGHT AND HOME

Light affects human behaviour, emotions, energy levels, and visual perceptions. Usages of light vary across disciplines, which can be divided into scientific and artistic. The former is concerned with physics, technical properties and capabilities. The latter is concerned with staging and emphasising of persons and objects, and complementing liveable environments through lighting.

In the context of the home, different activities related to dwelling and work take place. In order to carry out these activities and daily routines, natural light is not always sufficient, and artificial light becomes a basic need. In terms of Goffman (1959), the vast variety of activities taking place in the home domain can be labelled as occasions, where each specific and detailed occasion can be referred to as a situation. Social engagements, norms and relations affecting a specific situation can be referred to as encounters.

The smart home has been a subject in research and in commercial products, where intelligent solutions are put into daily life. Recent trends show a step towards the recording of activity patterns to adapt to the individual homes, e.g. with the Nest (Nest Labs inc, 2014) and Alba (Stack Labs Inc, 2014) systems. However, manufacturers provide their own ecosystems, and thus systems do not interconnect.

Different perspectives on the functions of light in the home environment provide a broader understanding of how light is used in the home. Additionally, the functions serve as a way to articulate lighting usages according to lighting needs. First, the need for basic visibility is fulfilled by the *general* lighting. Second, the need for lighting in specific tasks is fulfilled by *task-oriented* lighting. Third, the need to stage and highlight areas, and to set a mood and atmosphere, is fulfilled by *decorative* lighting.

Finally, we have introduced three properties relating to the human visual perception of light that will be used throughout this thesis. These are brightness (which can be adjustable), colour rendering (the ability to reproduce all human visible wavelengths), and colour temperature (warm or cold light spectrum).

THREE EMPIRICAL STUDIES ON HOME LIGHTING

To obtain domain knowledge on how lighting is used within the home context, we have conducted three empirical studies of lighting in the home. We were interested in identifying activities and habits whether generic or personal, and to which extent the context around them affected their lighting usage and control. The empirical studies served to inform our exploration of the design space from an early stage.

This section describes the studies, which are of different character. First, a contextmapping study was conducted to gain insights in home activities and the home context with a focus on light. Second, an interview was conducted with an architect and lighting expert. Third, interviews were conducted with long-term users of state-of-the-art lighting technology.

Contextmapping study on home lighting and activities

Initially, generative methods were prioritised to obtain domain specific knowledge before settling on any particular direction for our work. One of the benefits of using generative methods is the purpose of collecting latent knowledge (Visser, Stappers, Lugt, and Sanders, 2005). This is knowledge that researchers simply cannot ask directly for, as it is often connected to routines. People are carrying out tasks that they cannot explicitly elaborate on. We found inspiration in the contextmapping method proposed by Visser et al. (2005), and followed its five stages of preparation, sensitisation, session(s), analysing and communication.

The preparation stage encapsulates the formulation of the goals of the study, finding participants, choosing techniques, etc. The second stage, sensitisation, is meant to trigger and encourage the participants to explore the contexts, and prepare for the session(s) stage by giving them small activities related to the goal of the study. These small activities are to be carried out at home prior to the session(s) stage. The third stage, session(s), is when designers and researchers meet participants with the purpose of engaging in generative exercises. These exercises include creating artefacts and expressive components to express feelings, thoughts and ideas. The first three stages are followed by an analysis of the qualitative data, which is communicated to the design team in order to inform the design process. The communication lies within this section.

Offermans, Essen, and Eggen, (2014) conducted a similarly contextmapping study in the city of Eindhoven, The Netherlands. We were unknowing of the work of Offermans et al. at the time we conducted our contextmapping study. Later on, in chapter 4, we will compare the findings from both contextmapping studies, where we find a high degree of overlap and shared themes.

The next section will go into our planning and goals for the study, describing each step of the contextmapping study according to our approach.

Preparation, Sensitisation, Session (workshop) stages

In the preparation stage, the goal was to identify various activities and routines taking place in the home context, which affect the lighting usage and interactions with lighting. We recruited four friends as participants for a workshop (the session stage), two males and two females aged 21-27. The participants were all living in shared flats, although not flatmates with one another. The participants received an e-mail containing a small home exercise as part of the sensitisation stage. This exercise was sent out five days prior to the session in order to give them time to consider the response. The activity was to collect information on lighting installations in their homes along with the control interfaces, and a story of when and how they were used. Specifically, participants were asked to take pictures of their light sources and control interfaces, and annotate these pictures. The outline of the sensitisation activity can be viewed in Appendix 2, and the responses we received can be viewed in Appendix 3.

For the session stage, three exercises were prepared. The outline for the session can be viewed in Appendix 4. The session was arranged as a workshop, and documented via audio recording, supplied by pictures taken during the session and notes. The session had a duration of 2.5 hours.

The first exercise served as a warm-up exercise, where collected information from the home activity (sensitisation) was discussed. The warm-up exercise also served to loosen up the participants. We planned a few questions regarding the use contexts, qualities of particular light sources and the participants' tendencies to change the light settings according to activity. The first exercise along with a tentative question guide can be viewed in Appendix 4.

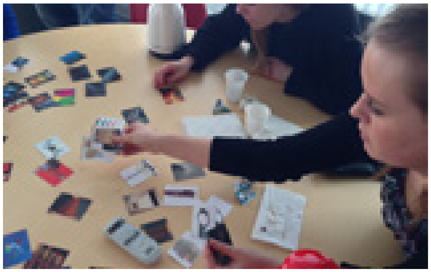


Figure 10. Exercise 2 of the workshop during the contextmapping study

Figure 11. Exercise 3 of the workshop during the contextmapping study

The following two exercises in our session stage were carried out in pairs of two, and incorporated components such as print-outs and objects to spark imagination and to move the thoughts away from daily life.

The second exercise (exercise 2 in Appendix 4) consisted of two fictive scenarios, where the participants were to host and plan a dinner setup, first for friends or family, and second for either the queen or a Danish celebrity. Having the dinner situation as pivot for this exercise forced participants to pay attention to different social settings, and to reflect upon the experiences this could potentially bring when preparing and staging one's home. We prepared a collection of image print-outs, drawings and cutting tools, and paper (Figure 10). The images served as inspiration for various lighting sources, and for creating atmospheres with lighting for their choice of dinner setup. The paper, drawing and cutting tools served to allow for creativity and to allow participants to express and manifest ideas. The aim of this exercise was to force participants into thinking, how they would adjust their lighting when planning for special occasions.

In the third exercise in our session stage (exercise 3 in Appendix 4) participants were asked to help generate ideas on new lighting interface and interactions. First, participants were showed the state-of-the-art lighting system, Philips Hue (more on this system in chapter 3), different types of lampshades and fixtures, and different types of light bulbs: clear, frosted, spot, bright, dimmed and coloured (Figure 11). This introduction to different types of lighting served to inspire when considering ideas for future interfaces and interactions. Further, we provided cut-outs of user interface (UI) elements, such as sliders, colour pickers in different shapes and colours spaces, buttons, and turning knobs. For this exercise, we wanted to generate ideas beyond the smartphone, e.g. by using their feet, speech, gestures, etc. and incorporate the presented technologies into activities in their home.

Analysis stage

The analysis stage of Visser et al.'s (2005) context-mapping study approach is outlined in this subsection. During the first exercise of the session, all participants agreed that lighting needs are highly dependent on the context and the activity taking place. As everyone had a main light source in the living room, this was almost always on when lighting was required, however, natural lighting from the windows were preferred. Often, the general lighting is switched on as a routine because, "*... I might need it later*", for being able to see. At other times, more task-oriented lighting was needed for performing activities around the dining table such as studying, eating, and hobbies. In casual, social contexts, the main light would stay turned on, but candlelights were preferred by the female participants, especially during the evening when the natural light was gone.

More interesting was the second exercise of our session, where the participants were instructed to arrange a special dinner. While talking about setting up a dinner with friends, participants expressed

> *"I could actually think of using green light, because I think it is fun [talking about a dinner setup with friends]"*
>
> – male participant 1

> *[talking about coloured light chains]… I think that it is pleasant (Danish: "hyggeligt") - when it becomes a garden thing, it is okay with coloured lights"*
>
> – female participant 2

The green light added something different and new when setting an atmosphere for the dinner activity, and the context deemed some types of light more acceptable.

In the second part of the exercise, preparing a dinner for celebrities, one female participant, who did not like coloured lights at first, suggested

> *"[talking about having celebrities for dinner]… then we CAN use the coloured lights!"*
>
> – female participant 1

While articulating the fictive scenario, the participant accepted the coloured lights as a supporting property of the atmosphere, due to the type of activity and personalities of the guests.

Interestingly, participants would do something extraordinary, ranging from acquiring some fancy coloured lampshades for the celebrities to moving outside in a large tent with the queen and set up cosy, hanging ceiling lights. This indicates that more effort is acceptable to put into the light settings on top of traditional decorations when hosting special occasions. Further, participants wanted to appear as "good hosts" by waiting on their guests. This included striving for a relaxing and welcoming atmosphere, where guests did not need anything in order to feel comfortable.

Following this discussion on setting an atmosphere according to dinner guests, frequent situations of having friends over for a visit, were also brought up. In these situations, more casual and informal situations were aimed for and sometimes it was deemed "too much" if putting too much effort into casual visits.

We discovered that the motivation was often non-existing for interacting with specific lamps, where the interface was hidden behind sofas or in far corners. These lamps became unnecessary when the general lighting in the room provided enough light, and the participants reflected upon themselves as being "too lazy to actually use them" However, when cosy atmospheres were aimed for, the extra effort of using these lamps could be considered.

We found that any light sources were rarely moved around. Even small light sources which can be classified as portable lamps had a fixed spot and were not moved, e.g. next to the bed or in the windowsill, as a female participant put it

> *"No, it [her small lamp] is always standing there [in the windowsill] … I never move it"*
>
> – female participant 1

During the workshop, the potential for automation systems were discussed, ranging from simple motion sensors to more advanced autonomous behaviour, where the system could guess the context. However, at the end the participants agreed that they mainly preferred to be in control themselves.

Summary of contextmapping study

Through our contextmapping study we identify that lighting needs are highly dependent on the contextual activities, mood, and social settings. In close relation, the amounts of efforts that participants are willing to put into interaction also vary according to context, e.g. being too "lazy" or wanting to create an atmosphere. In line, when providing a comfortable atmosphere for guests, we found that participants paid attention towards being a caring and good host by waiting on their guests. Further, portable lamps were usually not moved around to fit activities better as they had fixed positions. Lastly, a preference of being in control of the lighting was desired.

Interview with a lighting expert

To gain insights and a better understanding of light, we conducted an interview with Kätte Bønløkke Andersen, an architect from Aarhus School of Architecture, Denmark, with expertise in lighting. Kätte has been involved with writing the architectural part of the available material at Lysviden.dk, which is a large Danish database covering a broad variety of perspectives on lighting (Bønløkke Andersen, 2012). Kätte also teaches about light in her architecture classes.

The interview was semi-structured, as a way to stay open for new knowledge. The interview was carried out at Aarhus School of Architecture, and notes were taken during the interview, which had a duration of approximately 1.5 hour.

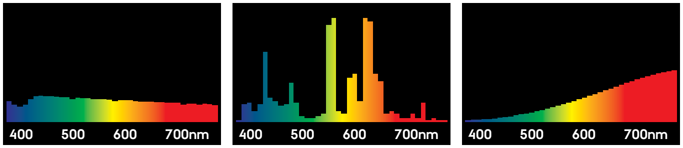
Discussion of interview

When designing lighting, Kätte suggested to find a standpoint on light, since light is a subjective phenomenon. As we presented our current knowledge on light, as obtained from Lysviden.dk (Bønløkke Andersen, 2012), it became clear that in her discipline, lighting experts worked with natural replication of colours in living settings. Kätte was concerned with light sources which only emitted some colours in the perceivable spectrum, because bad lighting could lead to strained eyes and give headaches. A notion that Kätte stressed was that the colour-rendering index (CRI) of the light source should be as high as possible, but not too bright, in order to relax the eye and make rendering of colours better. A personal preference of Kätte, was to use warm colour nuances in the home, and to only use cooler colour nuances in working situations.

Since colour rendering by the human eye can be affected a lot if a source only provides some of the colours in the perceivable spectrum (see Figure 13), a colour could be rendered wrong, see Figure 12. An example of this is the situation of buying a dark red shirt in a shop and then taking it outside where the colour is perceived as purple. Kätte emphasised that some lighting fixture designers and manufactures focus on certain lighting setting in shops to aim for specific reproductions of colours.

We brought up a discussion on LEDs that could change between many colours, and how people use these lights in practice. Kätte agreed that in celebratory settings it would be okay, but as part of daily life she expressed, *"Who would want to live with that every day?"* She stated that light should be as natural as possible in a liveable environment.

Kätte introduced us to the phenomenon of "Nordic Light", which is a special relationship between people living in the Nordic countries and sunlight. Here, the perception of the sunlight is different compared to Mediterranean countries such as Spain or Greece. In Nordic countries, the days are generally "shorter" due to longer periods of darkness, especially during winter season. In some periods, sunlight is only visible for a few hours, and in the very north the sun can be gone for months. The Nordic countries also have longer sunrises and sunsets, which provide a different set of sunlight colours near the red spectrum, compared to the Mediterranean, where sunset and sunrise happen faster and more abrupt. As a result, Kätte informed us that people in Nordic countries tend to appreciate the sunlight more.



The sun | Flourescent lamp | Incandescent bulb

Figure 13. Different light sources have different representation of the wavelengths in the visible spectrum, which affects the colour rendering

Figure 12. Two light sources illuminated by light from LEDs (left) and incandescent bulbs (right)

The Nordic Light phenomenon can be embraced in homes through architecture with windows placed high up, but also through the lighting design in the house. With Kätte, we discussed the opportunities for working with the latter, sand simulate the properties of the sun as the day progresses. The lighting in the house could, to some extent, follow the perceived movement of the sun throughout the day. Using soft and warm light could lead to a more relaxing atmosphere and the light could tell the story of when it was time for sleeping and waking up.

Summary of interview

Following the interview with lighting expert Kätte Bønløkke Andersen, it became apparent to provide people with the right lighting conditions, including attention to warm and cold colours according to activity. Further, colours could potentially change the visual appearance of objects, whether intentional or unintentional. Lastly, we gained knowledge on the phenomenon of Nordic Light, along with a discussion on imitating properties of the sun such as its perceived movement over the day and its changing colours.

Interviews with long-term users of Philips Hue

As part of our initial, empirical studies, we set out to gain insights in long-term usage of the current smartphone state-of-the-art systems, as we had only experienced the Philips Hue system for a limited period of time. We contacted long-term users of Philips Hue, a couple and a single male, which both were current long-term users of Philips Hue (see chapter 3 for a description of the system).

The couple, who was in their mid-thirties, invited us to their house containing eight Philips Hue smart bulbs which had been in use for approximately one year. Two bulbs were installed in their open sociable kitchen, four in their interconnected living room, and two in the bedroom. For the visit, a semi-structured interview was planned to cover some general questions while staying open to stories and habits, which we could not know in advance. The interview took approximately two hours, and was documented via notes and pictures. Our interview guide can be viewed in Appendix 5.

The single male (aged 25) was interviewed at his office, and a semi-structured interview was conducted, the interview took 30 minutes, only notes were taken. At home he had three bulbs connected.

Outcome of interviews

As we were introduced to the interviewees' habits around the system, we identified that the on and off switching was the far most used feature. Particularly interesting is, that it was not the smartphone solely being used to switch.

The traditional wall switch was still used, when it was more convenient to use this over the smartphone, e.g. when standing next to it or the smartphone was out of reach. A habit among the users was to remotely turn off the lights in the house from the bed.

The next most used feature was the dimming feature of the smart bulbs. Dimming takes place daily and up to several times a day. For example, for the couple, a bright light was preferred during cooking and when preparing dinner, but while eating, dimming of lights was preferred.

The least likely feature was colour adjustments. The couple was generally happy with the light as it often provides basic visibility. However, one mentioned that changing the colour temperature at the dinner table to warmer just before dinner time was of preference. He was also likely to change the temperature in other situations taking place at the dining table.

We became aware that even after a year, the only time the colours of Philips Hue had been used by the couple was during Christmas, where the kitchen was lit in green and red lights to go with the traditional Christmas decoration colours. The situation of the single male was the same, and he never found a reason to change colours, except when showing off to visitors.

At home, the couple wanted to maintain a smartphone free environment in favour of being together as a family, as a resident argued

> *"I try to put the phone away, when I come home"*
> – female participant

In this regard, the interviewee was reminded about social situations, where she was forced to explain her interactions

> *"I have to excuse for my use of the smartphone, I'm not playing, just adjusting the lights"*
> – female participant

The couple had tried to program and combine the Philips Hue system with IfThisThenThat automated web services (IFTTT Inc, 2011) (see chapter 3 for a description) to get weather information broadcast through the light bulbs in order to decide whether to bring raincoat and umbrella. The single male also had experience with this interconnectivity of services, and he used IFTTT to wake him up in the morning, simulating a sunrise in his bedroom as a part of a more natural alarm system.

Discussion of interview

From our interviews with the long-term users of Philips Hue, we identify tendencies to use the smartphone application as a portable on/off switch. An important finding is related to the difficulty of visually communicating actions and intentions when adjusting the lights through the smartphone, "*I have to excuse for my use of the smartphone, I'm not playing, just adjusting the lights*".

Generally, the long-term Philips Hue users limited their smartphone control to two features. Typically for switching the lights on/off remotely followed by brightness control. Only for celebratory or special events, the colour features were used. One user had incorporated an automated service in order to simulate a sunrise every morning in his bedroom.

Summary of empirical studies

This section summarises and narrows down the findings from the contextmapping study, interview with a lighting expert, and interviews with long-term Philips Hue users. These findings are formulated as themes that are being used onwards in this thesis.

Initial theme: Contextual lighting needs

Our contextmapping study indicates that lighting needs are highly dependent on the contextual activities, mood and social settings. Often, the general lighting is switched on as a routine because, "*... I might need it later*", which comes before the basic need of being able to see. At other times, more task-oriented lighting is needed in certain areas, e.g. at the table for studying or hobbies. From our interview with a lighting expert, the context should be supported by the right lighting conditions, e.g. warm lights for the home setting and colder light for carrying out work effectively. The long-term users of Philips Hue expressed their tendencies to control the brightness of white light relatively often, yielding it a frequent interaction.

Initial theme: Effort

The willingness to interact with the lighting is also dependant of the context and its needs. When creating a comfortable and pleasant atmosphere in the home, a relatively high amount of effort is likely to be put in, possibly with attention to the lighting. However, frequent and routine control of lighting requires less effort, e.g. switching on/off or increasing/decreasing the brightness of the lighting, which potentially happens several times a day either via switch or smartphone. Themes are often found to overlap one another. Thus aspects of a theme also relate to other themes.

Initial theme: Setting an atmosphere

The creation of pleasant atmospheres in the home is found as a common activity, which may require a considerable amount of effort. Situations include expecting and having guests and visitors, each with different personalities affecting the context. Other situations may invite for other atmospheres, e.g. when alone and doing different activities, or watching movies with a friend or flatmate. Again, different situations that might invite for different levels of interaction effort. From the interview with long-term Philips Hue users, a person was creating another type of atmosphere by having the colours of his bedroom lamps automatically simulate a sunrise every morning. Lastly, the interview with a lighting expert revealed another aspect, namely the phenomenon of "Nordic Light", as the importance of the sun in Nordic countries can potentially be imitated in lighting design. This includes the perceived movement of the sun and its colour spectrum.

Initial theme: Appearing as a good host

When having guests, e.g. dinner guests, on-going attention from the host is likely to be put into appearing as a good host. A good host was in our contextmapping study identified as a person that wait on her guests, e.g. by asking if anyone wants drinks, more coffee, or bringing in the prepared food from the kitchen Generally, a good host made her visitors feel comfortable during the visit and across activities. Social contexts may also affect the appearance of a person in other ways, as a long-term Philips Hue user put it, when reflecting on smartphone lighting control, "*I have to excuse for my use of the smartphone, I'm not playing, just adjusting the lights*".

PERSPECTIVE ON HOME LIGHTING IN THIS THESIS

This thesis, we will focus on light to support activities taking place in the home. We note that atmospheres in homes are complex and ambiguous, and are related to the interrelated dimensions set forward in the research. Based on the role of the home and our empirical studies, we acknowledge that people live differently in their homes and they do similar activities differently. For example, occasions might be the same but norms and behaviour may vary among people in specific situations. These variations will, arguably, also affect the interaction with lighting, and we acknowledge that this will be a design challenge. Across different occasions, we wish to accommodate the varying amounts of effort that people are willing to put into interaction with lighting.

As presented, we will adopt the terminology of general, task-oriented and decorative lighting when articulating the functions of light in the home, and the specific lighting needs that they target. These needs are related to visibility, functional tasks, or atmospheric, respectively (Table 2).

Following our three empirical studies on home lighting, the two themes contextual lighting needs and effort align with the terminology presented. First, the need for basic visibility is fulfilled by the general lighting, where interaction occurs frequently, and invites for least interaction effort. Second, the lighting need of task-oriented activities, e.g. reading or studying, is met by task-oriented lighting, and may possibly require more effort. Third, the need to stage and highlight areas or set a mood or an atmosphere is met by decorative lighting, and is likely to require the most effort. Our identified themes of setting an atmosphere, and appearing as a good host, are specifically connected to the decorative lighting categorisation, as they are special cases of lighting needs, where the user wants to do something extra.

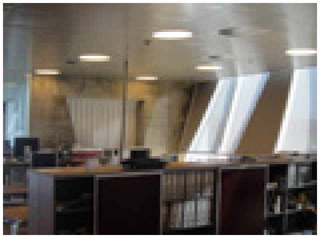
Functions of Light	Examples of Lighting Needs	Effort Comments
General Lighting Complements the room and the natural lighting in the room. The ambient luminescence serves to create a setting for more extensive lighting in a room.	 To provide visibility throughout the room.	Quick and easy interaction. Routinely when entering a room. Lights are switched on by a wall switch near the entrance. *Least interaction effort*
Task-oriented Lighting A specific type of light which matches the task, often white and bright light for giving detail and a better detail accuracy.	 To provide high contrast for comfortable reading conditions.	User might want to adjust the lighting for a more suitable light setting for the current activity. *More interaction effort*
Decorative Lighting Decorative lighting, can stage a mood or highlight areas and objects. As experienced in the theatre, decorative stage lighting can promote the visibility, focus, composition, depth and mood of a scene.	 To create a cosy atmosphere.	Extra effort is put into the light setting to create an atmosphere. *Most interaction effort*

Table 2. Articulation of the functions of light which will be used in this thesis, annotated by examples of lighting needs and comments on effort

3
RELATED WORK

This chapter outlines and discusses related work in the fields of domestic lighting control and in-air gestural interaction. First, a review of the current state of lighting control in commercial systems and in research is provided, followed by a discussion of qualities and shortcomings. The second section examines commercial and research approaches to in-air gestural interaction, and provides a list of qualities and challenges inherent to this interaction style. Further, a classification of hand-based gestures is presented.

DOMESTIC LIGHTING CONTROL TODAY

This section on the control of lighting is split into commercial systems, which are available now and in the near future, and recent research on interactive lighting systems.

Commercial lighting systems

Today smart lights can be controlled remotely from a smartphone. Examples of such commercial product systems are LIFX, Philips Hue, and Stack Alba (LIFX Labs, 2013; Philips, 2012a; Stack Labs Inc, 2014). Philips Hue is one of these state-of-the-art systems and has become accessible to consumers via exclusive deals in Apple Stores. The typical system consists of up to 40 "smart" light bulbs, which are inserted in existing light sockets. As with the other systems listed, the Philips Hue system features the traditional on/off control on an app (image on the left in Figure 14). Besides this, Philips Hue provides 16.8 million unique colour nuances available from a colour palette in the app interface, along with a dimmable brightness. A colour is configured for each individual bulb or using the "scenes" feature, where each bulb is positioned on a picture, as exemplified by the deep sea preset on the right in Figure 14. An addition to the Hue system is the newer Philips Hue Lux bulb which provides an alternative to the colour options of the original Philips Hue bulb, by providing a bright and dimmable white colour. The Philips Hue system thus functions as individual bulbs or as a connected system. The bulbs communicate via ZigBee to a dedicated bridge device, and this bridge communicates via the internet or locally to the user's smartphone (Figure 15). This way the individual bulbs respond to direct lighting changes in terms of colour and brightness initiated by the user.

Additionally, the Hue system allows for automatic behaviour, based on the web service IfThisThenThat (IFTTT Inc, 2011). This service has a broad selection of triggers stemming from other services such as today's weather, time of the day, incoming mail, social updates or sport news. When these triggers are fired, the Hue system takes temporary, automated control of the lights, dismissing any custom set lighting settings. Recently, Philips introduced the Hue Tap, which is a portable switch for the home including an off-switch and three on switches for different presets (Philips, 2012a).

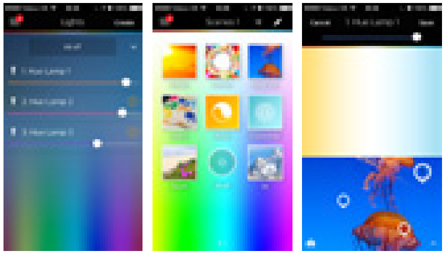


Figure 14. Philips Hue smartphone app for iPhone. Main switch and individual brightness levels (left), list of scene presets (centre), and the deep sea preset with additional colour temperature in the top (right)

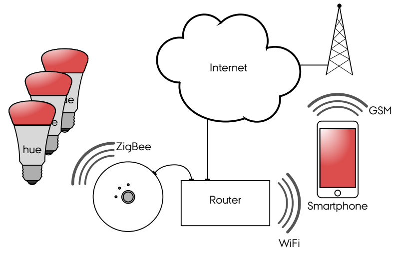


Figure 15. Philips Hue communication architecture, allowing smartphones to control the bulbs over WiFi

Figure 16. Fonckel One by Philip Ross (2011). A commercial lamp interacted through direct touch gestures on the back

Figure 17. AEI lamp by Philip Ross (2008). The result of the research through design in his thesis and predecessor to Fonckel One

The most recent competitor to Philips Hue system is the Stack Alba (Stack Labs Inc, 2014) light bulbs, which intentionally incorporate autonomous behaviour to lower power consumption and, essentially, provide the *right* light when needed. Over time, Alba bulbs adapt to home activities, by gradually learning the user's routines through machine learning techniques. This automation is intended to take the control of the home lighting, in contrast to Philips Hue, which is mainly reactive to user input (although allowing for IFTTT extensibility, as mentioned). Technically, Alba bulbs have embedded motion and light sensors to gather information for the algorithms. In table Table 3, a comparison of the mentioned smart bulb systems is provided.

Another interesting commercial example is Fonckel One by Philip Ross, as seen in Figure 16 (Ross, 2012). Fonckel One is a high-end consumer lamp, which is interacted through a touch sensitive surface on its backside. The interaction is radically different compared to other lamps, as you control the cast light under your hand by moving your hand around on the backside. Further, a set of finger gestures can be learned to narrow the light, adjust the brightness, and turn the lamp on and off. This, and the lamp being branded as "personal light for any purpose", yield the idea that the user can be expressive through interaction, and customise the light "just right" to fit the current activity.

The interaction in Philip Ross' Fonckel One is a result of his PhD work (Ross, 2008) on ethics and aesthetic in intelligent product, where the design process is noticeable. As a part of his thesis, Ross designs for behaviour in interaction using aesthetic experience as a mechanism for design, which leads to the design of the interaction found in Fonckel One. In his research through design process, Ross designs for aesthetic interaction *through* aesthetic interaction by using aesthetic experience as a means for design, as also pointed out in Ross and Wensveen (2010). Ross examines the aesthetic experiences within improvisational dancer choreography, targeting the behaviours of 'social power', 'helpfulness', and 'creativity'. Ross analyses the movements to inform his design process of designing behavioural lamps, for example, the AEI lamp seen in Figure 17.

Research on lighting control

With the new possibilities of the emerging LED technology comes new challenges. This has been recognised through a number of workshops on interactive lighting at the international conferences INTERACT 2011, AmI 2011, DIS 2012, CHI 2013, and NordiCHI 2014 (Aliakseyeu, Mason, Meerbeek, Essen, and Offermans, 2011; Aliakseyeu et al., 2012, 2013, 2014; Aliakseyeu, Mason, Meerbeek, Essen, Offermans, et al., 2011), where topics included ambient intelligence, interaction design, user interfaces, user studies, evaluation methodologies, connectivity with other systems,

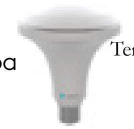
Light Bulb		Type of colours	Adjustable brightness	Interaction type	Autonomous	Description
Belkin WeMo		Static	Yes	App	With IFTTT	*Cheap smart lighting*
Philips Hue Lux		Temperature	Yes	App	With IFTTT	*Simple, smart beautiful warm white light*
LIFX		16.8 Million	Yes	App	With IFTTT	*Wifi enabled, multi-color, energy efficient light*
Philips Hue		16.8 Million	Yes	App	With IFTTT	*Every shade of white light. All the colors in the spectrum.*
Stack Alba		Temperature	Yes	App & self adjusting	Yes, with learning techniques	*The world's first responsive lightbulb.*

Table 3. Comparison of functionalities in commercial available smart bulb systems

degree of autonomous behaviour, and embedded lights in daily objects. This shows that research indeed has a strong focus on interactive lighting systems.

Tessella by Cheng et al. (2012) is an interactive, organic user interface that transforms its shape in the hands of the user. The system resembles an origami figure that creates light patterns depending on shape and is thus a "tangible light experience". The authors seek to create a playful, poetic interface that allows for users to be creative and expressive through interaction. Being expressive through interaction is also the idea behind the LightPad lighting controller by Magielse and Offermans (2013). LightPad is a touch sensitive pad that senses and interprets parameters of the interaction, namely the force and length of the stroke. Accordingly, this results in an adjustment of the general lighting environment. For this expressive interaction, an "energy metaphor" is applied to minimise the cognitive complexity when instructing users how to operate it. The amount of touch pressure applied to the LightPad is mapped to the brightness

Besides the expressive LightPad, Magielse and Offermans (2013) have also been integrating other means of lighting control in their work. The LightCube is a hand-sized, tangible cube which is lying around on a table and can be turned to change lighting atmospheres based on pre-sets by any of the persons present in the room. The LightApp is a stationary tablet interface running a lighting control app that leverages gestures known from smart devices to control the lighting environment in detail. In line, Offermans, van Essen, and Eggen (2014) have been using several smartphone apps with different approaches to lighting control, e.g. to adjust colours of individual lamps, the whole room, based on individual or social activities, or to reflect certain atmospheres. Offermans, van Essen, and Eggen have also been evaluating the Illuminating Touch Table (Le, Offermans, and Essen, 2012), which can be pressed on the top surface to change lighting behaviour in the room to match the table.

Touching upon the social dimension, Magielse, Hengeveld, and Frens (2013) conducted a design study to develop a light controller for a multi-user lighting environment. Based on initial designs and evaluation of both individual and shared controllers in multi-user environments, a resulting design was made highlighting the important aspects of being in a shared environment. Their system was able to both function when users were by themselves in a shared room, but also negotiate the light space between them when several users influenced each other. The system described shows how light settings can adapt in a social space. This inclusion of the social dimension is different from an approach taken in Magielse and Ross (2011). In their work on socially adaptive lighting environments the authors show how light can be used to guide the social situation, e.g. "*try to make person X talk, or let all participants lean forward*" by adjusting the light setting.

Discussion of domestic lighting control

In summary, new lighting interfaces emerge following the trends in LED technology. These new interfaces supplement home lighting with additional parameters that can be controlled in terms of colour and brightness. Recent commercial systems and research on interactive lighting show a variety of interfaces each with different ways to control individual or a whole system of light sources. The interfaces presented all vary in terms of the user's expressivity through interaction, and degree of sociality. Another important aspect stemming from the research focuses on the shortcomings of the user experience with current, commercial smart bulbs when the context ranges from solitary usage to social.

In this subsection we discuss the related work on lighting control in terms of pros and cons of smartphone lighting control, and qualities of interaction. The discussion of these aspects informs our design process.

Pros and cons of smartphone lighting control

We identify several practical benefits in utilising the smartphone as a central platform for interaction, e.g. dynamic interface; 'always' with you; remote access and control without dedicated remote controllers. As a result, the app decreases the interaction with physical switches installed in walls and along the cables. Apps, however, do not replace physical switches completely as a smartphone could potentially be displaced from the user at the time of intended interaction.

Socially, the action of physically switching the lights on/off or adjusting the brightness provides immediate, visible clues to other people in the context. In contrast, Magielse et al. (2013) note that interacting users are not necessarily co-situated physically, nor necessarily situated in the lighting environment they are controlling. Thus interactions may affect the situations and experiences of others relying on the light. At the same time, people in the house, including guests, cannot interact with the Philips Hue functionalities without having the app installed and having accessed the WiFi infrastructure.

In primo 2014, Philips introduced the Philips Hue Tab (Philips, 2012a) which acts as a physical and portable switch. This product can be viewed as an alternative way of controlling existing smart bulbs when the smartphone is not within reach. This also allows everyone to interact without being connected to the infrastructure.

Qualities of interaction

Moving away from the smartphone interface, Fonckel One, Tessella, and LightPad provide tangible gestural control, which let the user be expressive in her interaction. The interaction is thus perceived as personal and controllable. If the desired setting is not achieved the first time, the input can be slightly varied until satisfied.

When coupling action and function, LightPad uses a metaphoric mapping between input and output ("energy" metaphor where the amount of touch pressure is mapped to the amount of lighting), while Fonckel One and Tessella use a direct interaction approach (manipulate the light using surface gestures on the Fonckel One lamp, and manipulate Tessella between hands to adjust the emitted light). In the metaphoric approach, we see a potential in adjusting a variety of, possibly complex, parameters through simplified interactions. In the direct approach, the coupling between action and function guides the user to the intended use during interaction.

IN-AIR GESTURAL INTERACTION

Several interfaces for lighting control have been reviewed. These include tangible cubes (LightCube), touch sensitive surfaces (Tessella, LightPad, Illuminating Touch Table, and Fonckel One), and a series of smartphone apps. This section looks at a radically different interaction style, namely in-air gestural interaction. This interaction style can be categorised as part of an emerging paradigm of user interfaces labelled Natural User Interfaces (NUIs). Within this paradigm, we also find other input modalities such as body tracking, multi-touch, and gaze tracking, which all utilise different degrees of body movement. In addition, speech interfaces fall in this category, and may be combined to form a multi-modal, natural interface.

Well-known and commercial large-scale body tracking examples include Microsoft Kinect (2014), which uses in-depth cameras to track whole-body movement, and Nintendo's Wii (2010), which fosters bodily engagement with realistic tools such as tennis rackets or, in the case of Wii Fit, moveable pads to stand on. The Leap Motion (Leap Motion Inc., 2012)controller provides highly precise, in-air hand, finger and gesture tracking, using an array of infrared transmitters. Looking slightly into the future, the soon-to-be-announced Myo (Thalmic Labs Inc., 2013) armband senses and interprets the electrical activity of arm muscles when performing in-air finger and arm gestures. The Google Glass (2012) is expected to be a rich platform for gestural recognition as the user's hands are, naturally, in close proximity of the integrated camera.

A more subtle type of body movement is seen in the Amazon Fire Phone (2014) that uses four front-facing cameras to track the head of the user in 3D and act accordingly.

Turning to the research, we find several, novel systems and enabling technologies for in-air gestures. The WiSee (Pu, Gupta, Gollakota, and Patel, 2013) and the AllSee system (Kellogg, Talla, and Gollakota, 2014) leverage the surrounding wireless signals to distinguish different in-air and body gestures via machine learning techniques to provide fine-grained tracking. Leithinger et al. (2011) have found, that freehand gestures are superior for 2.5D displays. In practice, they have applied freehand gestures

Figure 18. Video frame from the SmartSkin project by Rekimoto (2002). Surface gestures are tracked using capacitive sensing in the surface, and graphics are projected from above

to functional controls (select, translate, rotate and scale) of their 2.5D shape display, Relief.

Hoven and Mazalek (2011) provide a survey of gestural interaction in list three categories, including gestures in 3D space, 2D surfaces, and with physical objects in hand. In 3D space, Hoven and Mazalek divide interfaces into 'gestures with glove devices' and 'unencumbered gestures'. The former encompasses the early Data Glove (T. G. Zimmerman, Lanier, Blanchard, Bryson, and Harvill, 1987) and the commercial G-Speak by Oblong Industries (2014) a commercial realisation of the famous interactions from the movie Minority Report (Spielberg, 2002). 'Unencumbered gestures' do not require specialised equipment for interacting and gestures are often recognised using computer vision techniques. Selected examples include Krueger's early work on VIDEOPLACE (Krueger, Gionfriddo, and Hinrichsen, 1985), Bailly, Müller, Rohs, Wigdor, and Kratz wearable ShoeSense project (2012), and the commercial available and successful Microsoft Kinect (2014) developed for the Xbox.

On 2D surfaces, gestural interfaces are divided into 'gestures with pen and stylus', and 'with fingers and hands'. In the latter division examples range from Krueger's pinching and zooming on surfaces in VIDEODESK (Krueger et al., 1985) to Rekimoto's SmartSkin (2002), where multiple finger and hand gestures are registered by capacitive touch in the table surface, and virtual objects projected onto the table from above (Figure 18).

Lastly, we find Hoven and Mazalek's category of gestures with physical objects in hands. These objects can be used to recognise gestures and be important parts of the interaction, e.g. when Wii Remote Tennis (2010) is used as a tennis racquet. Hoven and Mazalek divide these interfaces into gestures 'with mobile devices', 'with batons and wands', 'with game controllers and remotes', 'with dolls, toys, and props', and 'with custom tangibles', which we will not go further into.

Discussion of in-air gestural interaction

This subsection categorises the qualities and challenges of in-air gestural. In the next chapter, these categories are discussed against the framed design space of interaction lighting.

Expressivity of bodily movement

In several studies, NUIs have been found to possess a variety of qualities within the area of user experience. The expressive powers that bodily interaction possess are often claimed as an intuitive means of interacting as it builds upon the user's bodily awareness and capabilities (Jacob et al., 2008; Leithinger and Ishii, 2010).

Proximity of control

Current in-air tracking technologies are free of special markers, gloves or other devices that have to be carried for the purpose of recognition by the system. This increases the success rate of these enabling technologies. From a practical perspective, in-air gesture systems are

"*… suitable in some circumstances where touch input is less so. In living rooms, with digital signage, and in other environments where walking over and touching a screen might detract from the experience, in-air gesturing helps close that gap*" (Wigdor and Wixon, 2011, p. 97). Therefore, in-air gestures have been connected to the TV (Juhlin and Önnevall, 2013; Zoric et al., 2013). Here, authors challenge the ubiquitous remote controls, which may be hard to find in the sofa, thus making our daily life easier.

Sociality

Wigdor and Wixon (2011), two user experience experts from Microsoft Research highlight the benefits that a natural user interface can have in a social context, if designed correctly. Users can lift the experience from solitary to social. The interface should allow activities from several users simultaneously without disrupting the experience of one another (Wigdor and Wixon, 2011, pp. 37–41).

Visibility of Interaction

As a part of the interaction qualities within the NUI paradigm, Klemmer, Scott and Hartmann (2006) state that visibility of an activity is important, since interactions with a graphical user interface "*… all looks the same*". Therefore, spectators cannot explicitly see the on-going action. The authors argue that the visibility of an interaction is a social affordance when "*activities of a practice are made visible to colleagues and onlookers through the performance of the activity*". The opposite – not performing visible actions – was experienced during our empirical study of long-term usage of the Philips Hue system. Here, the house owner was forced to explain her interactions with her smartphone, "*I have to excuse for my use of the smartphone, I'm not playing… just adjusting the lights*".

Technical challenges

Some interaction challenges regarding gestural systems are revealed throughout the literature. Invisible interfaces, e.g. in-air and speech interfaces share the "live mic" problem (Wigdor and Wixon, 2011, p. 98). When is the system ready for interaction? Gestures may accidentally be recognised by the system without the user's intention, or the user may think she has performed a gesture, while it was not recognised. Such shortcomings can also be ascribed the lack of feedback in such systems. Related to the live mic problem is the "segmentation" issue (Ronkainen, Häkkilä, Kaleva, Colley, and Linjama, 2007), which deals with the temporal length of the interaction. When does the gesture start and end? In the Air+Touch project, Chen, Schwarz, Harrison, Mankoff, and Hudson (2014) utilise in-air gestures in combination with regular touch events on a smartphone to perform actions such as zooming, retrieving a context menu, selecting and copying text, etc. Here, the gestures take place before, between or after a touch event. In terms of interaction, the touch events help to avoid the segmentation issue as they clearly define a point in time for the gesture, while the in-air gestures provide expressivity of interaction (Chen et al., 2014).

Feedback and feedforward challenges

As in many interactive systems, feedback and feedforward is used to couple action (input) and function (output). The invisible interface of the in-air gestural interaction style inherently lacks both feedback and feedforward. Feedback as a design principle in interactive systems provides an informative response during and after the user's action. Feedforward provides information prior to the user's action.

For implications on feedback and feedforward, we turned towards the Interaction Frogger framework (Wensveen, Djajadiningrat, and Overbeeke, 2004), a design framework created as a part of the tangible user interface (TUI) paradigm. Although a part of the TUI paradigm, we find it a relevant way of articulating a central problematic of our work, and how to handle it in our design process. The framework proposes three types of information applicable to the principles of feedback (FB) and feedforward (FF): *functional, augmented* and *inherent*.

- *Functional* information communicates the primary functionality of the system, (e.g. FB: light turns on; FF: visible of controllers).
- *Augmented* information relates to information not relating to the action itself, but from an additional source (e.g. FB: stand-by LEDs or on-screen events; FF: on-screen instructional messages in Kinect games).
- *Inherent* information relates to carrying out the action (e.g. FB: feel and sound of a control; FF: shape of control to communicate rotation).

Wensveen et al. (2004) argue, that "*...'Natural User Interfaces' that make use of gestural and speech interfaces exploit the cognitive and perceptual motor skills of a person. These interfaces lack inherent information and completely rely on a direct coupling between action and function or on couplings through augmented feedforward.*", and that "*...The user receives little information about these action possibilities*".

Due to the lack of inherent feedback in interfaces for in-air interaction, the authors propose, that we aim towards a direct coupling between action and function. We see this done in practice in display-oriented full-body tracking applications, where the screen is updated according to input (augmented feedback). The lack of inherent feedforward implies that we need to focus on augmented feedforward to communicate the interaction possibilities to the user. This is also seen done in on-screen applications, where instructions can be given prior to interaction.

In research, the AIREAL system provides haptic feedback as a response to in-air interactions with the system. As the user interacts with the system, small rings of air are blown towards her hand and body, providing expressive, tactile sensations (Sodhi, Poupyrev, Glisson, and Israr, 2013). The type of feedback mechanism can also be classified as augmented feedback, and as an alternative to on-screen, visual feedback.

The BoomRoom project (Müller, Geier, Dicke, and Spors, 2014) is a recent example that utilises sound cues as interaction feedback to the user in an "invisible" interface. In BoomRoom, the user "touches" and "grabs" the intangible sound clips surrounding the user, which can be positioned and manipulated in mid-air (Figure 19). As the sound clips replay audio from their mid-air positions, the user can relocate, pick up or manipulate them later. In addition, as it can be hard to precisely relocate a floating sound, a spatial sound effect is provided as auditory feedback when a sound can be selected by a nearby hand. Further, the authors argue that once a sound is grabbed, positioned, dropped or manipulated, the spatial perception of the user's own body is sufficient for guiding interaction.

Figure 19. Video frame from the BoomRoom project (Müller et al., 2014). Intangible sound clips can be picked up, moved, manipulated, and positioned in mid-air using gestures

Classification of hand gestures in HCI

Gestures are expressive of nature and convey information. They are understood by humans and play a variety of roles in different contexts. Different fields of research have studied gestures including philosophy, psychology, and linguistics. In HCI, gestures are used to provide the input to digital systems.

When reviewing existing classifications of gestures, Hoven and Mazalek (2011) refer to Pavlovic et al. (1997), who provide a taxonomy for human gestures. This taxonomy has been used and accepted in HCI, and an adapted version of this taxonomy can be viewed in Figure 20. The taxonomy divides gestures into the *manipulative* and the *communicative* categories, after discarding unintentional arm and hand movements.

In the real world, manipulative gestures are used to manipulate physical objects, e.g. moving and rotation of an object. In HCI, a manipulative gesture can be detected by the system, which then issues the command in the system on virtual objects. Hoven and Mazalek exempli-

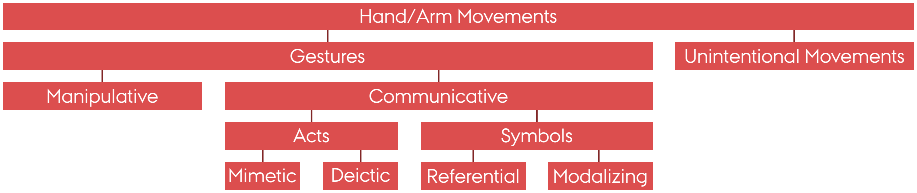


Figure 20. Adapted version of the taxonomy presented by Pavlovic et al. (1997). Only the layout is changed

fy this by describing how a hand wave gesture can be sensed by the system and translated into the rotation of a virtual object. On a 2D surface, the pinch gesture for resizing virtual objects is seen as another example of a manipulative gesture (also often called direct manipulation).

Communicative gestures have a symbolic function and carry meaning. Symbolic gestures are used as reference to actions (referential), e.g. referring a wheel by rotating the index finger in a circular motion, or to accompany speech (modalizing). Acts in terms of gestures either imitate known movement (mimetic), or is used for pointing, e.g. on objects in a virtual environment (deictic).

Mapping between gesture and light

We argue that the distinction between manipulative and communicative gestures can be used as mapping schemes between gestures and lighting functionality in interactive systems. An interactive lighting system could react to direct instructions issued through manipulative gestures. We consider this a *direct* mapping scheme. In contrast, the *symbolic* gestures could reference or imitate known phenomena, which in turn can be translated to lighting adjustments. We consider this as a symbolic mapping scheme. Our intention is illustrated in Figure 21 below. This thesis will refer to these two mapping schemes, when discussing the relation between gestures (input) and changes in lighting (output).

Gesture classification	Mapping scheme
Communicative	Symbolic
Manipulative	Direct

Figure 21. Gesture classifications and the proposed relation to mapping schemes between gestures (input) and lighting functionality (output)

Model of hand gestures

To articulate the temporal characteristics of a hand gesture, research incorporates a model with three different phases: the preparation, stroke and retraction phases (Hoven and Mazalek, 2011; Pavlovic et al., 1997).

- *Preparation*, positioning of the hand to where the actual gesture (stroke) takes place
- *Stroke* (nucleus or peak), the actual executed gesture
- *Retraction*, removing the hand away to either a resting position or repositioning for a new gesture phase

These three phases make up the hand gesture model, which defines the parts of the gesture in a temporal 3D space, and is illustrated in Figure 22 below.

Figure 22. After being in a resting position (left), the preparation takes place (centre) before the actual gesture is given (right). Subsequently, the arm is retracted (centre), possibly back to the resting position (left)

Input parameters and mapping

In-air gestures reside in 3D space, thus the hand and arm movements can be described technically by the three axes x, y, and z, along with the orientation of pitch, roll, and yaw (Figure 23). This is also known as the six degrees of freedom (6DoF). To measure the six degrees of freedom in 3D space, a sensor or a fusion of sensors measure these six parameters. It is worth to note, that these 6DoF solely describe the movement of the hand in space at any given time. Thus, the sensing of the 6DoF does not hold any conceptual meaning as to what a gesture means when perceived in the real world. As an example, a gesture of a closed hand can hold the meaning of a grab while one finger could suggest a pointing gesture. Furthermore, gestures may vary during the time of interaction and adopt another meaning throughout the gesture, e.g. a greeting gesture (waving) can transform into alert gesture (waving more intense) if the other person is in danger.

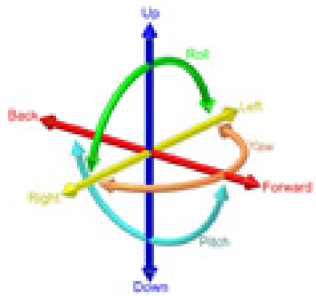


Figure 23. The 6 degrees of freedom in 3D space, here illustrating arm moment

SUMMARY OF RELATED WORK

In summary, new lighting interfaces emerge following the trends in LED technology. These new interfaces supplement home lighting with additional parameters that can be controlled in terms of colour and brightness. Recent commercial systems and research on interactive lighting show a variety of interfaces each with different ways to control individual or a whole system of light sources. The interfaces presented all vary in terms of the user's expressivity through interaction, and degree of sociality. Another important aspect stemming from the research focuses on the shortcomings of the user experience with current, commercial smart bulbs when the context ranges from solitary usage to social.

Within the paradigm of natural user interfaces (NUIs), we find in-air interactions such as hand and finger gestures. Systems responding to these forms of gestures allow for varying degrees of bodily movement, ranging from whole-body to subtle finger movement. Research has found that such natural interactions possess unique interaction qualities in terms of *expressivity of body movement, proximity of control, sociality,* and *visibility of interaction*. However, the area also holds design challenges in terms of the technical *live mic and segmentation issues,* and *lack of feedback and feedforward.*

HCI research classifies hand and arm gestures as a way to articulate human gestures. A distinction often used in classification is *manipulative* and *communicative* gestures, where the former is associated with (often direct) manipulation of objects, and the latter with symbolic meanings. We propose two mapping schemes, direct and symbolic, based on this classification. This thesis will refer to these two mapping schemes, when discussing the relation between gestures (input) and changes in lighting (output). Further, research models the temporal movement of a gesture in the three phases: preparation, stroke, and retraction.

After discussing the design space of interactive lighting in the next chapter, the interaction qualities, challenges and gesture classification outlined here, will be combined and framed into an initial framework for in-air gestural interaction with home lighting.

4

FRAMING THE DESIGN SPACE OF IN-AIR GESTURAL INTERACTION WITH HOME LIGHTING

The design space of interactive lighting has been explored by Offermans, Essen, and Eggen (2014), and a number of important themes have been outlined. This chapter presents these themes, before discussing them against the initial themes identified in our empirical studies (chapter 2). We then combine the areas of interactive lighting with in-air gestural interaction, and synthesise the knowledge gained so far into an initial framework for in-air gestural interaction with home lighting. Lastly, we discuss the identified opportunities for blending these areas, and pose two research questions.

DESIGN SPACE OF INTERACTIVE LIGHTING EXPLORED BY OFFERMANS ET AL.

In the following, relevant implications from Offermans, Essen, and Eggen's (2014) exploration of the design space of interactive lighting that has informed our work, is presented. In the next section, we discuss the overlap with our themes identified as we conducted a similar study (contextmapping study, chapter 2).

Due to the recent advances in interactive lighting systems, particularly in LED technology, Offermans et al. (2014) conducted a study to explore the design space of interactive lighting interfaces, and present important aspects regarding the interaction. The study is two-fold and includes 1) a contextmapping study, guided by Visser et al. (2005), in order to obtain knowledge on people's everyday lighting practices, and 2) through user evaluation of novel research interfaces for lighting control. The user's motivation for interaction was chosen as an overarching theme of the study, following the assumption that a high degree of motivation leads to improved user experience. Offermans et al.'s work is reported in great detail, step for step, and leads to a relational model, consisting of seven strongly connected themes that regard the interaction with lighting. The model should be viewed as an initial model to inform designers of everyday lighting systems in the future, although described as not yet coherent. The seven themes are divided in the two main categories *user in context* and the *user interface* (as seen in Figure 24).

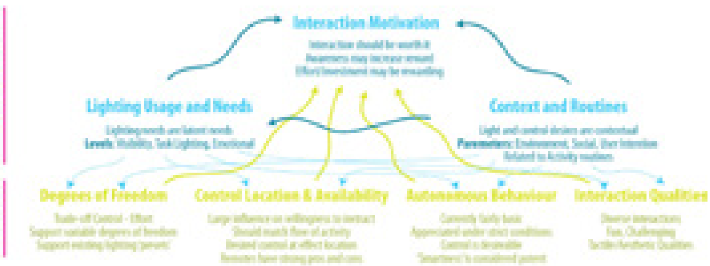


Figure 24. Initial model of the interrelated themes in the design space of interactive lighting, explored by Offermans et al. (2014)

User in context

Offermans et al. (2014) identify three varying levels of lighting needs, and their relation with the amount of effort put into the interaction. The three levels of lighting needs are *basic visibility, functional* and *emotional*. The lowest level of lighting need is basic visibility, which covers the need for basic illumination, orientation and safety. Functional needs emerge when people stay in spaces for longer periods of time, or when using the light to support a specific task or activity, e.g. a reading lamp. Emotional needs are described as serving "atmospheric" purposes which relate more to the environment, which the light is an integrated part of, than to the lighting or lamp itself. For example, peripheral lights that are dimmed, or lights that are described as "warm".

In this regard, the authors argue for a correlation between lighting need and interaction effort. When *basic* *visibility* is desired, minimal interaction effort is preferred. The activity of lighting up a dark room should be simple and easy to do with minimal effort. *Functional* needs are related to specific activities, typically taking place over time, and may gradually require more effort. *Emotional* lighting needs, however, are beyond general illumination and functional light requirements. In these situations, putting even more effort into controlling the lights is often acceptable.

The authors find that "*people's desire for lighting is for a large part determined by the user's context (or situation)*". Therefore, it is hard to say anything specific about lighting preferences, as these preferences change according to context. The activity taking place, however, can be taken into account when considering the level of control that the user is offered. Control should not require unnecessary focus or be positioned away from the user. This leads to another central aspect relating to the interaction willingness, namely the location of the control interface. Offermans et al. (2014)'s study shows that people are often too "lazy" to interact with distant light sources, or controls that are hard to reach. The authors state that people wish to control their lights from either near the door, or where the light is actually experienced in order to fit the current activity taking place. For the latter, the lamp and its control have to be positioned where the lighting need is, or it has to be controlled remotely by e.g. a dedicated remote control or a smartphone. In this regard Offermans et al. (2014) comment on the increased effort connected with bringing up the smartphone as compared to a dedicated controller. The authors find that routines activities such as "quick-in-and-out" from the kitchen, or hallway are basic and frequent, and should be supported without taking much effort. Further, "*interactions that are part of a routine should therefore be designed to be peripheral and being executed together with the primary activity*".

Further, the social context can be a motivation for interaction. The social context of having friends over can allow for creation of certain atmospheres, where specific lighting settings might be desired. In line, participants might set up the right lighting for the situation, as a participant elaborates: "*... for instance with a new boss I would like [brighter] lighting because you don't know each other*". The authors also find that people avert to disturb other people with the lighting in a room, e.g. while a person is watching a movie another person might not turn on the lights.

User interface

Offermans et al. (2014) refer to *degree of freedom* as the amount of adjustable parameters in a lighting system. These are brightness and colour for individual lamps, along with the number of lamps in a system. Therefore, many lamps with many individual parameters provide the highest level of control, possibly at the cost of more interaction effort. Following this, their study indicates that when controlling the whole environment as one, e.g. light up the whole room, a simple and easy solution is desired. However, more detailed control is desired when creating "atmospheres", which is often the case. Thus the authors believe that "*... it is important to support the user with varying levels of control, depending on the context of use*".

By combining the findings of degree of freedom and interaction effort, Offermans et al. (2014) mention the trade-off between control freedom and control effort that has to be considered. If many control parameters are provided, it requires more effort from the user to adjust accordingly. Again, it is dependent on the context how much effort is acceptable. If a certain atmosphere is desired then detailed control and more effort is acceptable. As a result of their finding, the authors advocate for supporting varying levels of control depending on context.

Following their study, the authors indicate that all the possibilities, which a smart phone application brings, needs to be labelled by the user as a type of presets. However, it should be possible to make small adjustments from here. As such the presets will function as a base to adjust from, instead of starting from scratch. In line, the authors suggest that such presets could be mapped to "human parameters", e.g. cosiness, liveliness, warm, working etc.

Related to interaction qualities, Offermans et al. (2014) highlight that interactions, which are diverse or fun, can encourage the motivation for interaction. Often, these types of new interactions can be rewarding themselves, meaning that the effort of interacting with the lights is balanced out by the experience of interacting. From their study, this is exemplified by pulling a rope to turn on a lamp, stepping on a footswitch as you walk by, or the novelty of smartphone interfaces. In line, the authors state that "*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*". Moreover, in terms of experience, Offermans et al. (2014) also hint that feelings of playfulness, magic, and skills can benefit towards the motivation, e.g. clapping to get light or owning a magic wand.

Offermans et al. (2014) also examine the use of metaphors for interaction in contrast to direct mapping schemes, where brightness is controlled via a dimmer control. One example of a metaphoric interaction is the LightPad, as mentioned in chapter 3. Here, an energy metaphor is used to map the gestural stroke to the amount of desired light in the environment. As soon as the metaphor was explained, people seemed to understand it, and were able to use it as a mental model. The authors claim that this opens up for the use of richer interaction paradigms, and state that "*... 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*", and "Such metaphorical mappings may support an intuitive understanding of the relatively complex interaction with a multi-degree of freedom system."

Further, the authors discuss interaction feedforward and feedback. When these concepts are missing, misunderstandings of how to use the interfaces could arise. Here, Offermans et al. (2014) suggest that designers can compensate by applying existing interaction paradigms and mental models. It might also be useful to leverage existing interaction paradigms and mental models, as they find that "*... people often used their knowledge of existing interaction paradigms from other domains and applied them to novel lighting interfaces*", e.g. by touching the LightPad for longer periods of time participants, expecting to get more light, before the metaphor was explained.

Summary of Offermans et al.'s design space

The existing design space of interactive home lighting has been outlined by Offermans et al. (2014), following a contextmapping study and evaluation of novel lighting interfaces. As a result, the authors have created an initial model of interrelated and overlapping themes regarding the user in context and the user interface. We have presented a number of these, which serve as implications for our work. A summary follows.

First, Offermans et al. (2014) divide lighting needs into *basic visibility, functional,* and *emotional*, depending on the context of the user. Second, a relevant and overarching theme is the effort of interaction. How much effort is the user willing to put into interaction with the lighting given the current context? The authors argue for a correlation between lighting needs and interaction effort, which imply that maximum effort may go into emotional lighting needs, and minimal effort into basic visibility needs. Also affecting interaction effort is the location of control. Is the physical location of control far away? If it is, it might be deemed too much effort to approach it, and perhaps the user feels "too lazy" to move there. The authors also argue that social settings might influence the lighting settings, and that diverse, fun, playfulness, and magical interactions are found to encourage and motivate interaction with the lighting. Moreover, these experiences can help to create awareness and appreciation of the lighting. As a result, these experiences might help balancing out the effort requirement related to interaction.

Third, Offermans et al. (2014) discuss the amount of adjustable lighting parameters per lamp, i.e. brightness, colour and number of light sources in a system. More parameters provide a higher detail of control, however, it has to suit the effort requirements and lighting needs of the context. Thus, the authors advocate for supporting varying level of control depending on context, as lighting preferences vary between contexts.

The authors also suggest relying on interaction metaphors and existing interaction paradigms in order to minimise interaction complexity, when integrating several control parameters, or as compensation for missing feedback or feedforward.

DISCUSSING THE DESIGN SPACE OF INTERACTIVE LIGHTING AGAINST OUR STUDY FINDINGS

When gaining insights in the domain of home lighting, we initially conducted a similar contextmapping study, also guided by Visser et al. (2005), unknowing of the work by Offermans et al (2014). Details on our study setup and analysis were presented in chapter 2. The themes found in our contextmapping study, along with our interviews with lighting expert and long-term Philips Hue users, support many of the themes identified by Offermans et al. (2014). When comparing our studies to Offermans et al.'s study, we acknowledge many of the same themes. We now discuss the design space of interactive lighting as explored by Offermans et al. against our important initial themes: contextual lighting needs and effort. As a result of this discussion, we label three important themes of the design space. These themes account for an integral part of the initial framework presented in next section, and thus of importance in the remainder of this thesis.

Design space theme: Contextual lighting needs

Most notably is the shared finding of the varying amounts of effort that people are willing to put into lighting interaction, according to the activities taking place and the lighting needs of these. The interaction effort theme will affect the following themes and be further discussed in its own dedicated heading.

Offermans et al. (2014) list the three levels of lighting needs *basic visibility, functional,* and *emotional.* We note that these correspond with the three functions of light

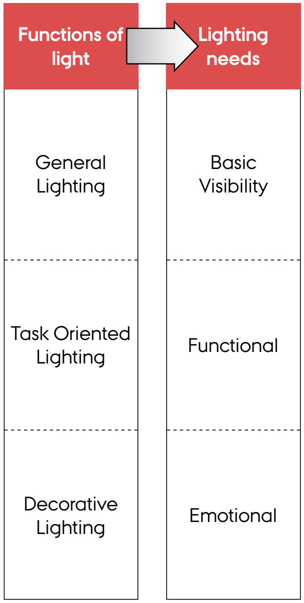


Figure 25. Illustration of how we now adapt the functions of light (chapter 2) to the notion of the three lighting needs of basic visibility, functional, and emotional identified by Offermans et al. (2014)

presented in our chapter 2. These were *general, task-oriented,* and *decorative* lighting. When the lighting need is related to basic visibility, then general lighting is sufficient. Further, when the user stays in the same place for longer periods of time, or carries out specific activities, e.g. studying concentrated for an exam, the need becomes functional in line with our notion of task-oriented lighting. This light setting might provide a clear vision and prevents tiredness, by aiming for a white and focused light. Finally, settings moods, staging or highlighting objects, or affecting an atmosphere, can be seen as emotional lighting in terms of Offermans et al. The correspondence between our functions of light and the lighting needs in terms of Offermans et al. can be illustrated in Figure 25. Thus, we will now adapt to the notion of the three lighting needs of basic visibility, functional, and emotional.

Design space theme: Detail of control in lighting systems

Offermans et al. (2014) mention the trade-off between effort and the freedom of controlling adjustable lighting parameters. When more lighting parameters have to be controlled, more effort is arguably required. With the LED technology, imagine the possibility of controlling 16.8 million combinations of the colours red, green and blue along with 256 brightness levels for each individual light source. These lighting parameters account for the lighting features that can be available to the user from a single light source. To provide an overview, we sum these up in Figure 26 below. On top of this, the user might potentially want to control a number of individual light sources in a system at the same time. This will provide a high detail of lighting control. However, the effort requirements, arguably, increase and the control interface of such systems have to be well considered. An example of an interface, which handles these control parameters of colour, brightness and number of lights is the Philips Hue smartphone app, which was reviewed in chapter 3. Offermans et al. (2014) argue that there are situations where high details of control are deemed acceptable. For example, when the lighting needs are emotional, the user is likely to accept the effort barrier as a part of building up an atmosphere.

In our empirical studies, we examined the frequency of interaction with these lighting features. The routine of

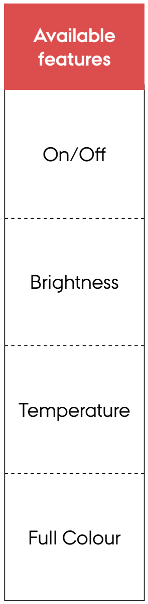


Figure 26. Illustration of the lighting features available from a single light source today (LED)

switching lights on and off to satisfy the basic lighting need was the most used feature, whether carried out by smartphone (for the Philips Hue owners) or traditional wall switch. If available, the second-most frequent feature was brightness adjustments, followed by adjustments of the colour temperature (warm/cold). The least used feature was the full 16.8 million colour functionalities for the Philips Hue owners, which was only done for special occasions.

Design space theme: Effort

Offermans et al.'s (2014) correlation between lighting needs and interaction effort is an interesting aspect of the current design space. The correlation deals with the balance between how much effort people prefer putting into interaction, depending on the current needs of the context. Basic visibility needs should require least effort, while emotional settings may require more. This corresponds with our findings. For instance, a person lying on the couch and feeling tired is less likely to get up and adjust the lighting, unless the adjustment is not absolutely needed. Also, routines were connected with simple, low-effort interactions such as switching the lights on and off, e.g. when entering or leaving a room. Further, when performing tasks such as reading or studying, it might be worthwhile to adjust the light setting, e.g. by adjusting an architect lamp, or increase the brightness to get a clear vision or prevent tiredness. High-effort interactions were acceptable when aiming for specific atmospheres and satisfying emotional needs. We found, that for arranging a dinner with guests varying from friends, to celebrities, to royalties, participants were likely to put extra effort into the lighting as part of setting up an atmosphere. An atmosphere was here created through both the lighting, e.g. candles, dimming of general lighting, etc., and through various decorative items such as napkins or precious objects.

As a result of this discussion, we identify and distinguish between two effort perspectives. The first, acceptable effort relates to the lighting need of the user. This relationship indicates the typical amount of *acceptable effort* that users are willing to put into interaction given a specific *lighting need*. This relationship is illustrated by two connected columns in the left side of Figure 27 below. Note, how the word *typically* is used to indicate this is not a strict relationship, as the context of the user may vary. Also, note that when discussing the lighting need and *acceptable* effort relationship, we do not consider the actual lighting interaction. The interaction can take various forms and possibly affect any of the lighting features available. Connected to this interaction is the *required* effort. That is, the amount of effort that a specific lighting interaction ultimately requires from the user. This is illustrated in the right side of Figure 27, which now illustrates the concepts presented in this thesis so far.

We propose that these two effort perspectives have continuous spectra ranging from low to high as it is hard to quantify both types of interaction effort. As a result, two lighting needs that are classified as emotional can be articulated relatively to each other in terms of effort. For example, it can be argued that the emotional need of creating a romantic atmosphere for a romantic dinner may allow for more interaction effort, than another emotional need of setting a relaxed mood for conversation.

Similarly, two lighting interactions can be positioned relatively to each other in terms of required interaction effort. Lighting candles around the house arguably require more effort than lowering the brightness via the dimmer on the wall, which again requires more effort than simply pushing a wall switch near the door.

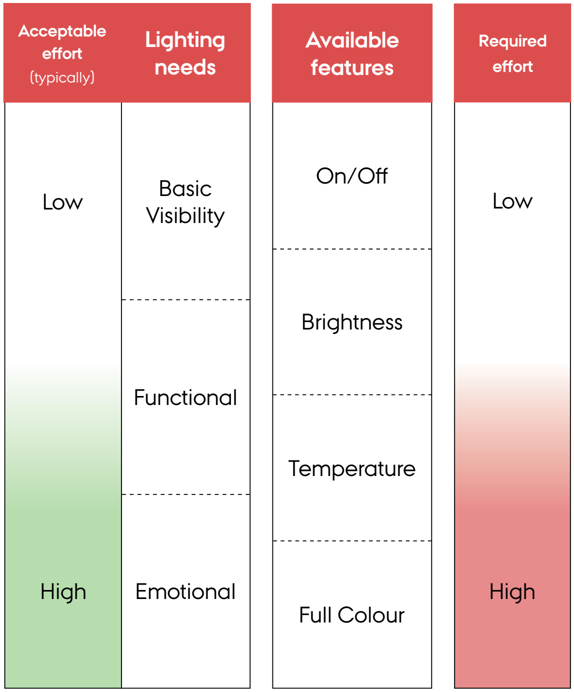


Figure 27. Illustration of the concepts presented in this thesis so far. Two columns illustrate the relationship between the typically accepted levels of interaction effort according to the lighting needs of the user in context. The required effort column represents the amount of effort that a specific lighting interaction ultimately requires from the user

INITIAL FRAMEWORK FOR IN-AIR GESTURAL INTERACTION WITH HOME LIGHTING

Finally, we combine the mapping schemes (in chapter 3) and the design space for interactive lighting that has been discussed in this chapter. Following this, an initial framework for in-air gestural interaction with home lighting emerges, and we illustrate this in Figure 28 below. This initial framework consists of the five dimensions *acceptable interact effort, lighting needs, available lighting features, mapping scheme,* t*required interaction effort*, which have been presented and discussed throughout this chapter.

For a quick summary, the two first dimensions visualise the acceptable amount of effort that users, typically, are willing to put into lighting interaction in relation to current lighting needs. Thus, when needs are emotional, higher interaction effort is typically acceptable compared to basic visibility needs, which should be quick and easy. The third dimension represents the lighting features that are available for user interaction. The fourth dimension, mapping scheme (chapter 3), categorises the relationship between gestures (input) and light setting (output). Lastly, the required effort dimension represents the amount of effort that is required to interact with the lighting based on the features and the mapping.

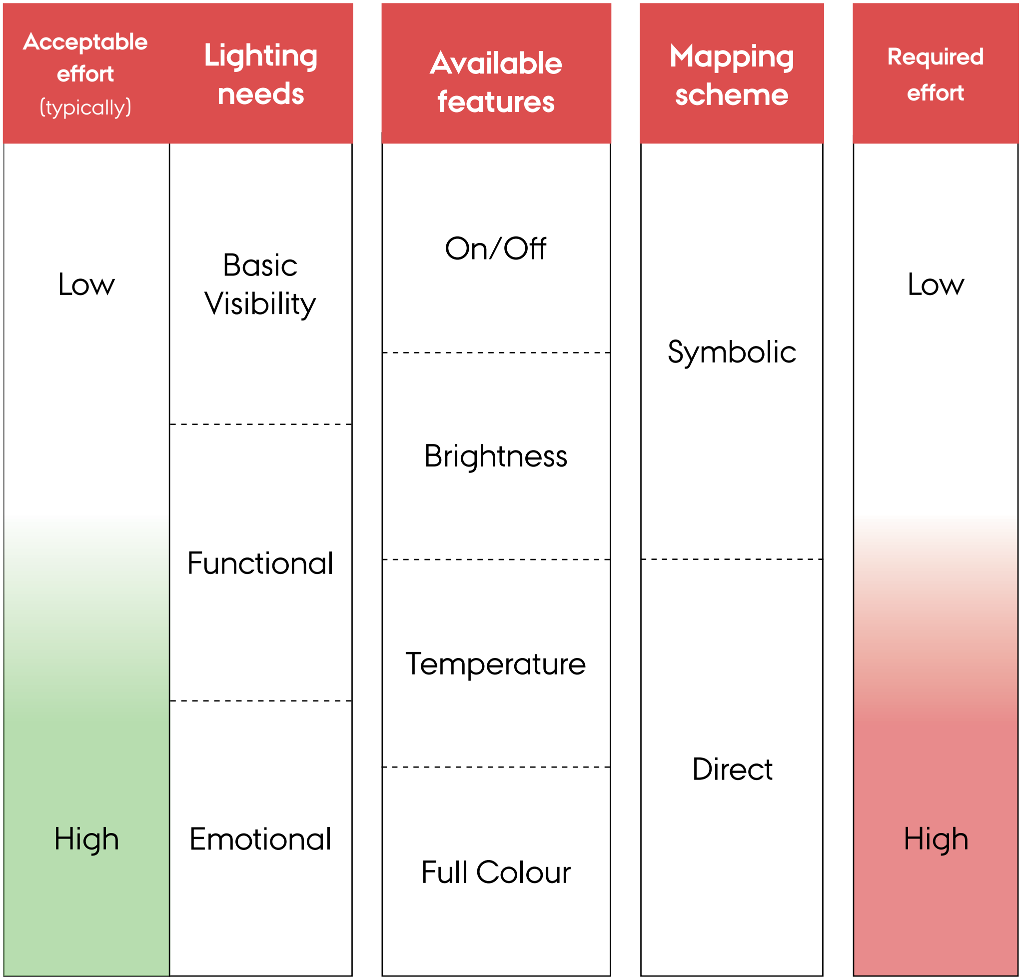


Figure 28. Initial framework for in-air gestural interaction with home lighting. The framework is a combination of the discussions in this thesis so far, and consists of the five dimensions of acceptable interaction effort, contextual lighting needs, available lighting features, mapping schemes, and required interaction effort

OPPORTUNITIES FOR IN-AIR GESTURAL LIGHTING

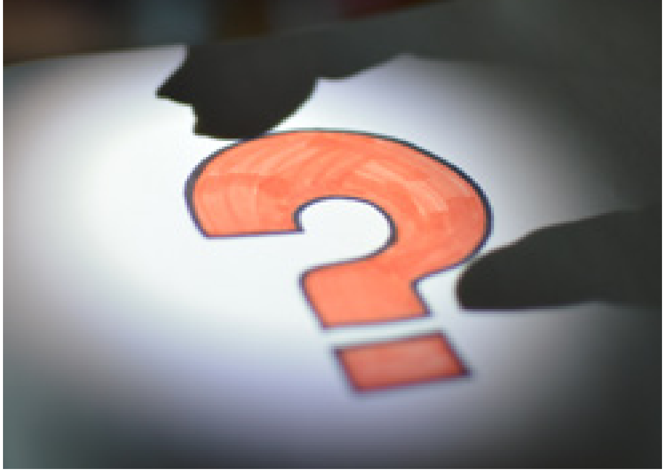
When addressing related work on in-air gestural interaction in chapter 3, we outlined the qualities of the in-air gestural interaction style. For a quick reference, these were *expressivity of bodily movement, proximity of control, sociality,* and *visibility of interaction*.

With in-air gestural interaction, we take advantage of the expressive qualities of bodily movement to address the varying detail levels of lighting control parameters. Further, the quality of interactions being visible affects social contexts, as actions are communicated through body language. It allows other people to quickly observe and imitate interactions. This visibility of interaction addresses the issue of personal smartphone interfaces in social contexts, as a long-term Philips Hue user stated during our empirical studies, "*I have to excuse for my use of the smartphone, I'm not playing, just adjusting the lights*" (chapter 2).

As discussed in this chapter, the location of the lighting interface affects motivation for interaction. If control is hidden or far away, it might not be worth the effort to control the lighting. Especially, if the minimum lighting needs are already met. As initially found, the Philips Hue system help to manage this issue, as long as the user carries her smartphone with the app installed. With in-air gestures, it is possible to provide input to systems from a distance. Thus, in the domain of home lighting, this provides the possibility of controlling the lights without physically moving to a stationary interface. Thus, interactions that previously required too much effort in terms of moving could potentially become easier accessible.

Research questions

Research on interfaces for home lighting systems shows the potentials of alternative interaction styles in daily contexts. In-air gestural interaction is another interaction style, and can be seen as radically different from the smartphone and tangible controllers reviewed here. From an interaction design perspective, the areas form an unexplored path for interactive home lighting. We have framed the design space of in-air gestural interaction with home lighting into an initial framework with five dimensions (Figure 28 on page 57). From here, we ask two questions, and subsequently scope our focus. The research questions are addressed in the remainder of this thesis.



Research question one

How can we design in-air gestural interaction with home lighting driven by lighting needs, features, and mapping schemes?

This question relates to the methodical approach of our research. It is answered through explorative design research with iterative prototype development. The prototyping (chapter 5) is driven by lighting needs, features, and mapping schemes, which refer to three of the five dimensions in the initial framework for in-air gestural home lighting (Figure 28). As the dimension acceptable effort is determined from the lighting need, and the required effort is the total amount of interaction effort required by a specific interaction, we do not consider these as drivers for our exploration.

Research question two

What implications and promising concepts does in-air gestural interaction hold for home lighting?

Through field studies and expert evaluations of developed prototypes, we seek to outline the contextual implications and promising concepts of in-air gestural lighting in the home context. It is worthwhile to note that the field studies and expert evaluations do not measure the performances of the prototypes, but provide directions that can inform designers of future in-air gestural interfaces for lighting in the home.

Scope: functional and emotional lighting needs at the dining table

The domestic environment provides many potential places for new technologies that support everyday activities. One approach is to aim for places, where social communication takes place, as argued by Crabtree and Rodden (2004). We choose to focus our work on the dining table, which serves as a fixed location for exploration, where various activities take place in daily life. In terms of lighting needs, we focus on the *functional* and *emotional* needs stemming from Offermans et al. (2014), as we identify these needs in activities taking place at the table. Examples are the functional needs for bright and focused light when studying, or for office or hobby activities; and the emotional needs for dimmed, cosy, or decorative lighting settings. Thus, the need for basic visibility is not specifically aimed for, as this lighting need is related to general illumination of a room, which shifts the focus away from the table. In future work, however, it would be relevant to explore how this could be an integrated part of interacting with the lighting at the table. Additionally, general lighting is often co-managed by a series of other light sources positioned around the room, along with the natural sunlight from the windows.

Extending current research

Following Offermans et al. (2014) exploration of the design space for interactive lighting, the authors provide future directions for their work on everyday lighting systems. This includes how "*... the design of interactive lighting control would benefit from a description of general interaction styles, accompanied by their pros and cons in different contexts*".

We see our work with the in-air gestural interaction style as a way to provide a detailed description of this particular interaction style for interactive lighting. Our gestural prototypes, which will be developed throughout chapter 5, are subjects to field studies in the home context (chapter 7), from where we outline the implications that take place in this context (chapter 8).


KINECT
XBOX 36

5

EXPLORING THROUGH PROTOTYPING

How can we design in-air gestural interaction with home lighting driven by lighting needs, features, and mapping schemes? Towards answering research question one, this chapter explores the framed design space of in-air gestural interaction with home, driven by the dimensions *lighting needs, lighting features,* and *mapping schemes* of the initial framework. First, the development of the Gestural Lighting Platform is presented and discussed. The platform is created to serve as a basis for prototyping at the dining table. This includes lighting setup, sensing technologies, and technical implementation. Second, this chapter presents and discusses eight prototypes developed on the platform, driven by the dimensions. The knowledge gained from this process extends the initial framework, which is presented as an answer to research question 1 in the next chapter.

DEVELOPING THE GESTURAL LIGHTING PLATFORM FOR THE TABLE

This section outlines the development of the Gestural Lighting Platform. The platform handles input by sensing in-air gestures, and provides light as output. The first subsection argues for the choice of a projector for our lighting setup. The second subsection argues for the two sensor setups used: Leap Motion (2012) and Microsoft Kinect (2014). Lastly, this section provides detailed information on the development of the Gestural Lighting Platform.

Lighting setup

This subsection argues for the lighting setup in the Gestural Lighting Platform. As mentioned, the exploration of in-air gestural lighting in this thesis is situated around the dining table. Through our empirical studies, we found that the dining table is often illuminated from a light source above the table. The light source is often positioned in a lampshade, which distributes the light evenly on the tabletop. As a rule of thumb, architects and interior decorators estimate the position to approximately 60 cm above the dining table, to create an even illumination of the table, and preventing the light bulb from blinding. Further, this height allows for eye contact and visibility across the table. For our platform, we wanted to incorporate this aspect.

In general, choosing the right light source is a challenge. Different properties of the light source come into consideration, e.g. rendering properties, fixed colour temperature, brightness, size, mounting, power consumption etc. To start prototyping, we searched for a dynamic solution, which could be adjusted in terms of colour and brightness, and ideally with the possibility of being moved over time.

Lighting solution 1: LED grid in a lamp (discarded)

Through the first iterations, we came up with different lighting solutions. First, we experimented with an LED grid solution, consisting of 48 individual regions, which served to create individually controllable light sources. This solution can be viewed in Figure 29. When controlling the LEDs individually through on/off switching and changes in brightness levels, we were able to move light from location A to location B (see Figure 30), which in turn altered the shadows from objects on the table. LEDs provide quick response time and a small form factor, but come with a cost of lumens. By increasing the amount of lumens, a higher brightness level can be reached. We thus grouped several LEDs together in each grid division to act as a single light source. By using RGB (red, green, and blue) LEDs we could configure 16.8 million colours. Brightness was adjusted through pulse-width modulation (PWM), which refers to turning the LEDs on and off, with varying intervals.

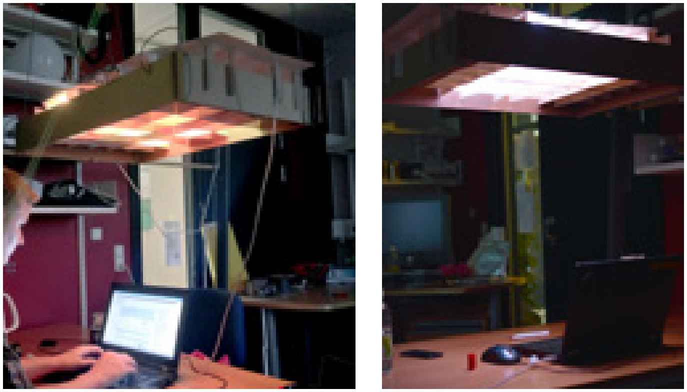


Figure 29. Early LED grid prototype lamp (discarded). Controlling each LED individually in software created an illusion of movement on the table

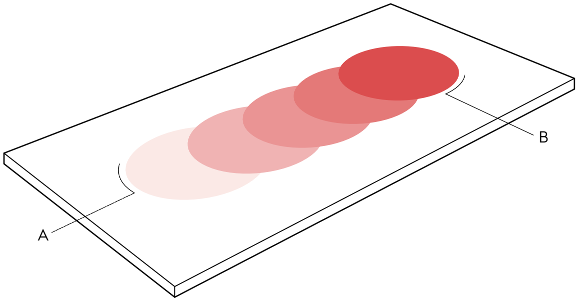


Figure 30. Light perceived as moving from A to B following individual control of each light source in a grid (here movement is exemplified in one axis)

Lighting solution 2: Projector (current)

The second option was to use a projector as light source, which allowed us to create quick mock-ups of light layouts on the table. A projector solution positioned in the ceiling above the table provided a high resolution light source in terms of pixels. Each pixel could then be grouped to simulate a light source with colour and brightness capabilities. However, choosing a projector could easily resemble a graphical user interface. Further, using one projector would provide us with one fixed light source, which could not be moved without a mechanical solution for rotation. Therefore, a projector was not able to change the directions of shadows.

To assist our approach of exploring in-air gestures in a rapid fashion, we chose the static projector solution, as we did not see any feasible solution for moving and rotating individual light bulbs. Neither did we see a solution of building new grid lamps with higher lumen LEDs.

Sensing setup

This subsection reports on the two types of sensing technology used, namely the Leap Motion sensor and the Microsoft Kinect sensor. In the next we argue how the sensors have been implemented in the Gestural Lighting Platform.

Both the Leap Motion and the Microsoft Kinect are sensing technologies, which allow for gesture recognition without the need of special lighting conditions, special gloves, or physical markers. Further, both sensors are well supported in terms of frameworks and APIs developed in different programing languages. Technical descriptions of the sensors are provided below, along with the pros and cons of each sensor. Subsequently, the KinectArms framework by (Genest, Gutwin, Tang, Kalyn, and Ivkovic, 2013) is presented as the main framework used with the Kinect sensor in the Gestural Lighting Platform.

Sensor 1: Leap Motion

The Leap Motion sensor (Figure 31) is a commercial 3D hand and finger tracking device, developed and manufactured by Leap Motion, Inc (2012). It is developed for computer input similar to a mouse, track pad or touch screen. The sensing technique consists of infrared (IR) camera tracking, which allows for tracking without interference from the lighting condition.

Technically, the sensor includes two monochrome IR cameras, three IR LEDs and a microchip for processing data. The three IR LEDs create a 3D pattern of dots, which the two IR cameras sense. The sensing can generate 280 frames per second (fps). The Leap Motion supports interaction in a hemispherical area (Airspace) with a distance of one meter above it and an accuracy of 0.01 mm. Further the Leap Motion tracks up to 10 fingers and incorporates a few standard gesture recognition and hand tools. The sensor delivers frames with the positions (x, y and z) and the orientation (yaw, pitch and roll) of a hand relative to the sensor.

The Leap Motion hand detection is solid because of the high resolution and high fps rate, and its abilities to filter out errors and provide sample images for gesture recognition. With its high precision, it can support subtle

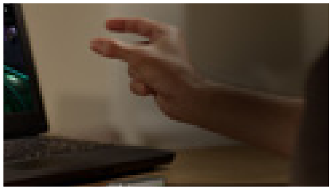


Figure 31. Leap Motion being used as an alternative to a mouse when manipulating 3D objects

Figure 32. Hands are placed above and orthogonal to the Leap Motion. The augmented grid illustrates the interaction space

gestures and track precise movement. The pitfall of the Leap Motion is the limited interaction space supported. Interaction needs to start in the centre of the Airspace. It is mostly reliable in terms of sensing when hands are positioned orthogonal to the sensor (see Figure 32). Further, if positioned on a table, the Leap Motion requires an open area around it, as nearby physical objects might obstruct the sensing area.

Sensor 2: Microsoft Kinect

The Microsoft Kinect sensor (2014; Kinect from now on) is a commercial and full body-tracking device, ideal for tracking, motion detection and gesture recognition. The Kinect has been developed for gaming similar to Nintendo Wii (2010) and PlayStation EyeToy (2014). Developers hacked the Kinect software to run on Windows-based computers, and to incorporate it in other contexts. Later, Microsoft made the API open and distributed the SDK for developers to use.

The Kinect consists of a range of different components for NUI interaction: a colour camera, IR emitter and IR depth sensor, an array of four microphones, and a tilt motor. The array of microphones is used for sensing directional voice and the tilt motor is to rotate the camera in a desired direction. The colour camera captures RGB images from the Kinect. The angle of view (Dobbert, 2012) is 43° vertical by 57° horizontal as illustrated in Figure 33. To calculate and create a depth frame the IR emitter emits infrared light beams that travel at the speed of light, and the IR depth sensor captures the reflected infrared light. By determining the travel time it is possible to calculate the distance. Subsequently, the depth sensor creates a height map from its viewpoint. The Kinect is capable of sensing with a resolution of 640 x 480 points with 11-bit depth. The depth sensing ranges between a minimum of 0.5 meter and a maximum at 4.5 meters. Anything beyond or closer than the maximum and minimum cannot be measured. The Kinect can capture a depth frame between 9 to 30 fps. The sensing is most accurate at 1 meter distance, giving a 2 mm precision, whereas at 3 meters, the precision is 4 cm. At 4.5 meters distance, the precision is 7 cm (Khoshelham and Elberink, 2012).

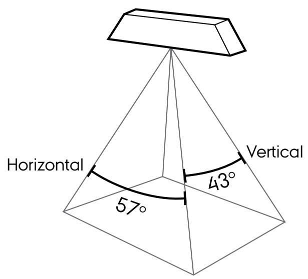


Figure 33. Horizontal and vertical angles of view of the Kinect

Out of the box, the Kinect supports full-body tracking, with support to detect hand and finger gestures and their positions (x, y, and z). The software detects features of the captured frames as it tries to fit the features of a detected body to a skeleton model. Further implementation of orientation of hands and fingers can be implemented through software. A whole body must be inside the angle of view of the Kinect, and if too many features are missing, the tracking fails to fit the body to the model.

This yields a problem, when a Kinect is positioned above the table, tracking the area above the surface of the table. In this setting, the Kinect cannot detect the full bodies. To overcome this tracking problem the KinectArms Framework (Genest et al., 2013) was developed as a quick and easy way to detect and track hands and fingers in such systems.

KinectArms Framework for detecting hands without a body

This section describes the KinectArms Framework. The framework, developed in C++, uses the OpenNI driver for the Kinect and the OpenCV library for analysing and filtering image information to detect features. In KinectArms, OpenCV detects the surface of the table and its boundaries, along with hands and fingers. The framework consists of four components: a camera component, a table detector, an arm and hand detector, and an arm tracker (see Figure 34). Further, Genest et al. provide a C# wrapper.

The KinectArms Framework provides an easy and rather stable vision tracking of hands and fingers positioned in 3D space. For each frame, the framework provides the detected hands with information about the positions and fingers. The tracking is limited to the precision of the Kinect.

The built-in table detection is used to determine if the hands are above the table, and provides the possibility of filtering out the rest. Further, it allows for better calibration when detecting hand and finger features. The program uses blob detection from OpenCV to find a large, even surface and its contours to determine the borders of the table. This functionality requires a table with an even surface, and no objects on or above it, to calculate the table size, position and height from the angle of view of the Kinect. If there is no table detected or if blob detection fails, the framework cannot track hands or fingers. Once the table is detected the framework reuses the detection throughout execution, but the table can be re-detected at any time during execution.

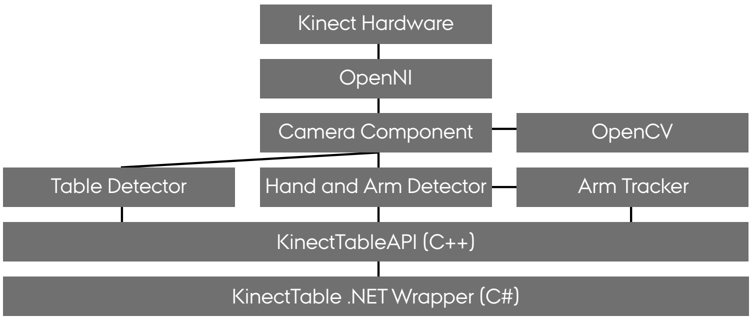


Figure 34. KinectArms Framework architecture. Adapted from Genest et al. (2013)

The following procedure describes the flow of the KinectArms framework for each frame:

1. Microsoft Kinect captures a depth frame
2. OpenNI sends the depth frame through a local TCP connection to the KinectArms (C++)
3. KinectArms (C++) detects hand features in the frame
    a. Remove anything outside the dimensions and location of the table
    b. Find hand contours features by using the Canny, Erode, and Dilate algorithms of OpenCV
    c. Find arm base with Contours algorithm, to determine if it is a hand is reaching into the interaction space above the table
    d. Find palm centre and number of fingers with the use of Hull (K-Curvature) algorithm
    e. For each hand contour, it creates a new Hand object with hand and finger information
4. KinectArms (C++) wraps the data and sends it through a local TCP connection
5. KinectArms (C#) receives the data
6. KinectArms (C#) handles the data and waits for new incoming data

Our implementation follows the sixth step, where the Gestural Lighting Platform handles the data from the framework. The next subsection will describe our implementation further.

Implementation of the Gestural Lighting Platform

Through iterations, the Gestural Lighting Platform was developed. In the early stages where experimentation was prioritised, we mainly relied on the Leap Motion sensor. As the platform evolved, the Kinect was introduced. Both iterations of the platform relied on a projector to output the light.

Projector implementation

The implemented projector is an InFocus IN114ST, with a high luminous flux at 2,500 lumens, a XVGA resolution (1024 x 768 pixels) and a short throw lens. The luminous flux of this projector is high compared to a normal light bulb, which has between 300 to 1100 lumens (Bønløkke Andersen, 2012). The resolution of 1024 x 768 pixels gives us 786,432 individual pixels to manipulate. Combined with a short throw lens we can project relatively large images from a short distance, at the time of writing.

The projector acts as a tiny light source, and with its

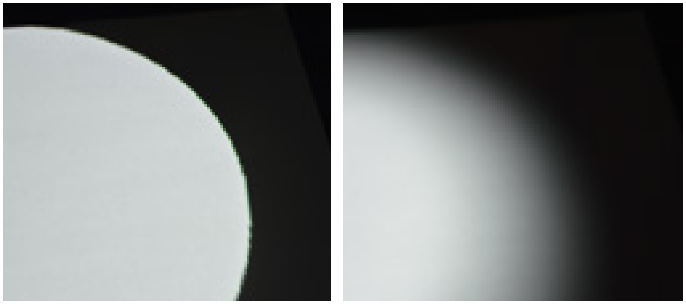


Figure 35. A circle projected onto a tabletop in darkness. Projector lens in focus with clearly pixelated regions (left) and out of focus with gradient applied in software (right)

high amount of luminous flux, it creates defined edge of pixels (which is typically good for GUIs), and highly focused hand and object shadows on the table. To avoid a display that resembles a GUI, two steps have been taken. First, physically the projector has been put out of focus, which blurs out the defined edges of each pixel. Second, we do not display pixelated material such as images or graphics, which are typical for screen-based applications. Instead, when rendering groups of pixels, we apply gradient or blur filters in software (see Figure 35). This is an attempt to make the projector light appear more natural as known from living environments, where diffused lighting is often used.

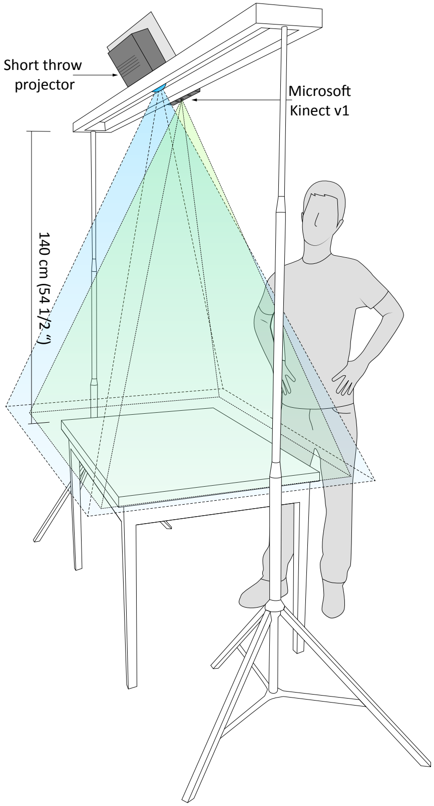


Figure 36. Frame, sensing, and lighting implementation of the Gestural Lighting Platform

Platform frame

The projector is positioned 140 cm above the table, and the projection can cover a 160 cm x 112.5 cm table, as seen in Figure 36. To elevate the projector a frame was build. The frame consists of two portable and adjustable tripods and a wooden bar placed on top of the tripods. The tripods extend to a height of 220 cm. With a table height of 70 to 80 cm it yields a distance from the rack to the surface of the table of 150 cm. In our implementation, the wooden bar has a fixed length of 210 cm, which allows the table to be 200 cm in length.

Sensing implementation 1: Leap Motion

The first iterations of the platform relied on the Leap Motion as sensing technology, due to its out of the box support of hand and finger tracking. The main purpose of the Leap Motion was to evaluate our ideas and concepts on in-air gestural interaction with lights at an experimental level. Leap Motion provided precise sensing and it was easily integrated with Processing (2004), which allowed us to experiment quickly. Although the precision is high and the tracking reliable, the interaction space was limited and gesture recognition was restricted to start above the sensor. Further, the tableware that is arguably positioned on tables in the home domain would obstruct the interaction space, as explained earlier.

Sensing implementation 2: Kinect with the KinectArms Framework

To enlarge the interaction space the Kinect was implemented, at the cost of precision. As explained, the Kinect cannot detect or track hands without seeing the whole body, which is why we rely on the KinectArms Framework by Genest et al. (2013). For the Gestural Lighting Platform, four parts were developed on top of the C# wrapper, which is illustrated in Figure 37 below. First, a preview window for displaying what the Kinect was "seeing" with its camera (Figure 40). Second, a calibration mechanism with a GUI to adjust and align input (hand sensing) and output (the light) (Figure 39). Third, a software filter for correcting errors and handling of noise. And forth, a window containing the light setting. With the projector connected to the laptop and running extended display mode, the preview and calibration windows can be placed on the laptop screen, and the light setting window placed on the screen of the projector.

To correct errors in hand detection, we implemented a filter mechanism and apply it to the data we receive from the KinectArms Framework. First, all detected hands and fingers that do not have an intersection point with the edge of the table are removed. Further, we do not allow for interaction below a certain depth measured from the surface of the table, usually 20 cm. This avoided finger and hand features being detected on tableware, and other objects positioned on the table.

Prior to interaction in new environments, our platform needs calibration. The calibration mechanism serves to align the projected image containing the light setting with the sensing area of the Kinect and the table. This way, the Gestural Lighting Platform can quickly be applied to any table of ordinary size. A limitation of the platform is the projected image size of 160 cm x 112.5 cm at 140 cm above the table, and the sensing

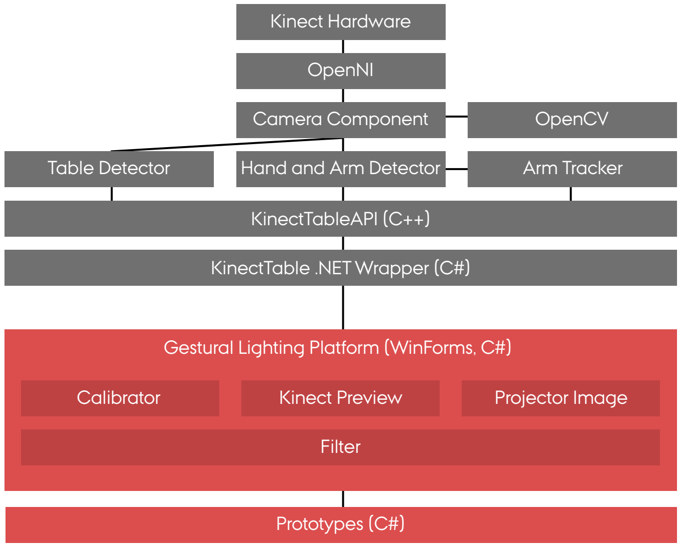


Figure 37. Existing KinectArms architecture (grey) and the Gestural Lighting Platform architecture (red). The prototypes introduced in next chapter is attached at the bottom

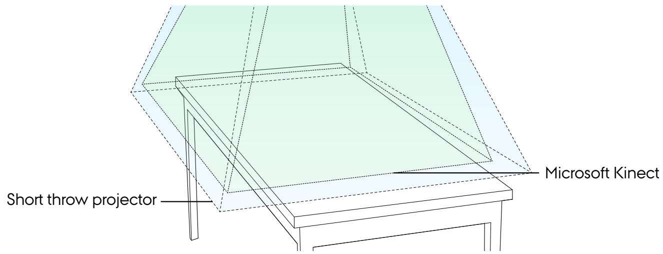


Figure 38. Field of view of the Kinect and projector space and table might be misaligned

area of the Kinect, as the projected image can be larger or smaller than the width and/or length of the table. As seen in Figure 38, the length of the table is larger than the projected image, but the width of the table is smaller than the projected image. If this is the case, we adjust the projected image to fit the surface of the table as good as possible, using the calibration mechanism. Further, there can be misalignments between the position of the sensed gesture in the Kinect interaction space and the projector space. This is handled in software when mapping between the spaces, by offsetting the sensed coordinate into the projector space with a dynamic value along the x and y axes.

We implemented a simple GUI to contain all calibration functionality, as seen in Figure 39. Further, as we developed the prototypes (introduced in the next chapter) a module for quickly switching between these were placed in the bottom of the calibration GUI.

Limitations of the Gestural Lighting Platform

The limitations in the sensing technology used, limits the platform. First, the Kinect does not deliver a steady amount of frames pr. second (fps). This makes it difficult to track hands across frames as they move. Following this, as the hand tracking is limited while moving, finger recognition is nearly impossible throughout a gesture. Although the Kinect has a high precision on fixed objects, tracking moving objects decreases the precision. In some cases, it is possible to detect fingers, and to track fingers across individual frames, however, only under strict conditions, i.e. moving the hand slowly and with an open hand, where fingers are spread. Due to this limitation of sensing, the platform is most effective when gestures rely on either open or closed hand poses, as seen in Figure 41.

The interaction space of the Kinect above the table is limited to the angle of view of the Kinect. Further, as the distance between the Kinect and the table increases, the precision drops. Here, we identify a trade-off between having enough interaction space and tracking precision. The limitation in angle of view affects the interaction, as the hand tracking is lost near the edges of the table (Figure 42).

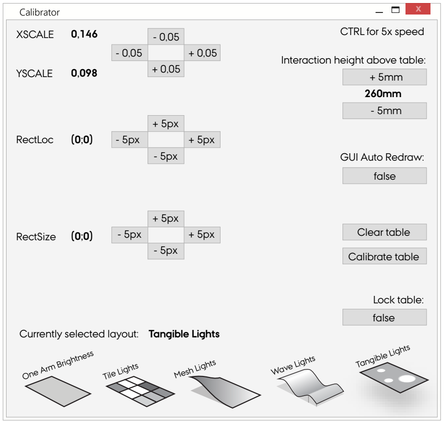


Figure 39. Calibration window used to align the Kinect interaction space, projector space, and table. Additionally, different prototypes of chapter 5 can be enabled from the bottom of the GUI

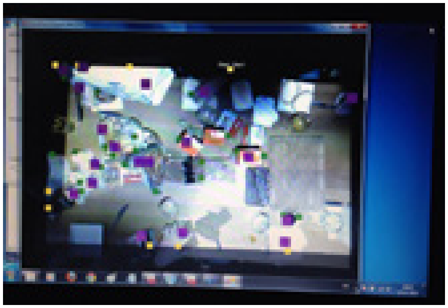


Figure 40. Preview window that displays what the Kinect "sees". Green dots are detected fingers, purple dots are centres of hand palms, and yellow dots indicate intersection with table border

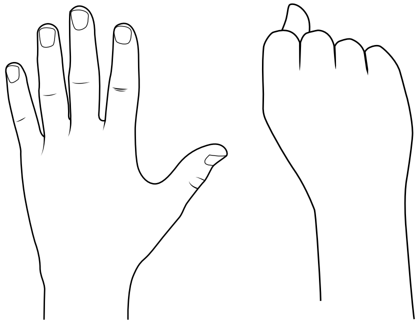


Figure 41. Most effective hand poses for steady recognition across frames in the Gestural Lighting Platform. Individual finger detection is nearly impossible with the KinectArms Framework

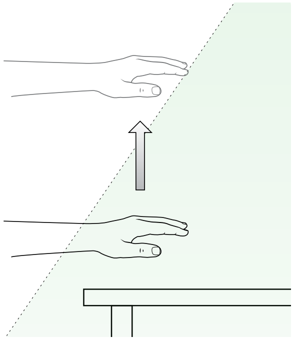


Figure 42. Illustration of a hand moving outside the angle of view of the Kinect (green area) near the edges of the table

EIGHT PROTOTYPES FOR IN-AIR GESTURAL INTERACTION WITH HOME LIGHTING AT THE TABLE

In addition to the illustrations provided in this section, a demonstration video (length 01:40) has been created to give a quick overview of the eight prototypes developed in this section. The prototypes run on the Gestural Lighting Platform and rely on either the Leap Motion or the Kinect sensor presented in previous section. Please refer to Vimeo (Andersen and Sørensen, 2014a).

To explore the first research question, eight prototypes are developed with our Gestural Lighting Platform within our scope of functional and emotional lighting needs. In our research through design approach, the prototypes are systematically developed to explore the dimensions of the initial framework for in-air gestural interaction with home lighting. For quick reference, the illustration of the initial framework is copied from chapter 4 and shown in Figure 43 below.

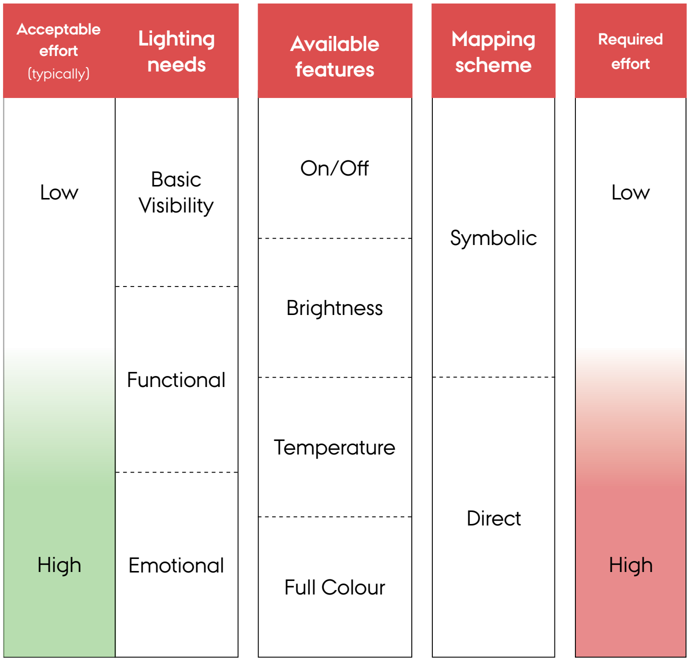


Figure 43. Illustration of the initial framework from chapter 4. Inserted for a quick reference

Methodological approach for prototyping

For our research through design approach, the initial framework is used as a generative tool for creating prototypes, exploring the different dimensions. In order to use the framework as a generative tool we apply the framework systematically, where a lighting need, a lighting feature, or a specific gesture creates an entry point into the framework. From the entry point, the other dimensions of the framework are addressed. As an example, the entry point of a prototype can be that it serves a functional lighting need, and through this entry point the lighting features and the mapping scheme are considered, subsequently. Alternatively, the entry point into the framework can be full colour features, and from here the lighting need and mapping dimensions are considered. In addition, prototypes are also inspired and motivated by other prototypes. In terms of effort, each prototype and its designed interaction result in a required amount of effort, which is not quantified, but can be discussed in relation to other prototypes. The next subsection will present the sources of inspiration and insights from the developments.

Each prototype is in itself the result of an iterative approach. For each prototype we iterate through the phases of design, implementation, and evaluation. Each prototype has been subject to numerous planned as well as sporadic iterations, and has been evaluated with 5 to 16 participants in our lab distributed over the number of iterations. Each iteration for each of the eight prototypes is not outlined. Instead, we provide one discussion for each prototype on important findings related to the lighting needs they are intended to serve, alternative interactions, gesture designs, control parameters, mapping between action and function, and other general challenges and concerns. After presenting and discussing each of the eight prototypes, we discuss how they interrelate in terms of interaction and challenges.

It is worth to note that the focus has not been on developing full-scale systems, which are capable of all possible lighting functionalities. Rather, the prototypes include limited functionality (e.g. only brightness control), and investigate different ways of controlling these parameters through in-air gestural interaction. The prototypes are not chronologically ordered.

Prototype 1: One Arm Brightness

One Arm Brightness (Figure 44) has its entry point in the framework in the lighting needs dimension by serving a functional need. It is developed to support task-oriented oriented activities, e.g. study or office work. In such activities we were informed that users strive for bright, white light, thus this prototype is controlling brightness. To interact, users can simply move an arm up and down anywhere above the tabletop. In-

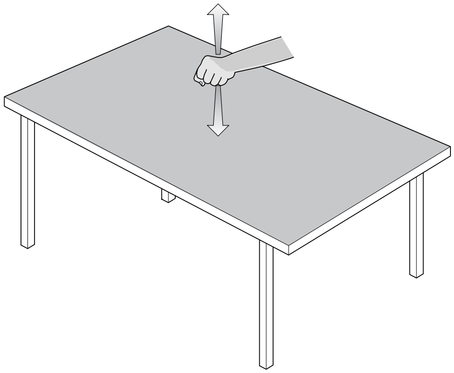


Figure 44. One Arm Brightness prototype. Arm is moved up and down to adjust brightness. A grab pose is one option for interaction

teractions thus affect the whole light setting, and are possible from anywhere around the table. According to intentions, it is possible to, for example, work with a laptop while casually putting one arm forward anywhere above the table to adjust the brightness level (Figure 45). Functionally, each time the gesture is performed, the brightness is continually adjusted from its current level, based on the distance that the hand was moved along the z-axis (delta height) between frames.

Evaluation and discussion of the prototype

For the basic actions of adjusting the brightness, we found that moving one arm up and down was an efficient and easy perceivable way to indicate more or less of something.

Having the palm of the hand oriented towards the tabletop felt like addressing the light reflected at the tabletop, in contrast to the light emitted from the light source (Figure 46). Evaluations in the lab indicated that this orientation of the hand was similar to the lifting or lowering of a lid on top of something (e.g. the hand imitates a pot lid) in order to contain or reveal more of the content. The gesture was also found related to the way dog owners instruct their dogs to calm down.

A number of alternative hand poses have been applied in practice. First, having the palm facing upwards was experienced as way to demand light directly from the source above, instead of addressing the tabletop (Figure 47). However, this hand pose was found less ergonomic due to the twist of the forearm. Second, in contrast to viewing the hand as a lid, a closed hand, indicating a “grab” gesture, could be associated with grabbing the handle of a pot lid. Thus, the hand gesture could now resemble both a lid and the grabbing of a lid.

As an alternative to the continuous adjustment of brightness, we defined a finite, one-dimensional brightness spectrum, so the lowest level was always near the tabletop, and the brightest level was near the light source in a reasonable height, reachable by hand. While this

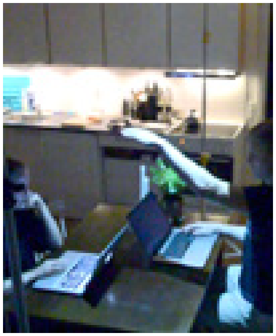


Figure 45. Adjusting brightness in a work related activity

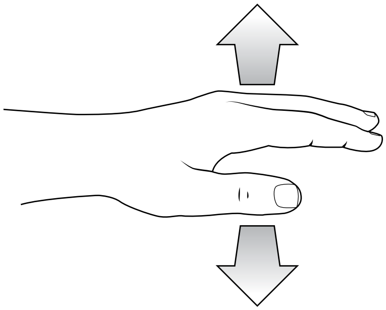


Figure 46. Palm facing down used as a lid on a pot to contain or reveal something

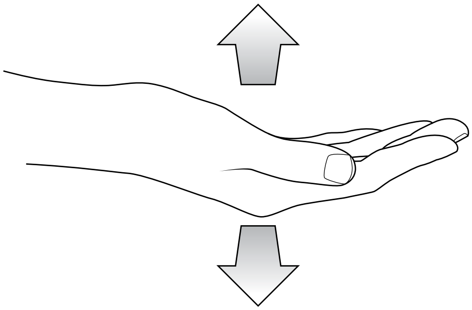


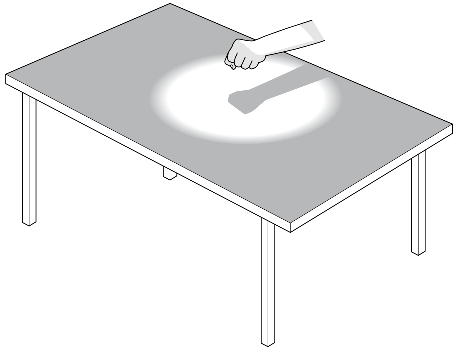
Figure 47. Palm facing upwards as a way to demand light directly from the light source above

could work to reduce the effort for the first adjustment, there is a drawback with further adjustments later in the activity. The user might want to slightly refine the setting, e.g. if the brightness is too bright. With a finite spectrum, this causes “jumps” in brightness levels, as users cannot remember the exact height that the level was set to initially.

The arm interaction of this prototype is suited for the adjusting of one lighting parameter. Here, we have chosen brightness as part of designing for a task-oriented activity such as studying. However, other one-dimensional lighting parameters such as temperature (cold to warm) could be controlled with the same arm gesture. Arguably, the same movement of the arm should not control both brightness and temperature in a system. In this regard, we propose that more lighting parameters can possibly be adjusted by utilising the individual position of fingers, e.g. spreading them apart, or only extending a number of fingers.

Prototype 2: One Spotlight

One Spotlight (Figure 48) is driven by a functional lighting need similar to the One Arm Brightness prototype. This prototype provides a simple and directed light similar to what a desk lamp or architecture lamp provides. This light is deemed suitable in activities where requirements are functional and task-oriented. In our initial studies we found that users tend to adjust the light setting slightly according to the activity, e.g. adjusting the angle of a desk lamp for reading a book. For interaction, the user can simply move the light to the areas or



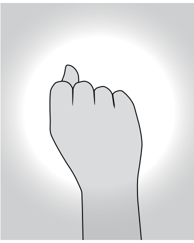


Figure 49. Grab gesture above the tabletop to select and hold onto the light

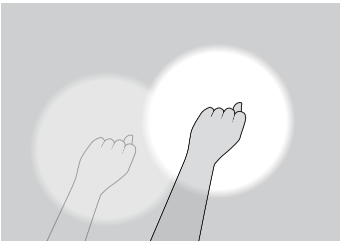


Figure 50. Dragging the light across the tabletop

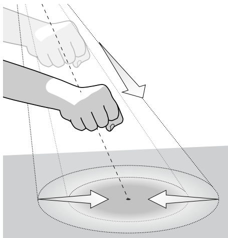


Figure 51. Resizing a light (here to enlarge)

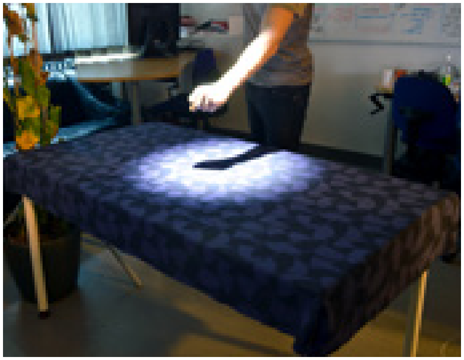


Figure 48. One Spotlight prototype. The cast light is “grabbed” near its centre and now subject to moving and resizing

objects of interest by grabbing the cast light near its centre (closing the hand, Figure 49) and dragging to the desired position (Figure 50). Further, to cover a larger or smaller area in light, the user can resize the cast light by moving her hand up or down (Figure 51). When the light is turned on, a default or last-known light setting is used as a starting point of the new light setting.

Evaluation and discussion of the prototype

Interactions are limited to only function above the boundaries of the cast light, so we argue that the interaction requires some effort when adjusting to current needs compared to the One Arm Brightness prototype. In One Spotlight, the spotlight is always available for the user to grab as soon as the prototype is started. Through iterations we experimented with how the user could create the light when needed, so it only appears when desired by the user. Here, initial discoveries on how such "create light" gestures could accommodate this, and the concept of moving and resizing the light, were the starting points for attributing light regions with a physical presence. This was the foundation of the Tangible Lights prototype, which is discussed as prototype 8 in this section.

Prototype 3: Sunrise

This prototype (Figure 52) allows for the control of one overall light, covering the table as a whole, similar to the One Arm Brightness prototype. The Sunrise prototype takes its entry point into the framework in the mapping dimension, as the interaction builds on a metaphor that symbolises and simulates the perceived movement of the sun across the sky. When the sun is positioned low in the horizon during sunset and sunrise, the sky takes a warm, red colour, while changing to the white and blue colour temperatures during the day. The idea behind a sunrise metaphor stems from our interview with a lighting expert during the empirical studies (chapter 2). We found that the sun, with its natural light, plays a significant role to people, especially in the Nordic countries. Thus, this prototype is associated with an emotional lighting need.

To perform the sunrise gesture, a hand is placed in an arbitrary position above the table. From here the hand is moved in an arc above the table, utilising one dimension at the table and the height of the hand (x, z axes) as seen in Figure 53. When the height of the arc increases, the colour temperature turns colder, resulting in blue colours. When the height of the arc decreases, the warmer colours take over.

Evaluation and discussion of the prototype

Following lab evaluation, we found that it was impractical to perform gestures with large arm movements, i.e. making large arcs, although large arcs allowed for detailed adjustments. By decreasing the magnitude of the movement, we were able to find a suitable balance between detail and arc. However, by making arc gradually smaller, the symbolic gesture shifted towards being a ball, eventually.

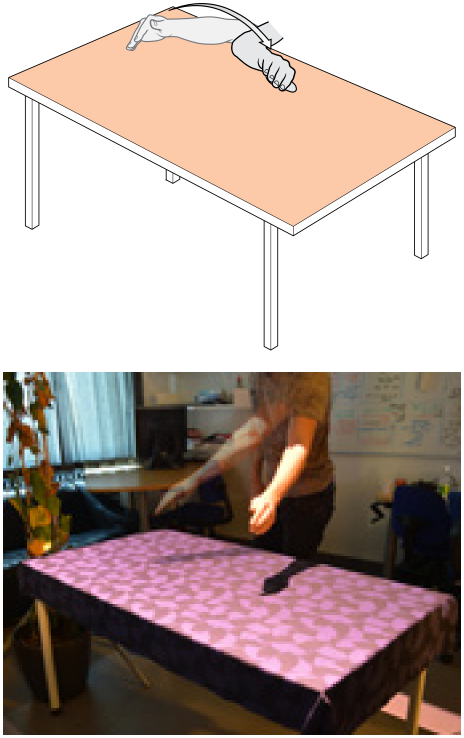


Figure 52. Sunrise prototype. An arm is moved, forming an imaginary arc

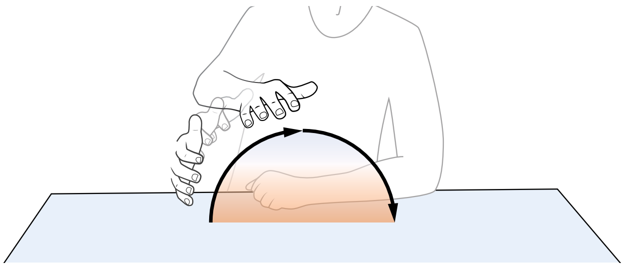


Figure 53. The user is moving her arm in an arc, where the lower parts of the arc provides a warm light, which gradually gets colder towards the top

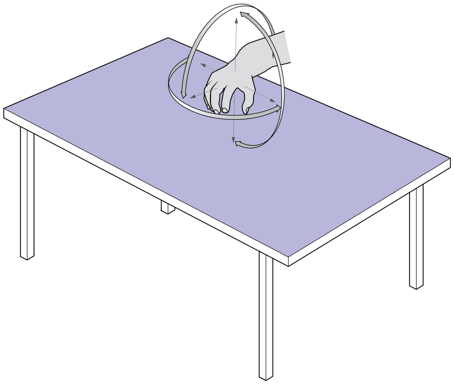
Prototype 4: Colour Ball

Colour Ball (Figure 54) is developed from the lighting features dimension as an approach to incorporate the 16.8 million colours experienced in the Philips Hue system. As mentioned in our studies, we found the full range colour functionalities to be of least interest when setting up and manipulating light in the home in daily contexts. This feature was primarily used for special occasions, e.g. Christmas or Halloween and for demonstrating the capabilities of the system. Thus, we also treat colours as an emotional need.

For interaction, we implemented another phenomenon from daily life to control the overall light setting: the act of holding a sphere-shaped object in the hand, e.g. a tennis ball. The fictive ball is enclosed in one hand and turned in the pitch, roll, and yaw dimensions by twisting of the wrist. The ball enables simultaneous control of the three colour dimensions red, green and blue, which in turn, are mapped to the pitch, roll and yaw dimensions, respectively. This is an intentional attempt to lower interaction complexity using a symbolic mapping. To interact with the fictive ball, a hand is placed in an arbitrary position above the table, where the fictive ball is turned.

Evaluation and discussion of the prototype

Regarding the interaction, our lab evaluations quickly revealed that the natural movement of the wrist was indeed suitable for delivering three degrees of input to a lighting system. However, in terms of targeting daily activities in the home, we quickly found that the colour adjustments were more a gimmick, similar to our findings relating to the colour features of Philips Hue (chapter 2). Moreover, we observed how ergonomic limitations in the rotation of the wrist were affecting the interaction, as the hand reaches its physical movement limits. Particularly along the yaw axis, the range of motion is limited to approximately 50 degrees (Figure 55) (Luttgens, Hamilton, and Deutsch, 1997). As a result, we mapped the blue colour range (256 levels) to this limited rotation angle along the yaw axis. However, the mapping of rotation in the pitch and roll axes allowed for wider ranges (ranges of motions of 120 degrees (Figure 56) and 180 degrees, respectively (Luttgens et al., 1997)). In practice this yields finer detail of control along the pitch and roll axes, as the 256 levels are distributed to wider movement ranges.



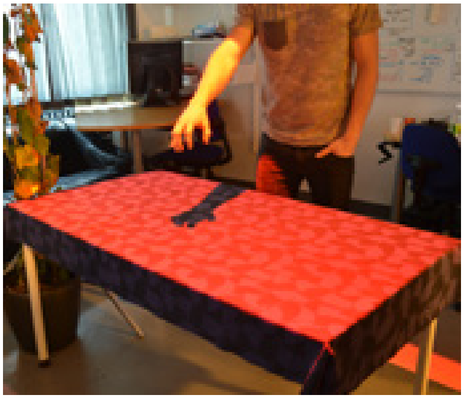


Figure 54. Colour Ball prototype. The rotation of the wrist manipulates the red, green, and blue colour parameters

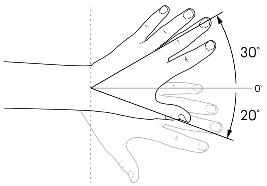


Figure 55. Top view. The range of motion along the yaw axis limits the mapping range of the lighting parameter

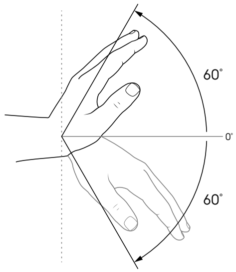


Figure 56. Side view. The range of motion along the pitch axis allows for wider mapping ranges of lighting parameters

Prototype 5: Tile Lights

As an alternative to adjusting one overall light setting, we started to explore how the light reflections on the tabletop could be laid out in different ways. A first, approach was to split it in nine tiles, and let each tile be targeted individually by positioning a hand above it, utilising the x and y axes, as seen in the Figure 57 below. In the context of a home, the tile layout was not intended to suit a particular need, experiment with specific gestures or lighting features. However, the prototype was a first attempt to allow interactions in multiple areas, which is seen in the next three prototypes.

In terms of interaction, we used the simple arm gesture of an arm moving up and down from the One Arm Brightness prototype. Thus, Tile Lights can essentially be viewed as nine equally sized One Hand Brightness prototypes. No particular finger pose was designed for this prototype, thus the system was only sensing arm movement along the z-axis.

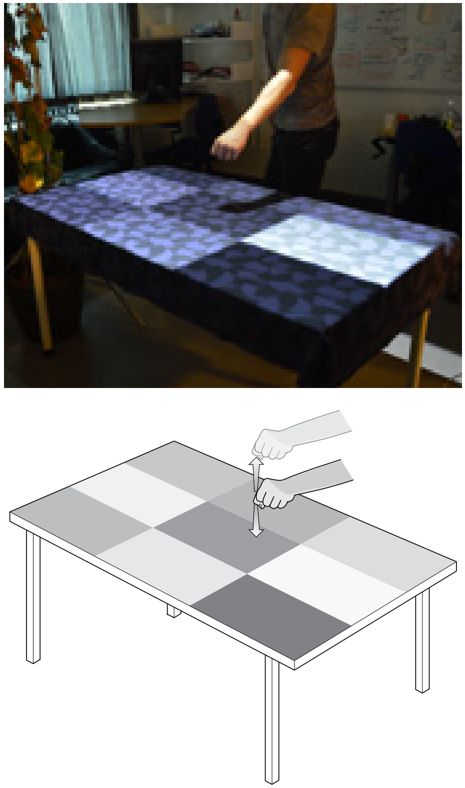


Figure 57. Tile Lights prototype. An arm is positioned above one of the nine tiles in order to select it. Up and down movement of the arm adjusts the brightness of the tile

Evaluation and discussion of the prototype

In the home, the tiles does suit any particular daily activity, however, we imagine larger collaborative spaces with larger tables could benefit from a division of areas for individual control by multiple users. Another thing that is apparent with this prototype is the clearly defined boundaries between the tiles. These boundaries appear rather obscure compared to the lighting found in the home today. However, our evaluation suggested it might trigger and enable new activities. In particular, social games were suggested such as tic tac toe, reversi or chess, where the illuminated tiles could be used as game board. As this new usage can be viewed as supporting a functional purpose in a game, we classify it as a functional lighting need. However, having the lighting as integral part of games is a new usage of home lighting, which is not directly concerned with the previously identified lighting needs.

Due to an intentional, loose sensing implementation in this prototype, it is possible to interact with all finger poses, e.g. open hand, closed hand, extended index finger, etc. This way, we could observe tendencies among participants in our evaluations. We observed that participants typically used an open hand pose, but when asked, they did not have a clear answer, as to why this was preferred. We believe this preference could be impacted by us in at least two ways. First, since participants had previously interacted with One Arm Brightness with an open hand pose. Second, due to the fact that the system instantaneously responded to their arm movements right away by adjusting the brightness.

As this prototype introduced individual regions, a challenge was to communicate this fact. One way was to assign varying brightness levels to the tiles in order to distinguish them from the beginning. Additionally we found that once users had interacted with one tile or seen an example of this, it was easy to figure out that there were nine of them with individual brightness levels.

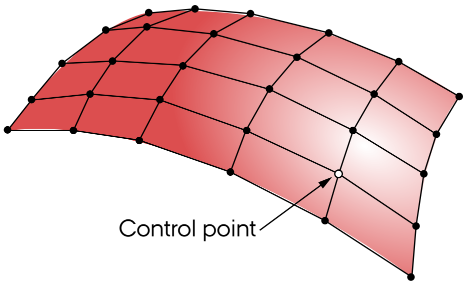
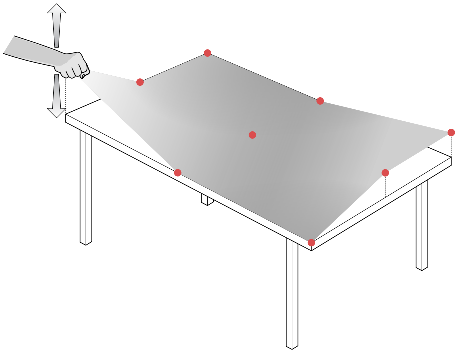


Figure 58. Mesh Lights incorporates a metaphor of a NURBS surface as known from 3D programs

Prototype 6: Mesh Lights

The Mesh Lights prototype was developed to further explore aspects of having individual areas, as found in Tile Lights. However, this time driven by a focus on gestures. In contrast to a tiled division of the reflected light, we wrapped the interface in a metaphor to serve as a conceptual model. Thus, Mesh Lights can be thought of as manipulatable control points in a NURBS surface as known from 3D programs, where the surface touches all control points (see Figure 58).

In Mesh Lights, we apply a direct mapping scheme between hand movement and brightness. A user interacts by “grabbing” one of nine invisible control points in mid-air with a closed hand. With the control point “in hand” the user can adjust the brightness by moving the arm upwards or downwards. If the arm is moved upwards while grabbing, an increase of brightness continually takes place at the closest control point, which in turn renders a linear gradient to all adjacent neighbours based on their current brightness values. This “flattens out” the light setting. In this prototype, neighbours with the distance of one are affected. Moving the arm downwards towards the table while grabbing causes a decrease of brightness. This similarly affects adjacent neighbours. An illustration of the behaviour and the gesture can be seen in Figure 59.



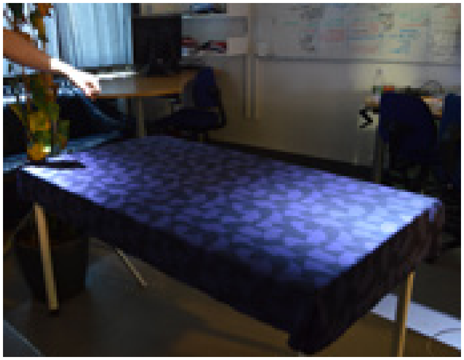


Figure 59. Mesh Lights prototype. Grabbing and holding onto a control point. Note how the control points are invisible in practice

Evaluation and discussion of the prototype

In line with the discussion of Tile Lights, this prototype is not designed to fit existing activities, but it is suggests more decorative usages, which categorises it as serving emotional lighting needs. Alternative ways of explaining the interface metaphor is to think of it as a fisherman's net, a tablecloth or a piece of fabric known from the physical world. However, here the shapes of the physical objects would collapse as soon as the grab was released.

In practice, the visual appearance does not hint a seamless curved surface, as can be viewed in Figure 59. However, all participators in evaluation expressed that the interaction was understandable, once they were informed about the NURBS surface, or the alternatives in case not familiar with 3D programs.

Prototype 7: Wave Lights

This prototype is introduced as a two-dimensional layout of separate regions with 20 control points (utilising the x and z axes), as opposed to Mesh Lights (x, y, z axes and 9 control points). The entry point in our framework is a symbolic mapping of gesture and lighting functionality. The interface integrates a metaphor of wind waves in the ocean, where wave crests represent high brightness levels, and troughs represent low brightness levels. Similar to Tile Lights and Mesh Lights, this prototype does not target any existing activities per se, but is created as part of our on-going exploration of having separate lights regions.

In the Figure 60 below, an arm is continuously moved along the y-axis of the table, symbolising several wave formations. In this particular illustration, movement is initiated and ended at the edges of the table. However, the wave gesture can be initiated and ended anywhere in the space above the table. Thus an interaction can affect only one wave or a few, if desired.

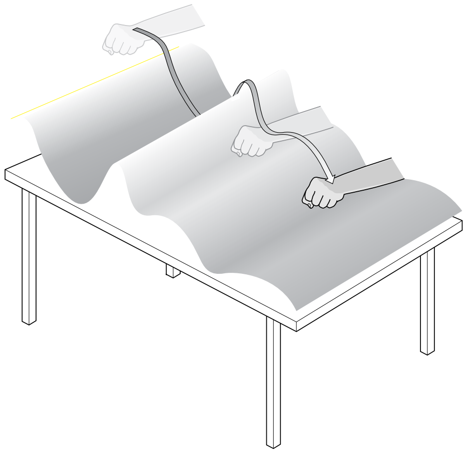


Figure 60. Wave Lights prototype. The interaction is based on a wave metaphor, and is interacted through continuous movement of an arm along the x and z axes

Evaluation and discussion of the prototype

In practice, the light in Wave Lights does not visually resemble waves. However, the prototype shows an effective way to conceptualise the interface and its interaction. Our lab evaluations indicated that the continuous wavy movement of the arm, along with immediate and unusual changes to the light, was a pleasant interaction. The ergonomics of the interaction was more pleasing, because it did not force the user into moving her arm or hand into uncomfortable postures. Further, the symbolic gesture eased the understanding of the coupling between input and output, thus lowering the amount of effort used when interacting with the prototype.

Prototype 8: Tangible Lights

The last prototype, Tangible Lights, has been subject to considerably more development and evaluation than the previous seven prototypes, as it was submitted and accepted for the 9th international conference on Tangible, Embedded and Embodied Interaction (TEI'15) as a work-in-progress paper (Sørensen et al., 2014). The paper can be viewed in Appendix 1. A video (length 01:23) walk-through of the prototype and its interactions can be found on Vimeo (Andersen and Sørensen, 2014b).

Inspired by the movable light approach seen in One Spotlight, and current exploration of several light layouts, the Tangible Lights prototype was initiated. Tangible Lights enables the user to customise the light setting at the table with precise control through several, individual illuminated regions, as seen in Figure 61 below. Each illuminated region can be manipulated freely in the space above the tabletop. As a result, the position and size of each individual illuminated region can be manipulated as desired through a set of interconnected in-air gestures.

The interactions designed provide a set of interconnected actions for manipulating the light setting. Actions in-

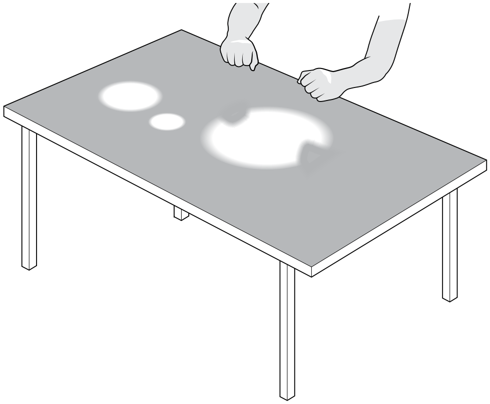


Figure 61. Tangible Lights prototype. Multiple spotlights can be created, grabbed, moved, scaled, and removed

clude spawning, selecting, deselecting, moving, scaling, and removing lights (Table 4). To simplify the interactions, we draw inspiration from known daily life actions such as grabbing, holding onto a plate or cup. On-going evaluations have helped shape the interactions to their current form as presented here.

The name Tangible Lights stems from our intentions of creating an interface, where the user feels as if she is "holding onto the lights" and controlling it at her fingertips. To accommodate this, we sought to draw on existing knowledge from daily life when grabbing and moving physical objects around. Thus, we have sought inspiration in the domain of tangible user interfaces (TUIs) (Ishii and Ullmer, 1997). We have applied a direct mapping scheme, which refers to the design of interfaces, particularly in the TUI domain, where input and output is tightly coupled in space. For our design of the direct mapping, a cast light is enabled for interaction when hands interfere with the projected light beam. This looks different in the case of one or two hands as seen in Figure 62. As a natural consequence of using one global light source (i.e. the projector), the centre of the cast light is occluded by the hand creating a shadow on the tabletop (also seen in Figure 62). This provides two concurrent means of visual feedback for the person interacting to visually make contact with and manoeuvre a lit region around the table. This instantaneous visual feedback of the cast light moving according to hand movement, provided an easy way for people to control the light around the table. As a result of our designed mapping, it is possible to reach far corners of larger tables, since the light cast on the tabletop is positioned with an offset to the interacting hand(s) as seen in Figure 63.

This prototype can be applied to existing activities, where lighting needs are highly emotional and high amounts of interaction effort is acceptable. This could include highlighting physical objects on the table, or

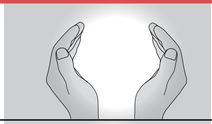
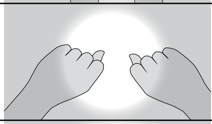
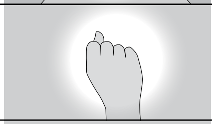
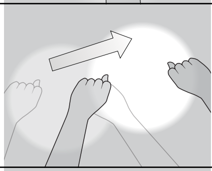
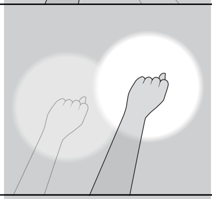
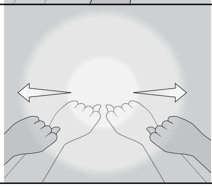
Gesture/ Action	Illustration	Description	TUI Inspiration
Spawn/Create *2 hands*		Spawning a new light by holding hands in a vertical position.	As holding onto a physical bowl
Grab/Select *2 hands*		Grabbing a cast light by closing the hands near its perimeter.	"Grabbing the light" near its perimeter as if it was a physical steering wheel
Grab/Select *1 hands*		Grabbing a cast light by closing the hands near its centre.	As holding onto a physical bowl
Move/Position *2 hands*		Moving a cast light by moving the hands, once they have grabbed the perimeter. The light aligns between the hands.	Physical movement of objects
Move/Position *1 hands*		Moving a cast light by moving the hand, once it has grabbed near its centre. The light aligns around the centre of the hand.	Physical movement of objects
Scale/Resize *2 hands*		Scaling of a cast light by pulling in both directions.	Flexible objects such as bags, rubber bands, fabric, etc. can be expanded by grabbing and pulling hands in opposite directions.

Table 4. Illustration of all gestures incorporated in the Tangible Lights prototype along with their inspirations from the TUI domain

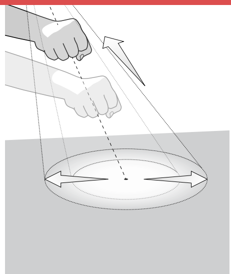
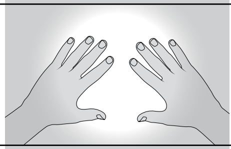
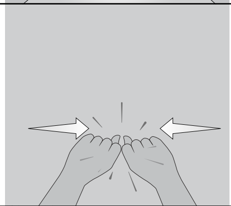
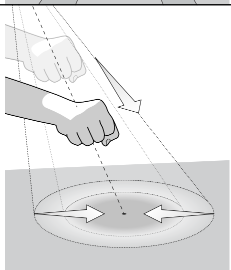
Gesture/ Action	Illustration	Description	TUI Inspiration
Scale/Resize *1 hands*		One hand scaling of a cast light by varying the height of the hand	Behaviour of a flashlight. Moving it closer or further from a surface results in a smaller or larger cast light
Release/Deselect, both *1 and 2 hands*		Releasing a grab by extending the fingers (reverse grab gesture)	As holding onto a physical bowl
Remove/Delete *2 hands*		Removing a cast light from the table by squeezing it together until it disappears. Essentially, this is the two-handed scale gesture being used to make the light continuously smaller until it disappears	Squeeze (press) something together
Remove/Delete *1 hand*		Removing a cast light from the table by "throwing" it into the tabletop. Essentially, this is the one-handed scale gesture being used to make the light continuously smaller until it disappears	Popping a water balloon or a throwdown (slightly far-fetched)

Table 4. (Continued)

food and plates when hosting a dinner. In these activities, the host is already willing to put in high amounts of effort when setting the table, as the atmosphere should be "just right".

Evaluation and discussion of prototype

To interact with the lighting in Tangible Lights, we needed a way to map the hands to the cast light. As it is our intention to design for the experience of tangibility when manipulating cast lights. The challenge here is that lights are generally perceived as non-tangible, although they do have an insignificant small physical mass, and the warmth of intense light can be felt on the skin

We have explored different interaction alternatives requiring both one and two hands, as the number of hands is found to possess different qualities. First, since two hands could yield a problem when carrying objects such as dishes, plates and cup, the one-handed grab often allows for quicker positioning than the two-handed grab.

Our evaluations on the implemented gestures suggest that the grab and release gestures are generally an accepted and straightforward way of selecting and deselecting a cast light. As one person explained *"it [grabbing the lights] just came natural to me… I had totally forgotten about last time"*. For him, grabbing was an unconscious action.

Once shown or told how to select and move light casts, people were able to independently explore the scaling functionality by moving the hands apart (or up and down if one hand). Scaling actions were almost always performed during the very first interaction and can arguably be contributed to the system behaviour of being reactive to changing distances between hands (or height if one hand). We used this approach strategically to gain knowledge on how people wanted to carry out different interactions. This particularly helped to form the grab and release gestures.

In this prototype, the sole lighting parameter utilised is on/off. The functionality lies in the gestures, where new lights can be created, resized and positioned as desired. It is possible to add more customisation possibilities by integrating the light parameters of brightness, temperature and colour. However, to fit the already established concept of tangibility, the interactions for controlling additional parameters must not conflict with existing gestures. It should also be noted, that the introduction of additional gestures adds to the complexity, since users have to remember these gestures.

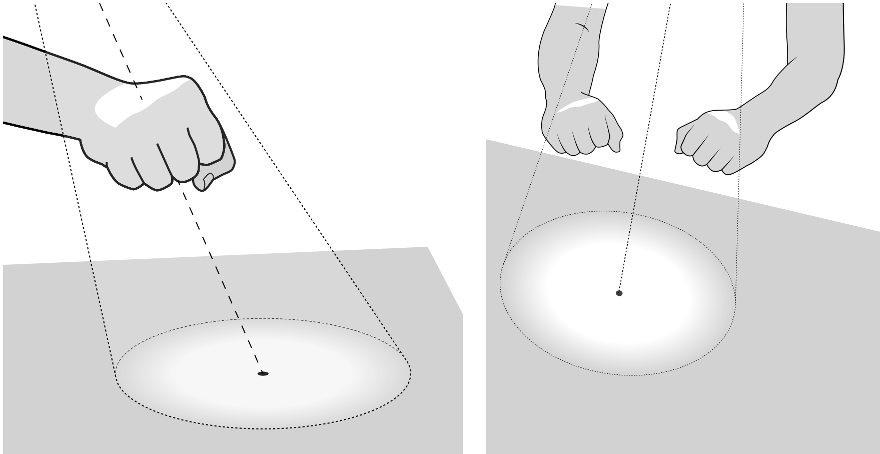


Figure 62. Mapping one and two hands to a light in the Tangible Lights prototype. Light strikes on top of the hands and causes shadows

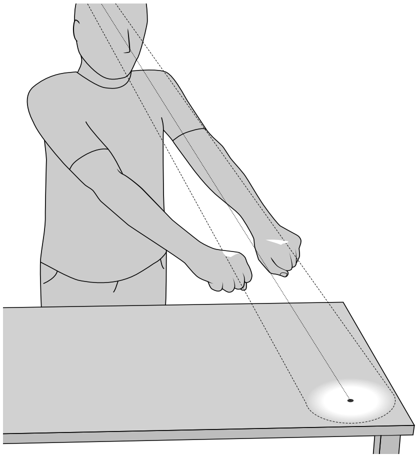


Figure 63. The mapping scheme in Tangible Lights allows reaching far corners of the table

DISCUSSION OF THE EIGHT PROTOTYPES

This section discusses interrelated aspects that span the eight prototypes. The discussion of these aspects contributes to an extension of the initial framework for in-air gestural interaction with home lighting, presented in chapter 4.

The new dimensions 'number of lights to attend to' and 'movability'

The *available lighting feature* dimension in the initial framework emerged from the *detail of control* theme discussed in chapter 4. Based on the eight prototypes described above, we argue that this theme can be expanded with two additional dimensions discovered through prototyping. First, with the four prototypes Tile Lights, Mesh Lights, Wave Lights, and Tangible Lights, we explored how the lighting layout could be separated into different regions. From here, the user can possibly attend to and control more areas of the table, which arguably increases the detail of control. Second, the concept of movable light regions stemming from One Spotlight and Tangible Lights can also be viewed as an increased detail of control. We illustrate this discussion in Figure 64 below.

Detail of control		
Available features	**Number of lights**	**Movability**
On/Off	One	Not movable
Brightness	Several	Movable
Temperature	Many	
Full Colour		

Figure 64. As a result of prototyping, two new dimensions related to the *detail of control* theme (chapter 4) emerge

Higher detail of control typically requires higher interaction effort

Related work on interactive lighting implies that detail of control (the controllable lighting parameters) correlates with required interaction effort (chapter 4). Following our development of prototypes, we have experienced that this is also true for in-air gestural interfaces, with the extension of the two extra dimensions *number of lights to attend to* and *movability*. Thus, when more details of control in any of the three dimensions are added, more effort is typically required from the user. Thus, when more light regions are added, the user has to adjust several areas. In addition to the extra amount of time this takes, the user also has to consider the resultant light setting by adjusting the regions in relation to each other. Moreover, when light regions become movable, as seen in One Spotlight and Tangible Lights, we find that the required interaction effort increases with the amount of individual regions that have to be positioned. It can be imagined how complexity will further increase if each individual light region in a system can be interacted in different ways, e.g. by having different movement patterns, or by integrating several lighting parameters such as brightness or colour.

As discussed, we varied between symbolic and direct mapping schemes for coupling gesture (action) and light (function). To lower the amount of effort required from an interaction, the symbolic imitation of a sunrise can be used to conceptualise the interaction. For example, when interacting with the Colour Ball prototype, the user changes the colour using the three axes of pitch, yaw and roll by understanding the interaction as a ball. Following this discussion, we can position our eight prototypes in a two-dimensional coordinate system (Figure 65), which illustrates how they interrelate in terms of required interaction effort and detail of control. The interrelation between prototypes should not be seen as strict, but merely as a visualisation.

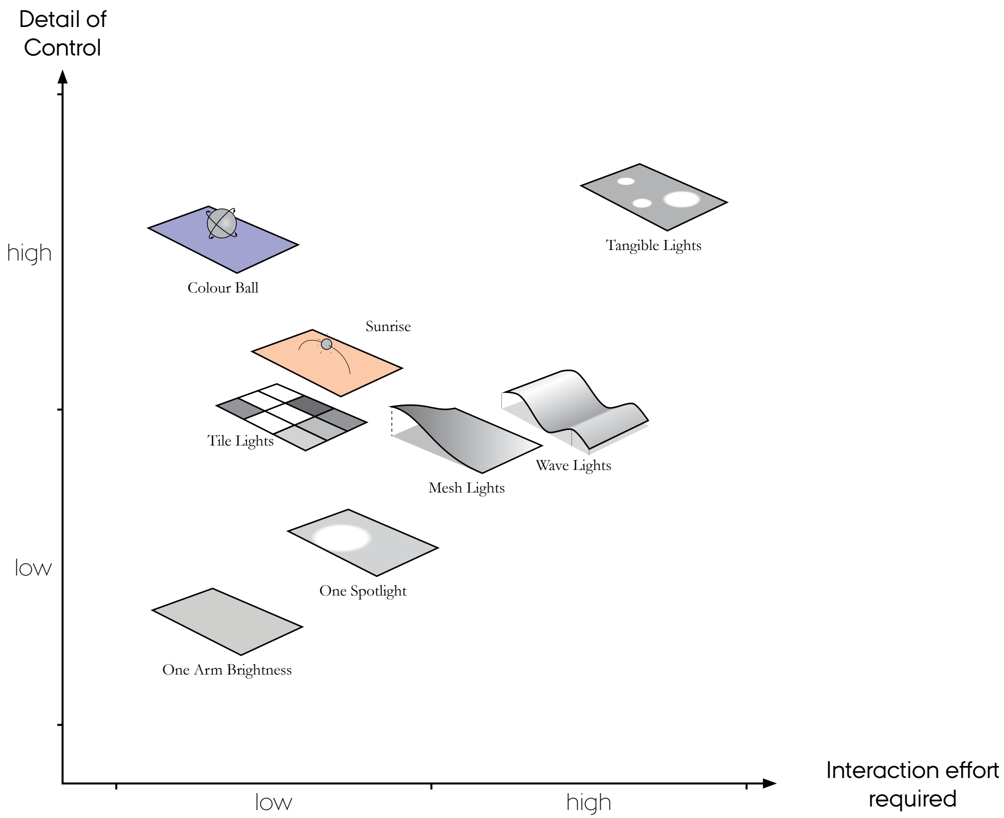


Figure 65. Interrelation of our eight prototypes in terms of required interaction effort and detail of control. Detail of control consists of the three dimensions: *available lighting features, number of lights to attend to,* and *movability*

Symbolic or direct mapping between gesture and function

In One Arm Brightness, the gesture can be categorised using a direct mapping, since the hand movement is directly mapped to the brightness levels. This is also the case for Tile Lights, as it essentially consists of nine equally-sized One Hand Brightness prototypes. Mesh Lights has a similar behaviour, except that interaction is perceived as control points being directly grabbed and manipulated, instead of tiles being hovered. Additionally Tangible Lights and One Spotlight also incorporate the grab poses and utilise these as a direct relation to the function (selecting). This relation between the gestures and functionality makes both Tangible Lights and One Spotlight instances of a direct mapping scheme. Symbolic gestures have also been explored in order to enable users to set up mental models of the interactions, e.g. using a gesture imitating a sunrise and rotation of a ball. Here, the movements of these phenomena are imitated with the arm, hand, and wrist. Consequently, we have explored approaches for interaction using both direct and symbolic mappings.

Combining gestures

Intentionally, the interactions in the prototypes 1-7 are designed as separate gestures. We argue that some of the gestures could be combined in future prototypes, however, not by blindly mixing a sunrise with a colour ball into the same system, as these represent two conceptual approaches to interaction. In this regard, we found that the existing interaction paradigm of TUI provided a strong basis for creating a set of interconnected gestures, as shown in One Spotlight and Tangible Lights. Neither do we advocate for relying on the same up/down arm movement to control multiple lighting parameters such as brightness and colour (as discussed in One Arm Brightness). In this case, the arm movement could possibly remain the same (up/down), if gestures are varied at finger-level, e.g. closed hand, fingers apart, index finger extended. In line, it would be possible to combine three dimensions of a hand wrist movement (as in Colour Ball) with up/down arm movement (as in One Arm Brightness) to target the four dimensions of brightness and red, green, and blue colours.

Gestures at arm, hand, and finger-level

Due to the technical implementation, we could not rely on stable tracking of gestures at finger-level with the Kinect sensor, as discussed in the limitations of the Gestural Lighting Platform in this chapter. As a result, the prototypes relying on the Kinect primarily focus on arm and movements and rely on open and closed hand poses. Additionally, the temporal dimension of hand (and finger) movement could further be used to distinguish gestures, e.g. by velocity and acceleration.

Lack of augmented feedback and feedforward

Offermans et al. (2014) identified conceptual misunderstands in their review of lighting interfaces due to the lack of feedback and feedforward. This was a challenge across all eight prototypes presented. The Interaction Frogger framework (Wensveen et al., 2004) presented in chapter 3 explains that in-air gestural interfaces requires a direct coupling between action (input) and function (output). This coupling can only be obtained using, what they define as *augmented* feedback and feedforward. This stems from the fact, that the invisible interface for this gestural interaction style does not inherit the information (there is no screen – just air).

In terms of feedforward in the prototypes, when approaching the table, new users do not know that it is possible to interact with the lighting with their hands unless the functionality is explained. How does the user know that she can interact? And which area above the tabletop is interactive? To answer these questions, we experimented with an approach that automatically created a light in the centre of the tabletop in the Tangible lights prototype. When the user grabbed this initial light, a new light was created shortly after, thus informing the user that arranging numerous lights is possible. We argue that other approaches to augmented feedforward have to be explored in the future, as this lack of feedforward is a challenge in this type of interface. Possible directions suggested in our evaluations include, how subtle behaviour such as movement and pulsation of lights can invite interaction; and how the projector can be utilised to provide instructions on the table, similar to how display-oriented, full-body applications, e.g. Kinect games, provide on-screen guidance. The latter was intentionally not explored, since we did not wish to resemble a graphical user interface, as discussed in the scope of this thesis (chapter 4).

In terms of feedback, there is no haptic or tactile feedback associated with our in-air interactions. In our prototypes, the technical implementation allows for instantaneous changes in light (output) following gestural interaction (input). These visual changes work as effective, functional feedback. However, interaction issues caused by insufficient sensing of gestures are not communicated to users. As a result, the feedback is non-existent and often frustrating for interacting users. These interaction challenges are discussed in the next paragraph.

Live mic and segmentation issues

As the interface is invisible, all prototypes suffer from the "live mic" problem (Wigdor and Wixon, 2011, p. 98). When does the system listen for input and when does it not? To handle the live mic problem the system must discard all unintentional gestures, and only listen to the intentional gestures. Thus, when is the gesture unintentional and when is it intentional? In the One Spotlight, Mesh Lights, and Tangible Lights, prototypes, gestures are designed to separate the unintentional from the intentional gestures, as the user has to "grab" (close the hand), before the system allows the person to interact with the light. However, situations unarguably occur, where a user reaches for objects on the table with similar hand poses. In this regard, we experimented with a time delay between each interaction to allow reaching for objects on the table. This is not a durable solution, and in the future we need to distinguish intentional from unintentional interaction. Approaches may include making sense of the context, e.g. by detecting items in hand, or by explicit instructions given to the system, e.g. through speech or buttons.


Lighting needs
Low
Basic visibility
Functional
High
Emotional
Available features
Number of lights
Movability
On/Off
Brightness
Temperature
Full Colour
One
Several
Many
Not movable
Movable
Mapping scheme
Symbolic
Direct
Low

6

EXTENDED FRAMEWORK FOR IN-AIR GESTURAL INTERACTION WITH HOME LIGHTING

This chapter provides an answer to research question one by outlining an extended framework for in-air gestural interaction with home lighting. The extended framework emerges from the eight prototypes developed for the Gestural Lighting Platform in previous chapter, which in turn builds on the initial framework defined in chapter 4. The dimensions of the extended framework are discussed in terms of the eight prototypes. Furthermore, we apply the framework analytically to a number of in-air gestural lighting applications, and argue how it can be used as a generative tool. Lastly, we discuss the limitations and future work of the framework.

EXTENDING THE FRAMEWORK FROM THE EIGHT PROTOTYPES

In the previous chapter, we discussed the interrelated aspects of our eight prototypes developed at the Gestural Lighting Platform. This discussion extended the detail of control theme with the dimensions *number of lights* and *movability*. As a consequence, we expand the initial framework for in-air gestural interaction with home lighting set forward in chapter 4. The *extended* framework thus consists of seven dimensions (Figure 66).

Positioning the eight prototypes in the extended framework

To visualise how the eight prototypes relate to the extended framework, and interrelate, we can trace their journeys through the different dimensions. Please refer to Figure 67 (page 101). In the following, we discuss the positioning of prototypes in terms of the vertical subdivisions in the seven dimensions.

In chapter 4, we discussed the two first dimensions based on implications from Offermans et al. (2014) and our empirical studies. *Acceptable interaction effort* relates to the *lighting needs* of the user. This relationship indicates the typical amount of effort that a user is willing to put into interaction given a specific lighting need. Note, how the word *typically* is used to indicate this is not a strict relationship, as the context of the user may vary. The eight prototypes intentionally supported varying lighting needs. The One Spotlight and One Arm Brightness prototypes were specifically designed to meet functional lighting needs, e.g. study or office work. In such situations, the user is typically willing to accept an effort investment in order to create a proper light setting that serves the activity. On the contrary, Sunrise and Tangible Lights are examples of prototypes that were designed to serve emotional lighting needs, e.g. creating a pleasant atmosphere using colour temperatures, or staging objects in a dinner setting, respectively. Typically, in these situations, the user is willing to invest even more effort than the functional needs, described before. In this thesis, the need for basic visibility has not been targeted in our prototypes, as discussed in the scope section (chapter 4).

It is important to note that when discussing the lighting need and acceptable effort relationship in isolation, we do not (yet) consider the actual designed interaction and its required effort. The gesture for interaction can be designed in various ways and is affected by the detail of control dimensions and the mapping scheme. This is discussed in the following.

The *available lighting features* dimension concerns the available lighting functionality in the prototypes, e.g. Colour Ball utilises all possible RGB colours, while Tan-

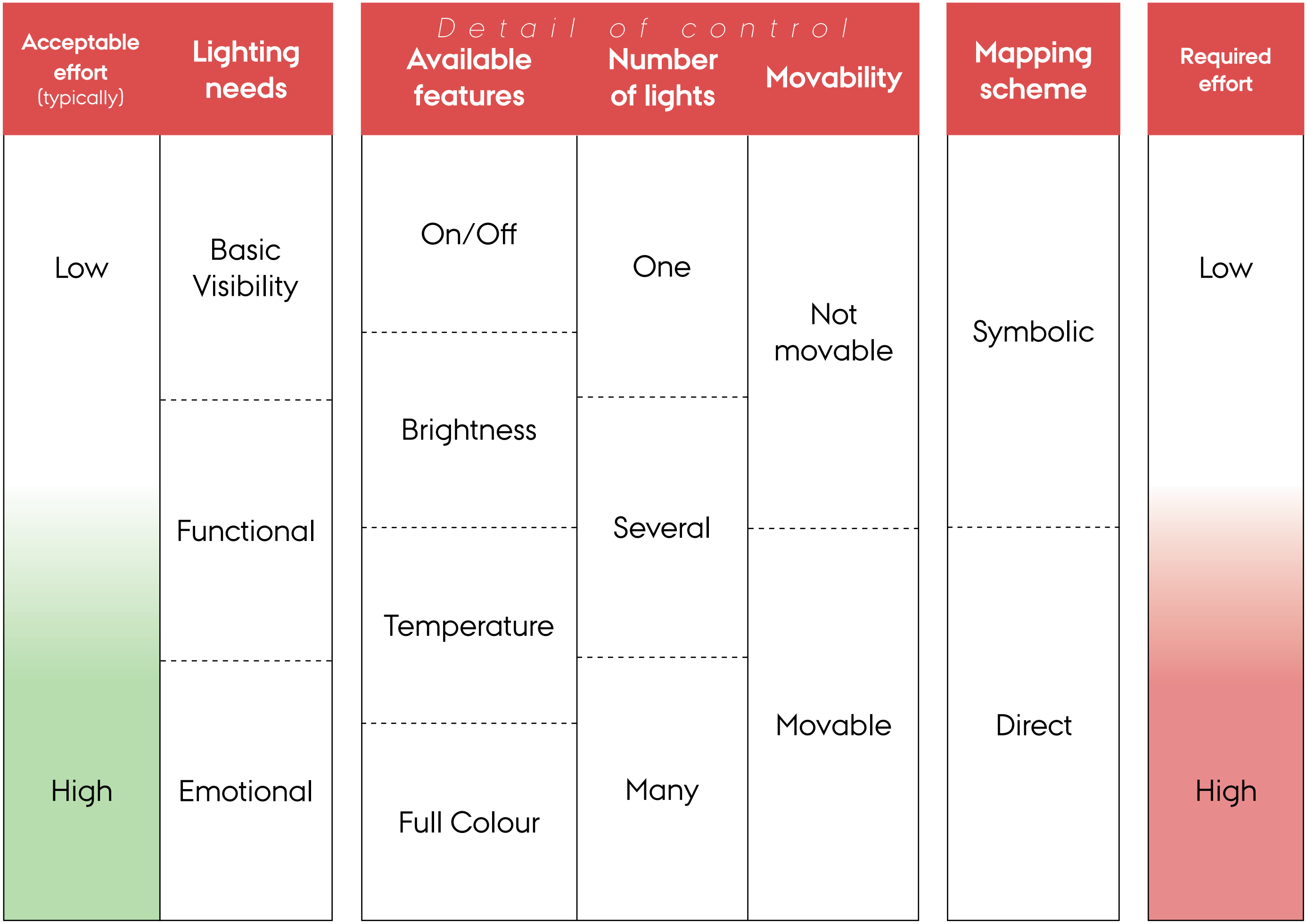


Figure 66. The extended framework for in-air gestural interaction with home lighting, which has been derived throughout this thesis

gible Lights only allows for turning lights on and off using the spawn and remove gestures. The Sunrise prototype deals with colour temperature, while Tile Lights and One Arm Brightness incorporate the brightness parameter. *Number of lights* relates to the number of individual light regions that users can adjust as part of the light setting. The vertical divisions of 'one', 'several', and 'many' can be exemplified by the prototypes One Arm Brightness (one light), Tile Lights (nine lights), and Wave Lights (20 lights). In Tangible Lights, an arbitrary number of individual spotlights can be created depending on intention of the user. However, for visualisation purposes, we consider a light setting with many spotlights, when positioning Tangible Lights in this dimension. The *movability* dimension relates to whether a light region can be dynamically repositioned on the table with the use of gestures, as explored in One Spotlight and Tangible Lights.

Mapping scheme categorises the relationship between gestures (input) and light setting (output). The eight prototypes rely either on symbolic or direct mapping (these categorisations are discussed in chapter 3). Symbolic mappings are approached by the prototypes Sunrise, Colour Ball, and Wave Lights, while direct mappings are exemplified in One Arm Brightness, One Spotlight, Tile Lights, Mesh Lights, and Tangible Lights.

Importantly, the interaction effort of gestural lighting interfaces can also be affected by the applied mapping scheme. Symbolic mapping approaches are found to lower the interaction complexity. For example, the Colour Ball prototype incorporates full colour features (a relatively high detail of control). However, the symbolic ball movement enables control of the three colour parameters through rotation of the wrist. We argue that symbolic mappings are not the only way to lower interaction complexity. As seen in the Tangible Lights prototype, a direct mapping scheme can be used to establish a conceptual model of the system.

Connected to the interaction is the *required effort*. That is, the amount of effort that a specific lighting interaction ultimately requires from the user. Prototypes that incorporate a high detail of control, arguably require high levels of interaction effort, as discussed in chapter 4. For instance, the Tangible Lights prototype possibly contains many, movable light sources, which we consider as a high level of required effort. A high effort requirement, however, is not necessarily problematic. As stated in the beginning of this subsection, it might be acceptable in certain situations, when the lighting needs become emotional. This way, the high effort requirement of Tangible Lights might be acceptable for decorative purposes such as staging food in a dinner setting.

On the contrary, One Arm Brightness solely allows for static brightness control by placing an arm anywhere in the interaction area. As this gesture suggests simple and precise control of brightness, the gesture is considered to have a low level of required effort. The One Arm

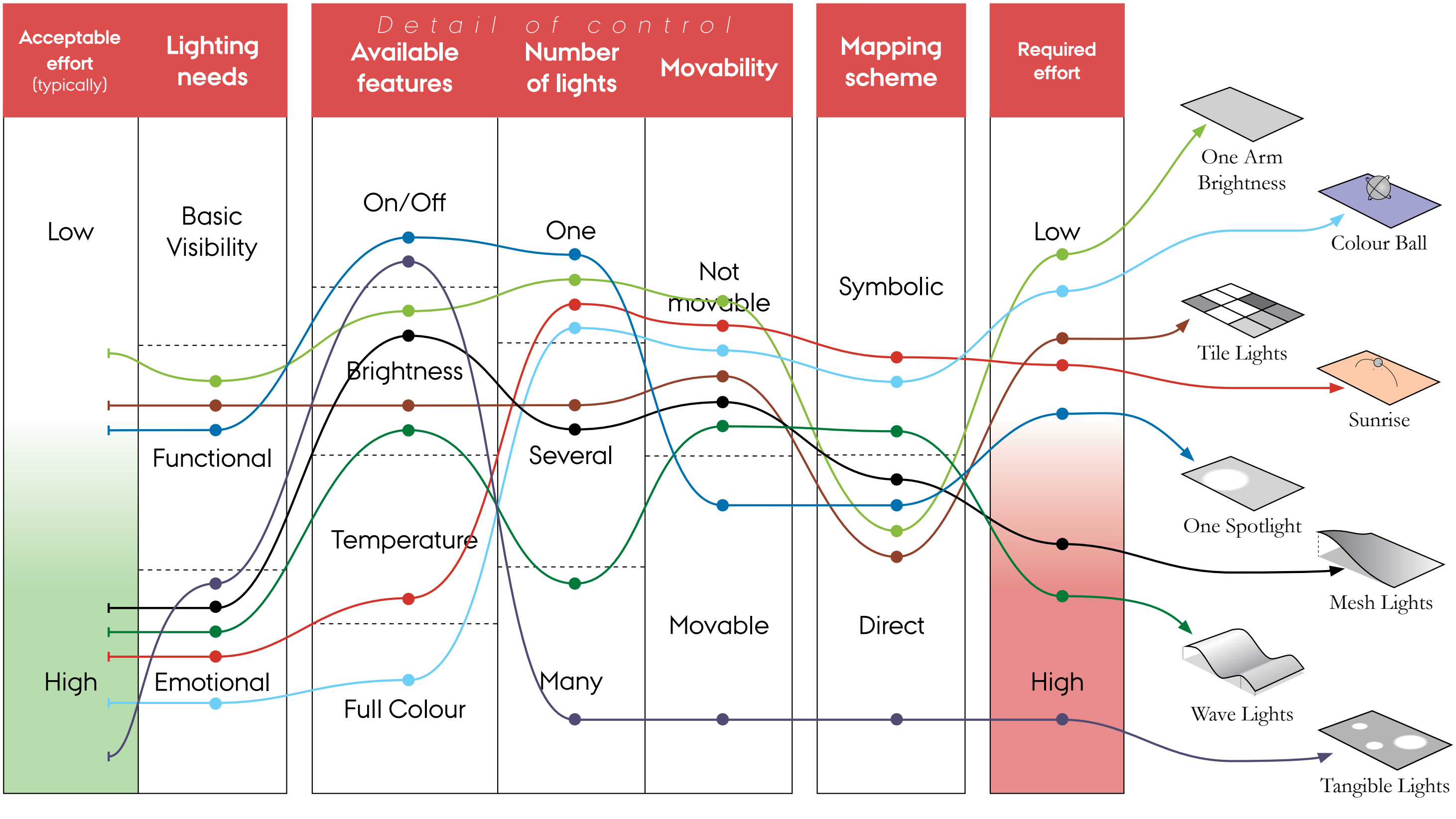


Figure 67. Visualisation of how the gestures of the eight prototypes relate to the dimensions of the framework

Brightness prototype was designed for task-oriented activities (e.g. study or office activities) with functional lighting needs, in which some effort is acceptable. Thus, in One Arm Brightness we theoretically find a harmony between the two effort levels, as the required effort level is lower than the acceptable effort level. The exact positions of prototypes in the two effort spectra could benefit from a dedicated evaluation, which will be discussed in the future work section in this chapter.

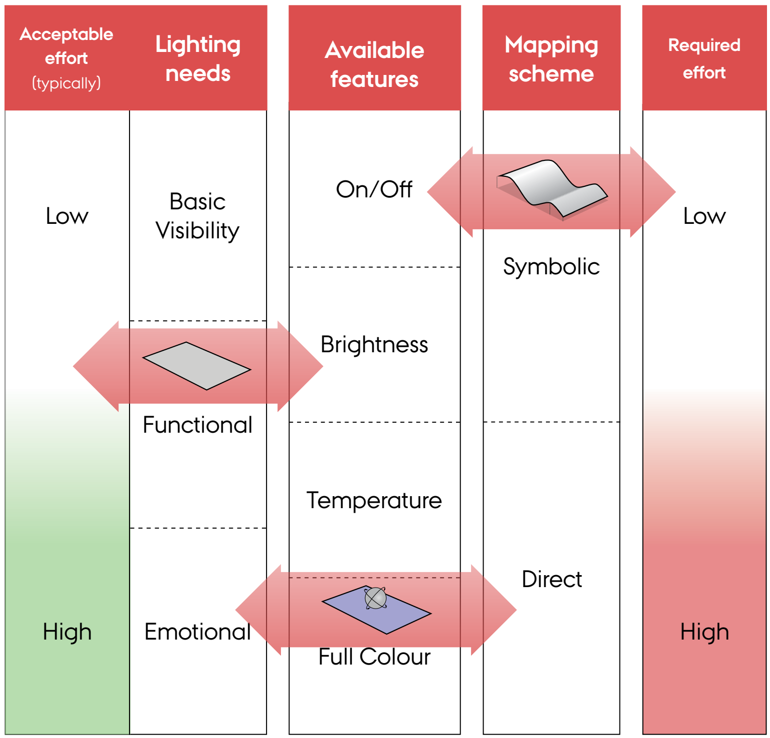


Figure 68. The *initial* framework was used generatively. Three examples of different entry points. One Arm Brightness emerged from a functional lighting need, Colour Ball from integrating full colour features, and Wave Lights from ideas on symbolic gestures

THE FRAMEWORK AS A GENERATIVE TOOL

The initial framework presented in chapter 4 was used as a generative tool to create in-air gestures for lighting control. Systematically, the initial five dimensions of the framework were used to drive our exploration of the design space in different directions, and ensure variation across the dimensions. Different entry points were chosen in the framework, thus some prototypes were motivated by a lighting need, some by features and some by the gesture. We exemplify in the following. The One Arm Brightness prototype was conceptualised based on a functional lighting need of practical lighting when studying or working at the table. As a way to incorporate other lighting features, Colour Ball stems from exploring the full colour abilities. Following the symbolic mapping of the Colour Ball gesture to changes in colour, we brainstormed on other symbolic gestures, and as a result Wave Lights was initialised. We illustrate these three different approaches in Figure 68.

As the initial framework was used generatively to explore as much variation as possible, we argue that the extended framework similarly can be used as a generative tool, where designers consider the different dimensions in relation to each other. In this regard, we argue that our eight prototypes and their paths through the framework can serve as inspiration when developing in-air gestures for home lighting. As the next section suggests, the framework can be used beyond the dinner table as well.

THE FRAMEWORK AS AN ANALYTICAL TOOL

To our knowledge, there are no existing in-air gestural lighting systems focusing on the table. However, we argue that our extended framework can be used to analyse in-air gestural lighting systems in the larger scale of the room context, as the seven dimensions are not specific to the table. This section analyses four applications for two types of lighting needs: *basic visibility* and *emotional*. The analysis shows that the extended framework can encompass other areas in the home, beyond the dining table. The two first applications were unnamed discoveries on the Internet, which in this section have been named the Myo Spell and Pebble Arm Rotation applications, hinting the underlying hardware. Both are home-brewed applications for non-commercial use. The last two applications for analysis rely on a combination of Philips Hue (2012a) and Gestoos (Fezoo Labs S.L., 2014), a commercial available software application for gesture control. The relation of the four applications to the dimensions of the extended framework is visualised in Figure 70 (page 105). Now follows a discussion of each application.

Myo Spell application

Vick has implemented two gestures that resemble magic spells. First, to turn on the light bulbs, a spell-like gesture is performed with a quick movement from an open hand towards the Philips Hue bulbs. For turning the lights off again, another gesture is performed, which takes the form of a forceful pull (Figure 69).

According to the framework, this application can be viewed as fulfilling the lighting need of basic visibility, where minimal interaction effort is preferred. In terms of detail of control, Myo Spell can be placed in the low effort area in the top, spanning on/off, one light to attend to, and not being movable. Although the gestures

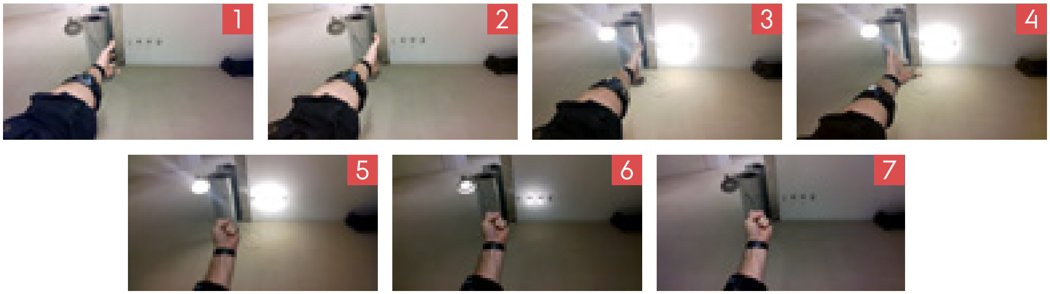


Figure 69. Myo spell. In the first row, a spell-like gesture is cast towards the light bulbs. In the second row, the light is forcefully pulled back again. Timeline from YouTube video)

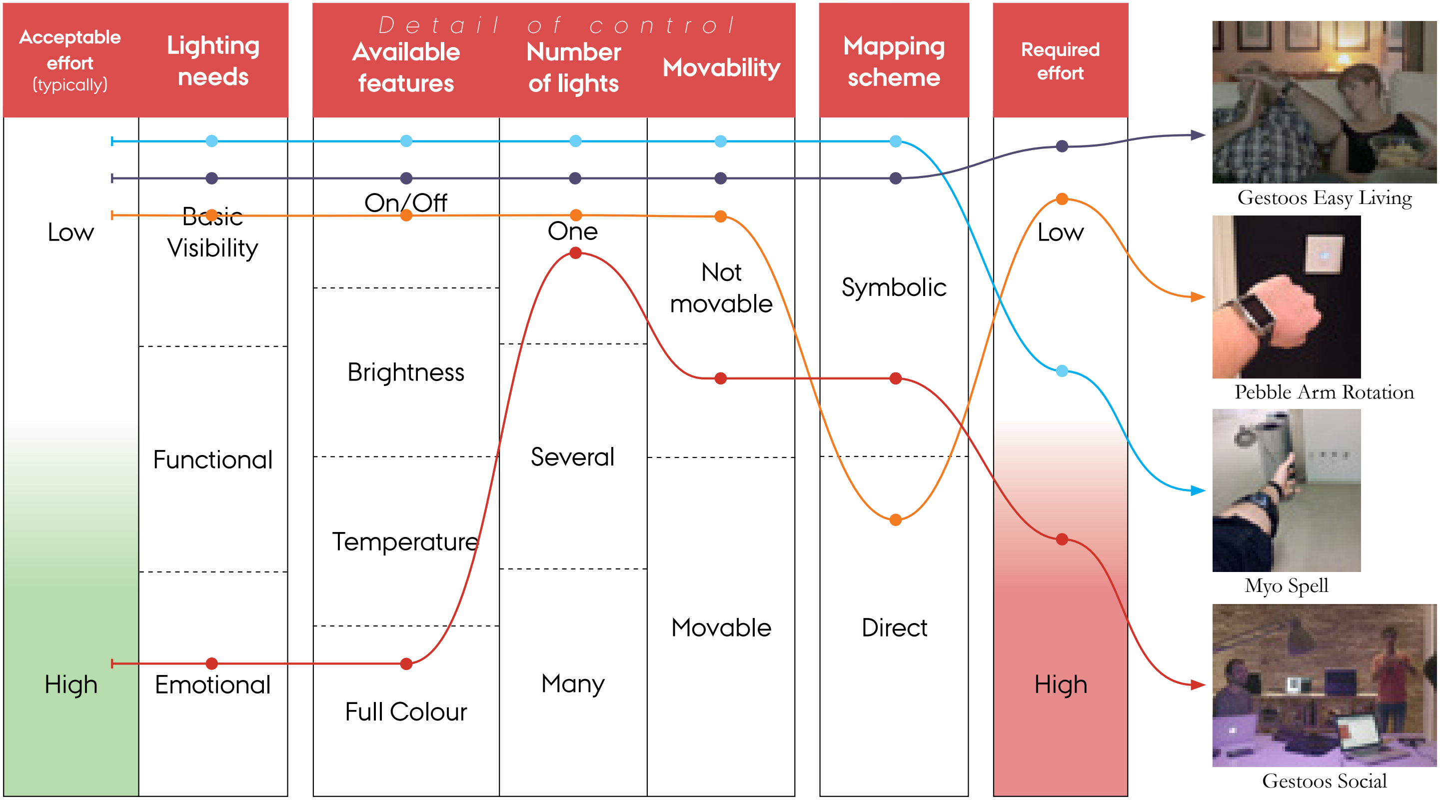


Figure 70. Analysis of the four applications Gestoos Hue (Easy living and Social scenarios), Pebble Rotation and Myo Spell

are only exemplified on one grouping of light sources, it is imaginable how directing this gesture to multiple groupings of light sources located throughout a home yield a higher number of lights to attend to, at the cost of effort. The Myo spells rely on a symbolic movement as it draws on knowledge from wizardry. Both gestures are considered to require a considerable amount of interaction effort, as the user has to be oriented towards the bulbs. Further, compared to other hypothesised gestures, e.g. performing a simple tap gesture as known from a physical switch, are arguably quicker to perform. However, we acknowledge that the Myo Spell interactions, arguably, are designed as novel (and fun) alternatives, intentionally.

Pebble Arm Rotation application

In another YouTube video by user Scott Curtis (2014), a Pebble Smartwatch (2014) is used to switch the lights on by rotating the arm to the left, and off by rotating the arm to the right. The system builds upon a radio-frequency positioning technique to determine which light switch is intended for interaction. The embedded accelerometer in the watch is utilised for gesture recognition. The system is a home-brewed system that uses a Raspberry Pi for controlling the lights and Wi-Fi for connection.

Curtis has created a gesture relying on the rotation of the arm, oriented towards the light switch designated for interaction. First, when rotating the arm to the left, the lights turn on. When rotating the arm back to the initial position, the lights turn back off (Figure 71). According to the framework, the application fulfils the lighting need of basic visibility and spans the low detail of control area, similarly to the Myo Spell application. In contrast, the Arm Rotation application differs by relying on a direct mapping scheme, where the interaction can be viewed as a direct instruction to the system. We argue that the required effort is lower than the Myo Spell application, as we consider the rotational movement quicker (possibly easier memorable) than the temporal dependant spells.

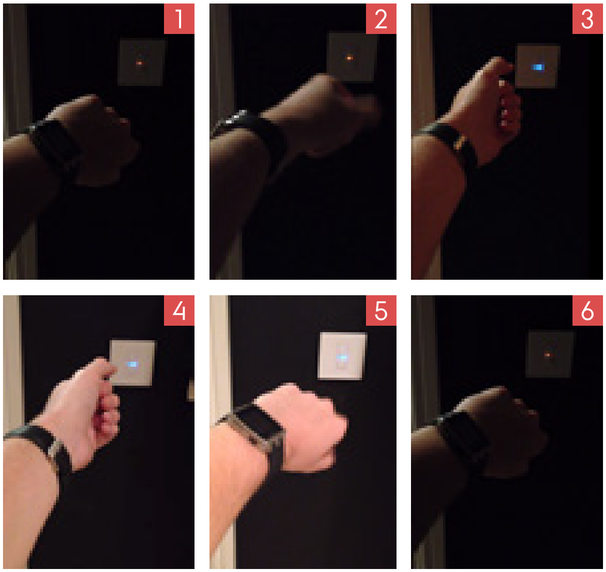


Figure 71. Pebble Arm Rotation. Video frames illustrating how rotating the arm to the left turns the lights on, subsequently off when rotating back to the initial position (timeline from YouTube video)

Gestoos Hue applications

Gestoos (2014) is a gestural recognition software that supports several different sensing technologies, e.g. Microsoft Kinect (2014). It allows the user to control different applications using gestures, e.g. the Philips Hue system. Gestoos' six pre-defined gestures can be set up to control a function in the designated application. The gestures supported are *next, previous, quiet, listen, time-out,* and *pause*, and they draw on known symbols, as seen in Figure 72. As the gestures are pre-defined, each gesture is not designed to map specifically to a function.

In their promotion video of the Gestoos software, the Philips Hue system is controlled. Here, two different use scenarios are presented, here denoted as Easy Living and Social, where five different gestures are used to interact with the system. In the scenarios the designers show two ways of switching the bulbs off (*time-out* or *pause* gesture) and one way of switching them on (*listen* gesture). Further, they show how changing colour scenes (a Philips Hue functionality described in chapter 3) can be accomplished using the *next* gesture. We imagine that the *previous* gesture is also mapped to this functionality. The first scenario, Easy Living, aims for the lighting need of basic visibility as a person sits in his couch and switches the lights off. The second scenario, Social, targets an emotional lighting need as the three friends are chatting while changing between colour scenes.

We analyse the use scenarios as two different applications. The Easy living scenario serves to provide basic visibility, where a low amount of effort is typically preferred. The Social scenario allows higher amounts of

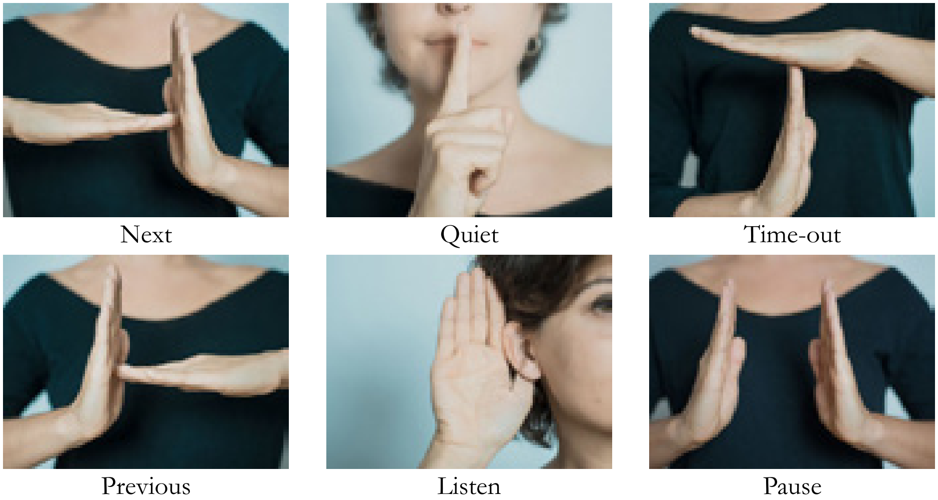


Figure 72. Gestoos' six pre-defined, symbolic gestures for interacting with applications

effort as it serves the emotional lighting need of changing colours to fit the relaxed atmosphere of the conversation. In both use scenarios, a person adjusts several bulbs at once, and the lights are not movable. As all six pre-defined gestures of Gestoos rely on symbols, we thus classify the Easy Living and Social scenarios as relying on symbolic mappings.

In the Easy Living scenario, the lights are switched off by the *time-out* gesture. We view this a simple and quick way to turn off the lights, where no temporal movement has to be considered, and the user does not have to orient the gesture in the direction of the lights (probably because the sensor is positioned in front of him, which cannot be determined from the video). Thus we position the Easy Living scenario as requiring the least amount of interaction effort.

In the Social scenario, the desired colour scene has to be located by browsing through a list of colours one by one using the *next* gesture. In terms of required effort, the continuous use of the *next* gesture is perceived as a cumbersome way, and thus we consider this gesture as requiring a high level of interaction effort.

LIMITATIONS AND FUTURE WORK OF THE FRAMEWORK

The initial framework (chapter 4) was presented prior to the development of prototypes, and the extended framework in this chapter was a result of the exploration of dimensions through prototyping (chapter 5). In this section we list and discuss the limitations of the two frameworks.

The Gestural Lighting Platform and our eight prototypes were developed to explore in-air gestural interaction with lighting centred on the table. Here, the table is also the first limitation. Although the initial framework provides five dimensions not specific to the table, the two new dimensions *number of lights to attend to* and *movability* were discovered by prototyping at the table. On the larger scale of the room context, gestures might not vary across these two dimensions. However, we argue that the four room-level applications analysed can be imagined as controlling multiple groupings of light sources throughout the room, instead of one. The concept of movable lights, contained in the *movability* dimension, is a result of the One Spotlight and Tangible Lights prototypes. We argue that taking this concept out into the room is subject to further exploration and will be discussed in chapter 8.

In terms of *acceptable interaction effort*, the eight prototypes are relatively positioned from 'low' to 'high' in Figure 70 according to the lighting needs they serve, as these dimensions typically correlate (discussed in chapter 4). On the other hand, in terms of *required interaction effort*, the prototypes are relatively positioned by the authors based on experiences from qualitative lab and expert evaluations. We argue that this is not an accurate way of measuring the relative effort levels of the gestures. We acknowledge that quantitative evaluations that consider the diversity of people and potential contexts could help to map out this relationship between acceptable and required effort.

In this thesis the framework has facilitated one gesture mapped to one lighting feature for each prototype, as each of the prototypes revolves around one gesture. An exception is the Tangible Lights prototype, where a set of interconnected gestures are used to manipulate individual lights. However the sole lighting parameter utilised in Tangible Lights is the on/off feature following create and remove gestures. A system could potentially incorporate different gestures to control different lighting features, similar to how the two scenarios in the Gestoos Hue application could be part of the same system. In such systems we argue that each gesture of the system can be analysed individually and have its own path through the framework. However, we acknowledge that the framework does not consider the possibility of one gesture controlling several lighting parameters simultaneously (e.g. *both* colour and brightness). Neither have our prototypes explored how multiple dimensions of the *detail of control* theme can be concurrently controlled (e.g. colour, number of lights, and movability). We propose that these aspects are yet to be explored through prototype development.

The frameworks do not provide a way to design and create the actual gestures (except that the eight prototypes can serve as inspiration). It is up to the designer to design the gestures for the system. In its current form, the mapping dimension can be used to distinguish between symbolic and direct gestures. In future work, it could be worthwhile to dig deeper into these two gesture categorisations, as Pavlovic et al. (1997) provide further categorisations (chapter 3). In line, Fishkin's (2004) levels of metaphors (none, verb, noun, verb and noun, and full) used in the domain of TUIs can be used to articulate and add nuances to the symbolic categorisation.

In line, it can be argued that additional dimensions concerning the gestures can be integrated in the framework. These could potentially consider gestures on hand, arm, and finger-levels, or consider the temporal dimension of a gesture over time (the temporal dimension can be observed in the analysed Myo Spell application). Due to the tracking limitations of Gestural Lighting Platform as discussed in chapter 5, we could not explore these possible directions. Additionally, no dimensions related to the user's experiences are included in the framework, e.g. playfulness, co-experience, motivation, or simplicity. We believe these dimensions hold a considerable potential based on experiences from lab and expert evaluations, and field studies.

Lastly, the frameworks do not consider autonomous behaviour. Our empirical studies (chapter 2) and Offermans et al. (2014) suggest that users generally prefer being in control of the lighting. Thus we did not explore how different degrees of autonomous behaviour could be incorporated. However, for future work, we argue that it could be worthwhile to explore how the system could initiate different "modes" autonomously. These modes could be simple stand-by and on/off modes, but also modes relating to different functionalities, which could be offered depending on activity. For instance, the system could automatically track "standard" objects, such as plates or laptops to offer context specific features. Further, objects held in hand could be used to initiate such mode switching or perform gestures. For this, we refer to Hoven and Mazalek (2011) who outline the design space for tangible gesture interaction. Moreover, the system could detect and react upon persons approaching the table and invite for interaction, similar to how Müller, Walter, Bailly, Nischt, and Alt (2012) catch people's attention by mirroring a passers-by as silhouettes on interactive displays.

7

FIELD STUDIES & EXPERT EVALUATIONS

What implications and promising concepts does in-air gestural interaction hold for home lighting? This is our second research question and to investigate this, three field studies and two expert evaluations were conducted with five of the eight prototypes presented in previous chapter 5. The three field studies had durations of one to twelve days, and a half to two hours for the expert evaluations. The setups and findings of all five studies are presented separately, followed by interrelated discussions of each study type. These two discussions serve as basis for a number of implications, concepts and future directions for in-air gestural interaction of home lighting. These are presented in chapter 8 as answer to research question two.

THREE FIELD STUDIES

This section presents the intentions, setups, and findings of three field studies conducted in the context of people's homes, followed by an interrelated discussion of contextual implications for in-air gestural interaction of home lighting. Findings related to usability are not presented and discussed unless they have significance for the contextual implications.

Intentions & setups of the field studies

This subsection presents the overall intention for conducting three different field studies, which varied in duration from one evening to ten days. For each field study, information regarding the participants, the context and our involvement is presented.

Aim of the studies

Three field studies were conducted to get an understanding of how the in-air gestural lighting technology is being used and adapted to in real world settings. Thus our intentions are beyond usability as we aim to a) investigate how the different lighting prototypes were used in daily activities; and b) to outline the implications and challenges for this type of interface in daily contexts.

We aimed for two types of field studies: one field study with our involvement, where we were a part of the context, and another, where the Gestural Lighting Platform would be part of daily life for a period of time without our presence. For the first study, we picked a short, well-defined framing of a dinner with the duration of one evening. For the second and third studies, we aimed for one week. For each study, we prepared five of the eight prototypes, namely the five utilising the Kinect sensor, One Arm Brightness, Tile Lights, Mesh Lights, Wave Lights and Tangible Lights. The remaining three prototypes were not considered due to their limited sensing area and physical presence on the table (discussed in chapter 5).

Field study 1 setup – Dinner activity (one evening)

We strategically "invited" ourselves out for dinner at a mutual friend's flat (60 m^2 in total), where he lived with his girlfriend (both students, aged 25), and asked if we could bring our Gestural Lighting Platform. The dinner setting served as an example of a concrete activity that typically takes place in the home contexts, where considerable effort and thoughts can be put into creating an atmosphere in various ways. In this thesis, this activity is thus considered to allow for emotional lighting needs.

Upon our arrival, the friend and his girlfriend were in the final stages of preparing the dinner. To make room for our platform, we had to move the dining table out into the kitchen-dining area (18 m^2 with a sloping wall) and replace the suspended lamps in the kitchen above the table. Previously, the table was placed with one edge against the wall (Figure 73). Aside from providing task-oriented light for activities centred on the table, the lamps also served as general lighting due to the relatively small room. The Tangible Lights prototype was configured, and a verbal introduction to the creation of light on the empty tabletop, was given. Subsequently, we passively observed how our two hosts set the table. We were positioned near the corners of the room, from where we documented the table preparations with camera and pen. This field study had a duration of two hours, starting at 6 PM and was carried out in October in Denmark. This setting allowed us to experience the change in natural lighting conditions from bright to dark throughout the evening, and how the artificial light setting affected the atmosphere in the room. After the dinner, we presented the four other Kinect prototypes to trigger a discussion.

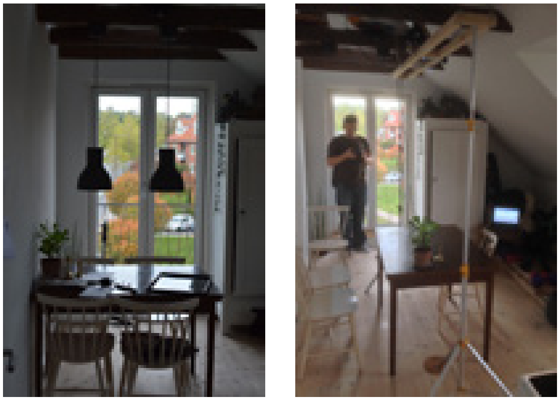


Figure 73. Before and after setting up the Gestural Lighting Platform in field study 1

Field study 2 setup – Integration in daily life (seven days)

As we wanted to gain insights from longer usage, we conducted a second longer field study. Three friends, all students and aged 24-25, who were sharing a flat (114 m^2 in total) agreed to have our lighting installations placed in their shared living room (30 m^2) for a week in November, 2014.

The shared living room was furnished with a large sofa region and a six-person dining table (180 cm x 100 cm). Directly above the dining table, two lamps were suspended from the ceiling at the height of 60 cm above the tabletop. We removed these lamps, as they were obstructing our platform. Following this, our Gestural Lighting Platform, unavoidably, became a substitution for lighting at the table (Figure 75). The two table lamps accounted for a large part of the general lighting in the room, and removing them resulted in an almost complete darkness in the room, as it was dark outside and no other light sources were lit. A third light source, a standing lamp with three energy saving light bulbs was placed near the sofa region on the opposite side of the room. During this week in November, the living room was fully illuminated by daylight from approximately 8 AM to 4 PM due to a two metre window section.

We briefed the three participants about the intentions of the study, i.e. to gain insights in the use of in-air gesture controlled light in daily life. We kindly encouraged the participants to use our platform whenever they needed light at the table for any on-going activities. We emphasised how they should not feel obliged to carry out activities just to satisfy us, hoping that this approach would provide more valuable field data.

Around 60 minutes were spent in their flat with briefing of intentions, a demonstration, and instructions on how to operate the platform. To report on the usage of the platform, we asked the three participants to send MMS messages including: a picture of the table, a description of the activity, social relations, and the role of the lighting. In order to receive the most immediate reflections, we encouraged participants to send these multimedia messages as soon as possible after finishing the activities. We handed out a laminated sheet of paper with written instructions, and placed it near the laptop in the windowsill. A translated version of this instruction sheet can be viewed in Appendix 6. At the end of the study, we conducted an informal, open-ended follow-up interview with two of the three participants.

Field study 3 setup – Integration in daily life (ten days)

To gain further insights from longer usage, we conducted a third field study, similar to the second field study. A couple living together in a 60 m^2 flat, both studying, aged 23-25, agreed to have our Gestural Lighting Platform placed in their living room (25 m^2) for ten days in December.

The living room was furnished with a four-person dining table (160 x 80 cm), an eight-person corner sofa, a large TV, and additional interior. In relation to lighting, the couple had recently moved into the flat, and not yet mounted a suspended ceiling lamp. However, two decorative lamps above the sofa corner and two floor lamps were used for general lighting. The lamps above the sofa were dimmable from a wheel in the wall near the door, and considered decorative by the participants as they were not bright enough for providing general lighting. The dining table was positioned out in the living room,

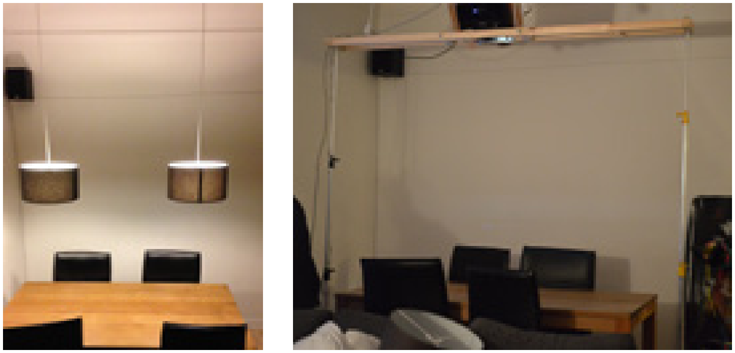


Figure 75. Before and after setting up the Gestural Lighting Platform in field study 2

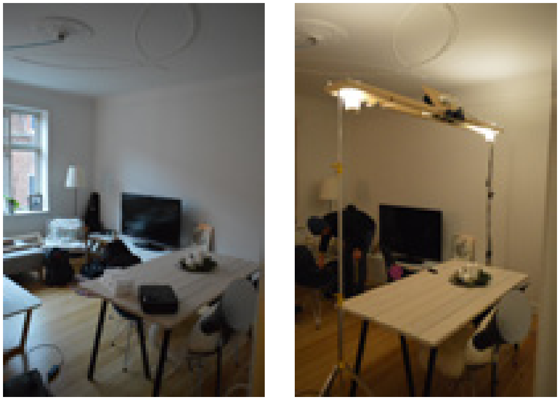


Figure 74. Before and after setting up the Gestural Lighting Platform in field study 3

providing a walking space around it. As there were no ceiling lamps above the dining table, we could easily set-up our Gestural Lighting Platform (Figure 74). As a lesson from the second field study, we provided two lamps mounted in lampshades on top of the platform to provide more general lighting in the room. Similarly to field study 2, we briefed the two participants about the intentions of the field study and handed out the laminated paper (Appendix 6). After ten days we conducted an informal, open-ended follow-up interview with the participants.

Findings from field studies

This subsection chronologically presents the findings from the three field studies, and thus no discussions are found here. The next two subsections discuss the inter-related, contextual findings of the three field studies. Findings related to usability are not included, unless they are of significance to the contextual findings.

Figure 76. Sequential video frames of the two participants setting the table in field study 1 (one evening study). Cutlery, decorative napkins, a plant, and two candles were placed on the table. The spotlights of the Tangible Lights prototype were used to highlight the foods.

Figure 77. Surface reflection reveals the textures of the foods clearly

Figure 78. Comparison of having and not having a spotlight positioned on the pie

Findings from field study 1 (one evening)

In the dinner setting of field study 1, the table was prepared by both participants as viewed in the video frames in Figure 76. As seen, the male participant was interacting with the spotlights in the Tangible Lights prototype after the cutlery, decorations and the main dish were in place (frame 5). At this point, not all of the food was in place, which resulted in the interaction being interrupted for a few moments, while the salad bowls were positioned (frame 6). At the end of the preparations, the participants discussed the light setting and, collaboratively, decided to highlight the salads as well (frames 8-9). While discussing the final table setting, the girlfriend expressed, "*I can see this being used in practice, now when we do all this other stuff [setting the table with napkins and candles]*".

During the dinner, the light was not changed further. However, we discussed the qualities and presence of this type of light. The spotlights positioned on the pie in the centre and on the bowl of feta cheese were found to provide a very detailed outline of the surface texture of the foods (Figure 77). This effect became particularly dominant after being seated for half an hour, as it became nearly dark outside. The pie topping was rendered very differently in the spotlight due to the bright reflections especially on the yellow areas of the egg omelette (see comparison in Figure 78). In the same way, the white colour of the feta cheese was very noticeable in the dark environment.

Findings from field study 2 (seven days)

While calibrating the minimum interaction height for our platform in relation to the dining table in field study 2, and performing a test run of the system, we noticed how one of the participants, seated on a chair, had to reach out with his hands in a slightly upright fashion. This was due to the chairs having a short height compared to the height of the table. As a result, we had to decrease the usual interaction height from 24 cm (default in our lab) to 15 cm above the surface of the table.

As planned, the documentation was received during the week and consisted of an MMS with a brief description of the context. In total, the three participants had used the Gestural Lighting Platform four times: two dinners with all three participants, one dinner with two persons, and one brunch activity with one of the participants and seven of his friends. Pictures from the four settings can be viewed in Figure 79 below. The table was, unfortunately, not used for other activities.

As can be hinted from the pictures, the three dinner settings were primarily lid by our platform, which resulted in a very dark setting in the living room. This can be ascribed the lack of general lighting, which was usually provided by the lamps that we replaced. As a result of this, the reflection at the surface of the table appears very bright and intense. During the follow-up interview we asked how this lighting contrast was perceived, and a number of expressions were noted, including

- *'The lights [in Tangible Lights] were a bit corny when it was just the two of us, so at one point we switched to the other setting [One Arm Brightness as seen in Figure 79, picture 1]*
- *"It gets a bit corny when it is just the two of us, since we know each other so well"*
- *"It [the lights] kind of sets an expectation … like it's a special occasion"*
- *"It is as if you are part of a theatre performance because it is so intense"*
- *"There is a lot of focus on the stuff in front of you [plates, food, etc.]"*
- *"The reflections from the plates were very intense, especially due to the dark surroundings"*
- *"There is no light on people's faces. It is kind of creepy"*

Figure 79. Compilation of the pictures received from the three participants during field study 2 (seven days study). The pictures show the four settings (3 dinners, 1 brunch) where the participants used our platform

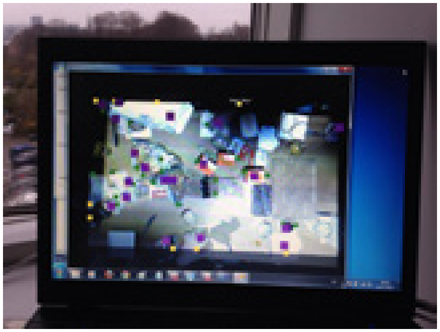


Figure 80. Additional picture reported following the brunch activity. The preview screen shows how the table is filled with objects.

Based on these statements and by reviewing the images, we conclude that the lighting conditions suffered from the lack of general lighting, and the light emitted from the projector was perceived as too intense and staged.

While reflecting on the use the One Arm Brightness prototype for dinner (as seen in Figure 79, pictures 1 and 3), one participant expressed, *"Brightness is quite simple and precise to adjust, which is nice … and also you can lock it. It [controlling the brightness] is a very natural feeling [moving an arm up and down fluently as imitating the interaction in One Arm Brightness]"*.

We asked whether the participants had started feeling used to the lighting system in their daily lives. *"When having it in the context of our daily lives, it is SO different than before"*, and, *"It was not here long enough in order to get used to it… at all"*.

We could see from the text accompanying the second dinner evening in field study 2 that Tangible Lights was used for *"providing an overview and decorative purposes"* for St. Martin's Eve ("Mortensaften" in Danish). At the interview we asked for an elaboration on this statement, and one participant expressed, *"Well, generally we don't really care – maybe girls would do it differently, I don't know"*. Immediately, the second interviewee interrupted, *"Ahh, I know you are into making things look nice in terms of arrangements!"* The first participant elaborated, *"Yeah, I mean, when it is just us, I don't care"*.

The seven guests for the brunch activity had never experienced the platform before, and everybody wanted to interact simultaneously, causing *"… a lot of randomness regarding who got to interact"*. This, coupled with a lot of food packaging being detected on the table (see Figure 80), caused the system to fall short on performance, and was a frustrating factor for the group. Consequently, *"At one point, the lights suddenly became bright and we just left it there"*.

Findings from field study 3 (ten days)

Over ten days, our platform had been in use a total of five times during field study 3. It was used four times for dinner settings. Three times running the Tangible Lights prototype, and once running the One Arm Brightness prototype. The last use included all prototypes as a demonstration to a visiting couple. Due to holidays and a weekend trip the platform was not used every day. In total, we received pictures from two of the five settings (see Figure 81).

From the reported pictures, we observed how the plates were positioned on the same side of the table. This was part of their daily dinner routine of eating and watching TV. In the follow-up interview, we were curious as to what extent the light interrupted this routine. *"While eating, we did not even consider it was there [spotlights]. At one point we discussed it and agreed that it was quite pleasant."*, and further, *"… the light felt non-synthetic"*.

The participants further elaborated on the dinner settings. It was explained how one participant first set up two spot lights and afterwards brought in the cutlery from the kitchen, *"I like to 'multitask'. While I was waiting [for the food], I 'placed' the light [spotlights] as I felt was right"*. For the dinner with One Arm Brightness, the participants also adjusted the light prior to preparing the table.

As the couple already had a physical dimmer control for their sofa light positioned near the door, we asked them to compare this to the One Arm Brightness gesture. "*It [the gesture] feels more 'real'... and it is funnier!"* When digging into this 'real' feeling, it was expressed how, *"you were close to it"*. Additionally, the male participant predicted how he would be likely to adjust the brightness while casually passing by the table, if the system was always running.

The participants emphasised how they always eat dinner at the table, as an important part of their everyday life. In this regard, they showed interest in the system and expressed how the light setting affected the atmosphere, *"… the light [spotlights] made it more intimate and romantic"*. We asked to their usual habits of creating such settings, and found that the whole flat was usually lid by candles in the evening in addition to the general lighting. When asked to compare the spotlights of Tangible Lights with candlelights, it was expressed that spotlights were, *"…like candles, in some way"*.

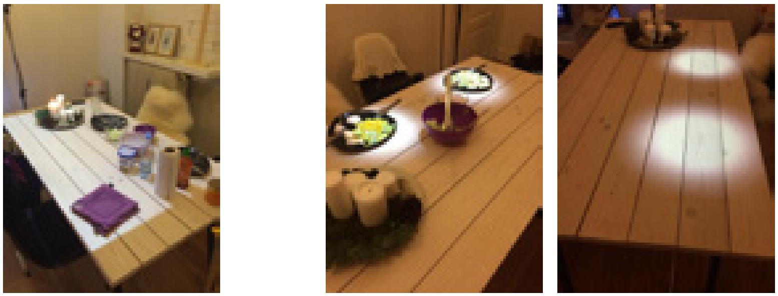


Figure 81. Compilation of the pictures received from the three participants during field study 3 (ten days study). The pictures show the two settings (2 dinners) where the participants used our platform

Discussion of field studies

An important part of our field studies was to gain insights in the context for which our prototypes were intended. Specifically, we were interested in patterns emerging from the use of our prototypes related to the in-air interaction style and how the prototype-specific lighting was used. This included how gestures and light settings supported various daily activities, how they blend into daily contexts, and which challenges that occur.

Thematic analyses of the findings from the field studies were conducted. As the three field studies were conducted chronologically in time, the first study could inform the second, and the second could inform the third. Thus, we were continuously able to improve usability issues between studies, and evaluate and reconsider the themes proposed. This was also beneficial, as we did not install video cameras in participants' flats and neither asked for video recordings in order to respect the privacy of participants in their homes.

This section now presents and discusses the identified themes spanning the general lighting level, the precision of control, effort, and to what extent this interaction style blends into the home context.

General lighting level

In field study two, the pictures (Figure 79) show how the living room lacks general illumination. The two first expressions on the bullet point list in field study 2 explain how the participants switched from Tangible Lights to One Arm Brightness during a casual dinner for two. This change between prototypes was ascribed to the spotlights being experienced "corny" between the two friends in the predominantly dark room. In addition, the expression about the spotlights being "intense" and "staging", imply that the contrast between darkness in the room and bright spotlights created an undesired focus on the objects on the table. Following these implications of how the general lighting level can affect the contextual experience, we propose that it is worth to explore how in-air gestures at the table can be extended to affect the general lighting in the room, e.g. lamps pointing upwards, as we had mounted in field study 3. In chapter 8 we include this discussion as part of the potential future directions of this work.

Precise brightness control

In the second field study a participant expressed, *"Brightness is quite simple and precise to adjust, which is nice … and also you can lock it. It [controlling the brightness] is a very natural feeling [moving one arm up and down fluently as imitating the interaction in One Arm Brightness]".* Our interpretation here lies in how a considerable simple in-air gesture can provide a detailed control of lighting parameters, where the interaction is associated with the positive experiences of simplicity and expressiveness.

This interpretation is based on manipulation of one lighting parameter, as we solely incorporated the brightness parameter in the One Arm Brightness prototype. However, we could change this to affect other one-dimensional parameters as well, e.g. colour temperature. Furthermore, we acknowledge that the control of multiple parameters with the same gesture is subject to further investigation (as also discussed in the future work of previous chapter).

Effort

In chapters 2 and 4, we discussed effort barriers in current home lighting. These relate to the lighting control being located too far away from the user, the user being too "lazy", and control being hidden behind furniture. Furthermore, we identified an effort barrier when the user is required to locate or bring up her smartphone, subsequently the lighting app. In chapter 4 we proposed that in-air gestural interaction might overcome these issues. Field study 2 suggests that the One Arm Brightness prototype allows for precise control of brightness through an acceptable and simple hand gesture, while being seated during dinner. Thus users can perform fine-grained adjustments without physically moving. Additionally, field study 3 suggests how *"It [the up/down gesture] feels more 'real' … and it is funnier"*. As discussed in the future work of previous chapter, future work on the framework includes exploring potential dimensions related to the user's experience.

All three field studies show how participants used spotlights for staging dinners and highlighting tableware. In fact more than half of the reported pictures show the use of spotlights in dinner settings. For "traditional" dinners (i.e. without the Gestural Lighting Platform), we argue that such decorative behaviour is normally associated with creating certain atmospheres, e.g. cosy, romantic, emotional. These atmospheres typically require extra effort in terms of putting up decorative artefacts, candlelights, etc. (participants of field study 2 used candles extensively for creating cosy and romantic atmospheres). Therefore, the considerable amount of spotlight dinners reported from the field hints how in-air gestures can potentially minimise the effort barrier of creating such atmospheres.

Support of existing activities at the table

As discussed throughout this thesis, the lighting needs vary according to the context including activity, user's emotional state, sociality, etc. Based on the pictures received from participants, the observed dinner activities were divided into lighting needs.

Emotional needs in dinner activities. For all three field studies, we report that the Gestural Lighting Platform was used for dinner settings. Looking at the responses, we conclude that half of these dinners were supported by the Tangible Lights prototype, and the other half being the One Arm Brightness prototype.

In relation to the spotlights of Tangible Lights, one of the house residents in field study 1 stated, "I can see this being used in practice, now when we do all this other stuff [setting the table with napkins and candles]". This expression particularly supports our intentions of utilising the Tangible Lights prototype for emotional lighting needs. It indicates that this type of emotional lighting can be a part of the decorations in terms of highlighting and staging food and objects. However, while reports from the field support this claim in dinner settings, prolonged integrations into daily life yet remains in order to determine the usefulness of this type of gesture controlled lighting in other activities.

Functional needs in dinner activities. A preference towards one overall light setting during dinner activities, as provided by the One Arm Brightness prototype, can be deduced from field study 2. Particularly in line with participants' expressions of reserving the spotlights for "special occasions", and that the brightness could easily be adjusted with high precision, while seated. Thus, we also view in-air gestural lighting as serving a functional need during a dinner setting. Coupled with the positive experience of fine-grained control, we believe this functional use is transferable to other activities as well, despite the fact that field studies only reported on dinner settings.

Other activities. Looking beyond dinner settings, the brunch activity of field study 2 (shown in the far right picture, Figure 79) shows how the table is occupied by a relatively high number of bring-your-own brunch related foods, accessories, bags, etc. The unstructured nature of this particular activity causes the table to appear messy in contrast to the dinner pictures. It was stated during the follow-up interview that Tangible Lights was used in conjunction with this "messy" table layout, however due to sporadic interactions from the seven brunch guests, the party preferred the overall light setting of One Arm Brightness, eventually.

Unfortunately, we did not receive more "messy" pictures, which could potentially yield highly valuable insights into the use of in-air gestures for more diverse, everyday situations. Neither can we report on any activities that suggested using the three prototypes Tile Lights, Mesh Lights, and Wave Lights.

Blending into the daily context

Despite the fact that we "invited" ourselves and our platform for dinner in field study 1, we believe our observations show, how adjusting the lights using in-air gestures at the dining table can be a collaborative task, on the same level as setting the table with ordinary objects such as plates, candles, napkins, flowers, etc. First, since the sequence of frames 5, 6, and 7 in field study 1 (Figure 76) show how the male participant was interrupted, while adjusting the spotlights to fit the pie that was placed in the centre of the table. This incident is a first indicator of the platform being a part of the context, as the interruption does not prevent the main activity of setting the table from being carried out. The lighting control appears as a subroutine to the preparation routine, and is temporarily overridden by other parts of the routine.

In addition, the last frames in field study 1 (frames 8-9), show how the final light setting is discussed by the two participants, while collaboratively operating the light setting. This indicates that, in the same way as the physical table setup is negotiated silently or verbally among participants, the lighting can also become a subject for discussion during routines.

To further address how in-air gestures blend into the daily activities, we asked whether our participants in field study 2 had started feeling used to the lighting system in their daily lives. However, “it was not here long enough in order to get used to it… at all”. Thus, we cannot elaborate further on long time usage, and we believe longer integrations in daily lives still remain in order to outline the contextual consequences, e.g. to what extent in-air gestures interrupt the current activity, affect the social context, etc.

Ergonomic considerations

In field study 2, we observed how the relation between the heights of the chairs and table had an impact on the performance of gestures, as a participant was holding up his arms in an awkward position. This finding is an example of a contextual challenge, which we did not thoroughly consider. Although we could compensate by decreasing the minimal interaction height using our calibration mechanism (described in chapter 4), it poses another challenge related to the use context: in a fictive scenario with similar height differences between chairs and table, we imagine how plates with food could be placed in front of seated people, forcing them to reach up in an uncomfortable height above the plate, while interacting. Furthermore, significant differences in heights across people, e.g. a family with children, could add to the ergonomic considerations of using in-air gestures above the tabletop. From our lab studies, several gesture specific considerations are also identified, including the rotational movement of the arm, wrist, hand and fingers; and the temporal length of gestures, which arguably also influence the interaction. As a result, we propose that ergonomic considerations play an important part of in-air gestural interactions with home lighting.

Limitations of the field studies

For the three field studies, we identify a number of limitations that are believed to have influenced our findings. Below we have divided the discussions in headlined paragraphs.

Demand characteristics

Arguably, the findings from the three field studies can partly be ascribed the psychological term “demand characteristics” related to the Hawthorne effect, where *“users shape or enhance their behaviour in a trial or experiment, in response to the imagined desires of the investigators”* (Brown, Reeves, & Sherwood, 2011). Thus, the increased attention from us could make participants feel obliged to contribute to our research in certain ways. This could include turning on the system in situations where they normally would not bother to use light at all. Further, participants could arguably feel forced to prototype specific obligations, e.g. create spotlights. We will not go further into demand characteristics here.

Relatively small flats without much general lighting causing forced use

The first limitation to discuss is the fact that we primarily conducted our field studies with students, living in study flats ranging from 60 m to 114 m. Here, the lamps suspended from the ceiling above the dining table were often the primary light sources for general lighting in the room. This was due to the flat sizes, limited power outlets, and the fact that dining tables occupied a relatively large space in the room. As mentioned, an overarching aspect of field study 2 was the lack of general lighting in the room, since we demounted the two suspended ceiling lamps. This arguably affects our findings, as it “forces” participants to turn on our platform in order to get illumination in the room during the evening. In bigger houses, the situation regarding general lighting might be different, due to possibly bigger living rooms. Thus, it is argued that our field studies in the home context could benefit from a more diverse set of residents and social factors such as wider age spans, professions, social hierarchies (e.g. families). Moreover, cultural differences in lifestyles also need to be taken into account.

Effort when powering on the platform causing abundance of dinner settings

The projector requires approximately 30 seconds to power up, has a high wattage, and the cooling system is relatively loud. Thus it is unacceptable to leave it running in participants’ homes. In order to explore the full range of diverse activities that potentially take place in the home, we argue that the projector is a hindrance. The delay is seen as an effort requirement. Therefore, in-air gestures have not been thoroughly used for a diversity of activities, whether routinely or sporadic. These activities are believed to potentially hold further important implications and challenges. We consider this the main reason why reports were primarily concerned with shared dinners between flatmates and couples. In these dinner settings, the extra effort of powering on the system is arguably more acceptable (as discussed in chapter 4). In the near future, a platform needs to overcome this issue by continuously allowing for interaction.

Besides the obvious purpose of a dining table, i.e. to sit down and eat dinner, we arguably also influenced the tendency among participants to report on dinner activities. When introducing the platform, we often explained a dinner preparation scenario, verbally. Here, we exemplified how movable spotlights could be used to light up objects such as plates or food. Although, this arguably has an influence on the use, we ascribe the required effort aspect discussed above as the main reason.

Keeping up appearances causing lack of general activities and routines

Lastly , we note that participants usually provided very “tidy” pictures, as seen in Figure 79 and Figure 81. For instance, we note the pictures that contain spotlights neatly aligned to the centre of a plate. Only two “messy” pictures were reported, i.e. the brunch in field study 2 (picture 4, Figure 79), and a casual dinner in field study 3 (picture 1, Figure 81). We believe that this behaviour is rooted in a desire to present one’s home as tidy and well-organised. Thus, the pictures do not reveal the messy parts of daily activities and routines. This concern could possibly be eliminated to some extent by recording video or data logging of the use, as mentioned earlier in this chapter. However, we desisted, as recording could possibly promote the very same behaviour of keeping up appearances, along with an intimidation of privacy.

EXPERT EVALUATIONS

In addition to the contextual insights from people's homes, we use our Gestural Lighting Platform and the developed prototypes to facilitate expert evaluations with people working at the crossroads of architecture, technology, user experience, and design. Through demonstrations, we intent to foster discussions on our current interactions along with opportunities for looking into other domains. We view this feedback as relevant on a conceptual level, in contrast to the three field studies conducted, where focus was on daily life integration.

Intentions & setups of expert evaluations

We conducted two main evaluations with experts. The first evaluation was conducted in our lab with Dr. Ted Selker (Selker, n.d.), who is a researcher on user interfaces and industrial design, IBM fellow and former director of the Context Aware Computing Lab at MIT Media Lab. The duration of this session was 30 minutes, and we demonstrated the One Arm Brightness and Tangible Lights prototypes. A picture from the session can be viewed in Figure 82

The second expert evaluation was carried out with architecture students at Aarhus School of Architecture, and organised as an open session via architect Kätte Bønløkke Andersen (2012), who was also introduced in chapter 2. We installed the Gestural Lighting Platform in the middle of a big studio environment. All interested students using the studio for project work were invited to visit our platform at any time during our two hour visit. At this time of the day, we counted 14 architecture students coming and going. The students were currently finishing up their final postgraduate projects, of whom a few were working with an architectural approach to lighting. A picture from the session can be viewed in Figure 83.

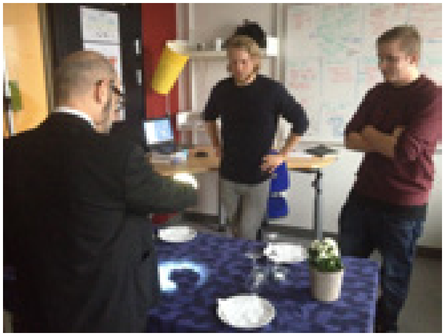


Figure 82. Picture from an expert evaluation carried out in our lab with Dr. Ted Selker

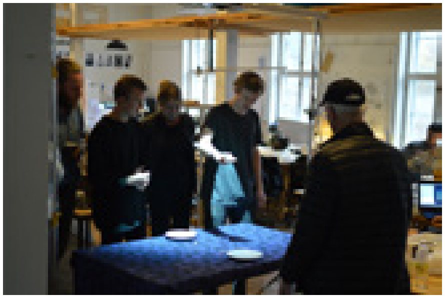


Figure 83. Picture from an expert evaluation carried out at Aarhus School of Architecture

Findings from expert evaluations

When presented with the Tangible Lights prototype, the architecture students politely took turns in the beginning, while observing how fellow students created and moved lights around. However, out of temptation several students reached in above the tabletop to interact simultaneously, and were quickly given consent, as we had developed it to support any number of persons concurrently.

We quickly sensed that the students were fascinated by the ability to "create light" using their hands above the tabletop. One student sporadically expressed, *"It feels like being God! Light here… Light there! [Imitating the spawn gesture from Tangible Lights in mid-air with his hands, while moving the hands around him]"*. This expression emerged into a shared discussion, where one student deliberately expressed, "*You could actually create light anywhere… not just at the table"*. The students and we agreed on the benefits of creating lights just about anywhere in your house, as lights typically are put up with different purposes, not just at the table (four different approaches to the functions of light was given in chapter 2 and summarised in Table 2 on page 29).

Further building on this discussion, we presented an idea of "moving" lights away from the table, and around in the house. This triggered a discussion on how the lights could follow you around once a person "grabs" it, especially when it is dark outside.

During both expert evaluations, while running the Tangible Lights prototype, we performed a "clear" gesture in order to clear all spotlights (see video frames in Figure 84 below) using a Wizard of Oz technique (one author pressed a clear button on the laptop). Following this particular gesture, the experts in both studies became emotionally charged and immediately tried to replicate it. Ted Selker noted the simplicity of the interaction and how the differences between each gesture were clear, and not merely a point and click system. He emphasised how it was important to keep a *"limited number of gestures"* that provides structure to the user.

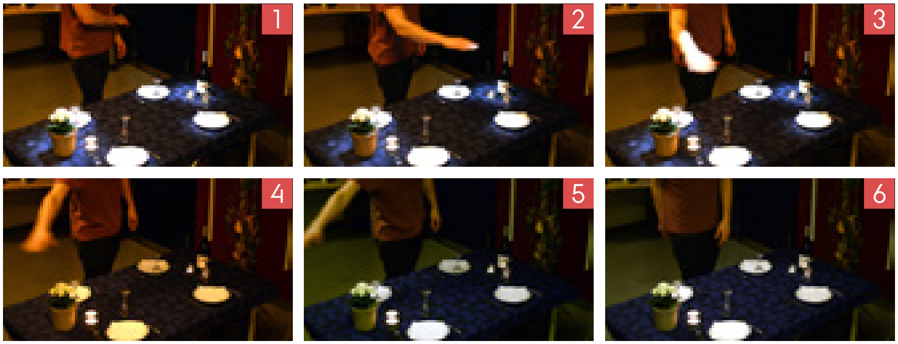


Figure 84. "Clear" gesture performed to clear all lights from the table. Video frames from Tangible Lights presentation demo (Andersen and Sørensen, 2014b)

This way we offered a frame for the user to be creative within, as opposed to an approach of providing a lot of freedom.

Discussion of expert evaluations

The evaluations in this section were carried out with experts in terms of 14 postgraduate architecture students, architect Kätte Bønløkke Andersen with expertise in lighting, and Dr. Ted Selker. An important thing to note is that these persons were able to discuss and reflect upon specific aspects of the prototypes on an abstract level. This was our intentions, and a complement to the field studies, which served to provide insights from in-air gestural interaction with lighting in daily life.

Creation of light as a strong concept candidate

During our two hour session with the architecture students, an interesting theme identified was the ability to simply "create light" using your hands, or as one student sporadically put it, *"It feels like being God!"* The general consensus about this concept of creating light, and the students' abilities to reflect upon this experience as a group, imply that parts of the Tangible Lights prototype can be seen in isolation. Further, the discussion suggested being able to create new regions of light anywhere in the home, and not just at the table.

This way of articulating individual aspects of a prototype was not seen in the contextual field studies, where participants primarily used the lights for their activities. We believe this "create light" concept and the emotional experiences derived from it shows an interesting potential in terms of in-air gestures, possibly reaching beyond the Tangible Lights prototype, and beyond the borders of the table. Thus, we believe that it is worth to explore this concept further in the future and show its potential in other areas of the home, in other use situations, and possibly in other domains. In the next chapter, this is discussed as a future direction for this thesis when considering other potential domains for in-air gestural lighting.

In terms of Höök and Löwgren (2012), we classify the create light concept as a *strong concept* candidate following their characteristics of such. Thus, we propose that the concept serves as *"intermediate design knowledge"*, is an *"interactive behaviour rather than static appearance"*, and *"resides at the interface between technology and people"*. We further propose that the concept of creating lights where you are, with your hands, carries a core design idea. However, before making it a truly strong concept, the authors state that the strong concept candidate has to potentially *"cut across particular use situations and perhaps even application domains*". This is why we label it as a strong concept candidate, similar to Höök and Löwgren's slingshot idiom stemming from the Rovio game Angry Birds (2009).

Movability of light

Another concept identified and discussed in isolation was the movability of light. Being able to move the lights, or making it follow a person, also gives an additional perspective on how gestural lighting can be extended from one location to another beyond the table. While our work show how lights can be moved using grabbing gestures, it might come out completely different when moving into other contexts. Similar to the creation of light concept, this concept is discussed in the next chapter as a future direction for in-air gestural lighting in other domains.

Tangibility of light

The tangibility of light is the third interesting concept identified. In the Tangible Lights prototype, we applied a direct mapping scheme inspired by in the domain of tangible user interfaces (TUIs), where input and output are tightly coupled in space. The set of gestures were conceptualised in tangible phenomena, e.g. grab and move the light as it was physical objects (for the full set of TUI inspired gestures, please consult Table 4, page 86, in chapter 5). Evaluations and field studies suggest that the gestures are generally an accepted and straightforward way of interacting above a two-dimensional tabletop, coupled with the continuous feedback of lights being rendered according to arm movement.

We argue that by leveraging the TUI interaction paradigm, it is possible to provide an instantaneous mental model for interactive lighting, where gestures are easily understood and can be explored independently by the user. Further, we see the potential of the tangibility of light to cut across use situations and domains. Thus, the concept, along with the Tangible Lights prototype running on the Gestural Lighting Platform, was submitted and accepted for the 9th international conference on Tangible, Embedded and Embodied Interaction *(TEI'15)* as a work-in-progress paper (Sørensen et al., 2014).

However, we believe that the tangibility of light concept cannot be directly transferred to the rest of the living room or house without adaption. The lighting here is different and often covers larger areas with diffused light over longer distances, where the boundaries of the light can be hard to distinguish. Also, the designed gestures of Tangible Lights correspond to the relative sizes of spotlights at the table, on where they are easily perceived to follow a grabbing hand. We argue that to adapt the concept into the larger scale of the room context, the gestures arguably need a redesign, and the movement of light should not necessarily follow the hands, as this might be hard to perceive. Perspectives to other domains can be found in the next chapter in conjunction with the discussed concepts of creation and movability of light.

8 FUTURE POTENTIALS

Based on the exploration of in-air gestural lighting in the home, spanning the development of prototypes, field studies, and expert evaluations, an answer to research question 2 is provided. This chapter presents a number of contextual implications and promising concepts, that can be used to inform and inspire future development of in-air gestural interfaces for interactive home lighting. The home, more specifically, the dining table has been the primary scope, however, in the last section of this chapter, we present perspectives to other domains.

CONTEXTUAL IMPLICATIONS

In the previous chapter we discussed the findings from the three field studies and two expert evaluations, which were conducted with the Gestural Lighting Platform and five of the eight prototypes. The essential parts of these discussions are here divided into a number of implications with explanatory headings. As the implications derive from the prototypes being a part of the home context, we name them contextual implications. These contextual implications serve to inform future designers by highlighting the strengths of in-air gestural interaction with lighting in the home context.

Fine-grained adjustments are possible using in-air hand gestures

Following our field studies, we argue that in-air gestures can yield a simple means of fine-grained and precise control of lighting parameters, if designed with simplicity in mind. Further, we note how this use of in-air gestures can lead to positive experiences of simplicity and expressiveness.

In-air gestures to overcome effort barriers

In chapter 4, we identified and discussed effort barriers in current home lighting. These relate to the lighting control being located too far away from the user, the user being too "lazy", and control being hidden behind furniture. Furthermore, we identified an effort barrier when the user is required to locate or bring up her smartphone, subsequently the lighting app. We propose that in-air gestural interaction could potentially overcome these issues, as we show how users can perform fine-grained adjustments without physically moving. Further, we imply how gesture controlled light can be used for decorative purposes without requiring considerable effort from the user.

Existing activities can be supported by in-air gestural lighting

Following our empirical studies, we identified the different functions of light including general, task-oriented, and decorative (chapter 2). We merged these with Offermans et al.'s (2014) three lighting needs, including basic visibility, functional and emotional, respectively (chapter 4). Through our prototypes we targeted the latter two needs. Based on our exploration of the framed design space, we argue for an identified potential for in-air gestures to support these types of needs. Regarding functional needs, our results suggest that in-air gestures can be supportive of activities where task-oriented lighting is needed, e.g. by providing fine-grained control of brightness. Further, our results suggest that emotional needs can be supported, as in-air gestural lighting can be utilised for decorative purposes, e.g. by highlighting and staging food and objects.

In-air gestural lighting can blend into the daily context

Our results suggest that in-air gestural lighting holds a potential to be a part of daily routines and activities taking place in the home. Although the exploration of the design space in this thesis focused on the table, we document how the gestural control of lighting can be temporarily overridden by other parts of a routine, and how the interaction can be a part of a discussion.

PROMISING CONCEPTS IDENTIFIED

In our work, we have identified three concepts in isolation. The concepts are isolated aspects which stem from our prototypes and believed to hold potentials that can inspire for further development of in-air gestural lighting. These concepts point to future directions for in-air gestural interaction with lighting which will be discussed in the next section.

Creation of light

An interesting theme identified, following the two hour session with architecture students, was the ability to simply "create light" using the hands, or as one student sporadically put it, "It feels like being God!" We believe this creation of light concept, and the emotional experiences derived from it, show a promising potential in terms of in-air gestures.

Movability light

Another concept identified and discussed in isolation was the movability of light. Being able to move the lights, or having the lights follow a person, also provides an additional perspective on how gestural lighting can be extended from one location to another beyond the table.

Tangibility of light

In the Tangible Lights prototype, a direct mapping scheme was applied, which refers to the design of interfaces, particularly in the domain of tangible user interfaces (TUIs). We argue that by leveraging the TUI interaction paradigm it is possible to provide an instantaneous mental model for interactive lighting, where gestures are easily understood and can be explored independently by the user.

FUTURE DIRECTIONS FOR IN-AIR INTERACTION WITH LIGHTING

Throughout the last chapters, future directions have been pointed out for in-air gestural control of lighting beyond the table. In this section we argue for applying the identified concepts to other areas of the house and in other domains.

Beyond the table

In this thesis we narrowed the focus to the table. Here, the activities taking place were considered to have functional and emotional lighting needs. A common perspective for our work has been how we can move beyond the table and out into the living room, possibly the house. In either case, we arguably need to consider the lighting need of basic visibility, which is typically met by the general lighting.

We believe the gestures developed in this work cannot be directly transferred to other domains, as they are explicitly developed for the table. On room level, the lighting is different and often covers larger areas with diffused light over longer distances, where the boundaries of the light can be hard to distinguish. On house level, rooms could be affected from a distance without the user physically being there. However, as we have discussed the three concepts of *creation, movability,* and *tangibility of light* in isolation, we now discuss the adaption of these to the larger scale of the room context.

First, the implementation of the "create light" concept in this thesis relies on a gesture, where two hands form a circle, suggesting a spotlight can be enclosed within the hands. While promising on the dining table, the concept could possibly rely on larger scale gestures when considering the room level. These gestures are subject for further exploration, and could possibly include the mapping of gestures, performed by the whole body, to areas with lighting in a room. Second, we argue that the tangibility of light concept neither can be directly transferred to the rest of the living room or house without adaption. The implemented gestures found in this work are designed to correspond to the relative sizes of spotlights at the table. Here, evaluations suggest that the gestures are easily perceived to follow a grabbing hand. On room level, where the scale is different, we propose that lights could potentially follow the user's body movement instead of the hands. In either case we hypothesise that normal, diffuse room illumination might be hard to conceptualise as tangible.

Potentially, in-air gestures can also extend beyond the room level and affect the house as a whole. For instance, when approaching or moving away from a specific room, in-air gestures could be utilised to adjust the light settings in the remote location. Currently, we see this remote room control in practice when smart bulbs are controlled by smartphones from other rooms. In the example with in-air gestures, the user is moving, e.g. walking, which possibly poses a separate challenge.

In conclusion, when looking beyond the table, we believe the proposed concepts hold a potential, which is transferrable from the dining table to the room and house levels, however, the interaction is subject to new explorations.

Beyond the home

We now present emotional and functional purposes incorporating the concepts of the creation, tangibility, and movability of light. Looking beyond the home opens up for a variety of possible application domains, where artificial lighting is already present.

Restaurant setting

First and foremost, we experienced several comments on how the concepts of in-air gestural lighting at the table could be transferred to a restaurant setting. Here, servants wait on the customers throughout the visit to allow for delightful experiences. Today, many restaurants integrate experiences as a way to give the customer extra value, and make the visit memorable (Ryu and Han, 2011). This customer experience can be built up using suspense, e.g. by bringing in the dishes one by one, bringing wine, candlelights, etc. We foresee a promising direction for the concepts of creation, tangibility, and movability of light, where waiters continuously build up and change the light setting at the table, while the customers sit back and watch. Continuous adjustments of the lights throughout the dinner could give each dish a unique perceptual dimension using "just the right colours", or lights could simply be moved and resized to fit the tableware. Additionally, customers could potentially be a part of an interactive experience by allowing them to control (parts of) the lighting throughout the experience.

Figure 85. Restaurants as a potential domain. The customer experience could be affected by a waiter (or customers themselves) who configures the lights at the table through the concepts of creation, tangibility, and movability of light

Figure 86. Museums as a potential domain due to their explorative nature. The picture illustrates how the movability concept can be used to search for hidden objects in complete darkness

Museum exhibitions

Next, we consider museums as a potential domain due to their explorative nature. Here, a scenography could be created distributed across different areas, e.g. an urban environment. Museums could also utilise the tangibility and movability concepts by letting visitors "bring their own light" as part of exhibitions, in order to discover hidden objects or areas of a room. This was hypothesised in a lab setting while conceptualising on the Tangible Lights prototype. As seen in Figure 86 below, we searched the table for coloured glasses in complete darkness.

Automotive domain

Turning to the automotive domain, the artificial lighting in cars is often limited and typically positioned in the ceiling. Being able to create light wherever needed, or having spotlights that follow the hands of a user, could help recover items dropped on the bottom of the car (Figure 87). This functional purpose could also avoid undesirable situations, where other passengers are exposed to light, e.g. when driving during night. Another potential scenario that builds on this concern is when individual passengers need light for specific purposes during night driving, and thus are forced to turn on the ceiling light. If given the opportunity to create personal light in their seats, passengers could demand individual lights for activities such as reading or putting on make-up (Figure 88).

Figure 87. Cars as a potential domain. The picture illustrates how the creation of light concept can help recover dropped items. Spotlights could also follow the hand

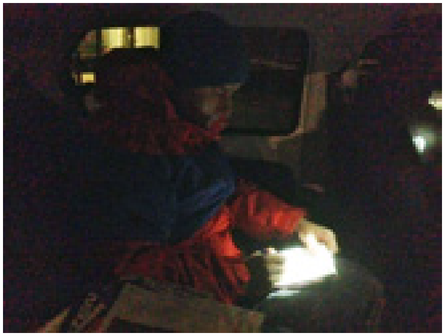


Figure 88. Cars as a potential domain. The picture illustrates how the creation of light concept can be used to provide personal a light, without bothering the driver and other passengers

CONCLUSION

This thesis has set out to explore how the in-air gestural interaction style could be combined with home lighting. In summary, this thesis has provided the following contributions: 1) First, as a result of our exploration through prototypes, we presented a framework for in-air gestural lighting in the home. This framework can be applied analytically and serve as inspiration for future interfaces of this type (chapter 6). 2) Second, a number of contextual implications and concepts to inform and inspire designers of future in-air gesture lighting interfaces in the home were provided (chapter 8).

The framework initially consisted of five dimensions including: acceptable interaction effort, contextual lighting needs, lighting features available, mapping schemes, and required interaction effort. Through eight prototypes taking different approaches to the dimensions, we extended the framework with the dimensions number of lights to attend to and movability. Since we showed how the initial dimensions drove our prototyping process to ensure variation across the dimensions, we argued that the frameworks can be used generatively. Further, we analysed four other interfaces for in-air gestural lighting control, and thus deemed the frameworks relevant as analytical tools.

However, we argued that the frameworks did not provide a way to design and create the actual gestures. In terms of future work, we stated how it could be worthwhile to add more gesture specific dimensions that considered hand, arm, and finger level movements as well as the temporal dimension. Additionally, dimensions related to the user's experiences could be explored.

We presented three field studies of varying lengths (one evening, seven days, and ten days), where participants had our gesture-controlled prototypes integrated in their homes. Based on these field studies, we gained insights from in-air gestural lighting as part of daily life. These insights were formulated into a number of contextual implications for this interaction style combined with home lighting control. Implications included how in-air gestures could be used for fine-grained adjustments, to overcome effort barriers, to support existing activities, and to blend into the context.

However, due to the technical setup, our platform was not continuously running in participants' homes. The required effort of powering up the system was perhaps too high, which may have negatively impacted the experiences. Additionally, we need to gain more thorough insights into the diversity of activities within the home. These activities, whether routinely or sporadic, could hold further implications and challenges for in-air gestural control of home lighting.

Moreover, two expert evaluations were presented in order to discuss the interaction in isolation and the potential in other domains. As a result, we presented the concepts of creation, movability, and tangibility of light, which we deemed promising for gesture-controlled home lighting. The potentials of these concepts in other domains have been discussed. This included looking beyond the table, and into the larger scale of the room context or house as a whole. Further directions for looking into other domains have been proposed, including the restaurant setting, museum exhibitions and the automotive industry.

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APPENDICES

Appendix 1. TEI'15 work-in-progress paper, "Tangible Lights": In-Air Gestural Control of Home Lighting

"Tangible Lights": In-Air Gestural Control of Home Lighting

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Abstract
While there has been much focus on tangible lighting interfaces embedded in physical objects and smartphones as remote control, there has not been sufficient attention on how the expressivity of bodily movement can be used when designing interactions with light. Therefore, we investigate interaction with lighting technology beyond the smartphone and physical controllers. We examine the usefulness of the in-air gestural interaction style for lighting control. We bring forward "Tangible Lights", which serves as a novel interface for in-air interaction with lighting, drawing on existing knowledge from the tangible world. Tangible Lights has been subject to initial evaluations.

Author Keywords
Interactive lighting; lighting control; in-air gestures; user interfaces; home customization

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces.

Introduction
Lighting is a key aspect of the design of interior spaces, which serves functional purposes of illuminating tasks, accentuating the objects and materials in the room, and setting the atmosphere experienced by the occupants. More recently, the commercially available, mul-

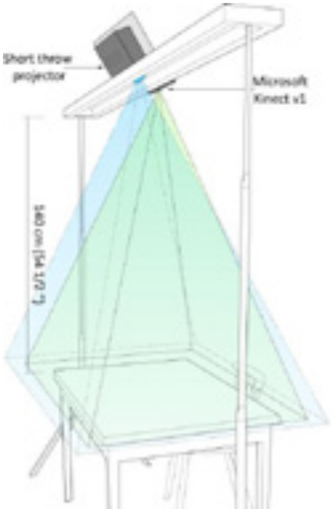

Figure 1. Technical setup

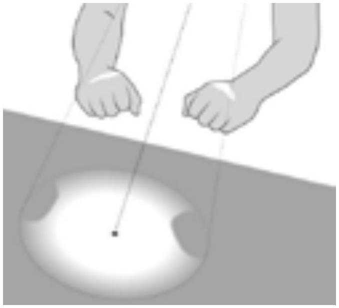

Figure 2. Mapping two hands to a cast light. Light strikes on top of hands and causes shadows

ticolored light emitting diodes (LEDs) have been introduced in the home domain providing new possibilities when using and controlling light. How can technology and interactive lighting enable new customization possibilities of the home and support desirable experiences in daily life? We take a step towards this vision by combining interactive lighting with in-air gestures. As a result we present the "Tangible Lights" platform for in-air gestural lighting control at the dining table. As our work is currently in progress, this paper focuses on the initial aspects of interaction and mapping.

Commercially, we have started to see interconnected smart bulbs for the home, which can be controlled from smartphone apps, e.g. Philips Hue, Samsung Smart Bulb, Stack Alba, and LIFX. We see several practical benefits in utilizing the smartphone as a central platform for interaction, e.g. dynamic interface; 'always' with you; remote access and control without dedicated remote controllers. However, this direction comes with a list of shortcomings: smartphones can be displaced from the user, other residents and guests cannot interact without connecting to the wireless infrastructure, and interacting users are not necessarily situated in the lighting environment they are controlling [7]. Socially, the action of physically switching the lights on/off or adjusting the brightness provides immediate, visible clues to other people in the context.

With the new possibilities of the emerging LED technology come new challenges. In research, this has been recognized by Aliakseyeu et al. [1] who set up a workshop on "Designing Interactive Lighting" at DIS 2012, and by Offermans et al. [8] who explored the initial design space of interactive lighting interfaces, and present important aspects regarding the interaction in a relational model. Researchers have also developed various physical interfaces for lighting control [2, 6, 7, 8].

Focusing on In-Air Gestures

Research has found that interactions relying on bodily movement possess unique interaction qualities in terms of expressivity and supporting the capabilities of the body [4, 5]. In-air gestures as an input style effectively allows for communication of your intentions to other participants through interaction and allows for the possibility of engaging multiple users simultaneously. However, working with in-air gestures also poses challenges, such as the lack of tactile and haptic feedback due to the inherently invisible interface. As with the "live mic" problem in audio, when is the control system listening? Moreover, we find the "segmentation issue", which deals with the temporal length of interactions. When does a gesture start and end? Our work combines the area of interactive light control with the interaction style of in-air gestures. This style of interaction can be seen as radically different from typical smartphone and tangible controllers.

Use Scenario: Dinner with Friends at Home

We created a scenario to illustrate some of the existing practices in the home, which Tangible Lights is envisioned to support. The scenario illustrate the current practice of decorating and setting a table, where considerable effort and thoughts are put into creating the right atmosphere both in terms of ordinary decorations and attention to lighting.

Julia awaits three guests for dinner and starts cooking dinner two hours before. She wants to set the table, and she finds four identical, nice looking plates and cups. She figures she wants to do something extraordinary and brings in colored linen napkins and arranges

Figure 3. Mapping one hand to a cast light. Light strikes on top of the hand and causes a shadow

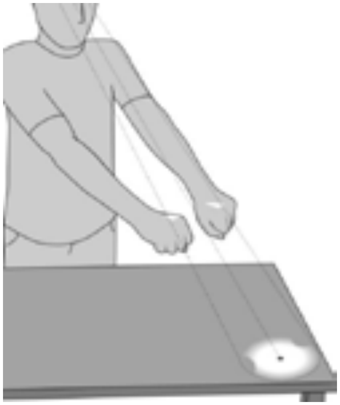

Figure 4. The mapping scheme allows reaching far corners

them evenly on top of the plates. Julia also wants to do something to the lighting to create a sense of coziness. She decides to dim the main light via the dimmer in the wall where it has been set to full brightness due to the darkness outside. Further, she decides to switch on two small lamps near the dark corners of her living room, and brings in two candlelights for the table. As her guests are welcomed they immediately comment on the lovely atmosphere and the detailed table decorations. After the dinner, Julia puts the brightness back up while her guests help her move the dishes to the kitchen. The friends suddenly decide on playing a board game while chit-chatting and having evening coffee. One of the friends notices the now bright lights from above the table, and locates the wall dimmer in order to again fit the relaxed atmosphere.

Tangible Lights

We now present our system called "Tangible Lights" which serves as an interactive lighting platform around the dining table. Tangible Lights enables the user to customize the light setting at the table with precise control through several, individual illuminated regions, which can be manipulated freely in the space above the tabletop. As a result, the position and size of each individual illuminated region can be manipulated through in-air gestures as desired. The name Tangible Lights stems from our intentions of creating an interface where the user feels as if she is holding onto the lights and controlling it at her fingertips. To accommodate this, we seek to draw on her existing knowledge from daily life when grabbing and moving physical objects around. The challenge here is that lights are generally perceived as non-tangible, although they do have an insignificant small physical mass, and the warmth of intense light can be felt on the skin.

Technically, the platform consists of a short-throw projector and a Microsoft Kinect sensor (see Fig. 1). The short-throw projector serves as the light source as it provides an easy and dynamic way to position an arbitrary amount of illuminated regions on the tabletop. The Kinect sensor continuously streams depth maps to the gesture recognition software at 30 frames per second. Our software is an extension of the C# wrapper for the KinectArms project developed for quick mock-ups by Genest et al. [3].

Direct Mapping between Hands and Light

To interact with the lighting in Tangible Lights, we needed a way to map the hands to the cast light. As it is our intention to design for the experience of tangibility of manipulating cast lights, we have sought inspiration in the domain of tangible user interfaces (TUI). We have applied a direct mapping scheme, which refers to the design of interfaces, particularly in the TUI domain, where input and output is tightly coupled in space.

For our design of the direct mapping, a cast light is enabled for interaction when hands interfere the projected light beam. This looks different in the case of one or two hands as seen in Fig. 2-3. As a natural consequence of using one global light source (i.e. the projector), the center of the cast light is occluded by the hand creating a shadow on the tabletop (also seen in Fig. 2-3). This provides two concurrent means of visual feedback for the person interacting to visually make contact with and maneuver a lit region around the table.

As a result of our designed mapping, it is possible to reach far corners of larger tables, since the light cast on the tabletop is positioned with an offset to the interacting hand(s) as seen in Fig. 4.

Figure 5. Spawning a new light by holding hands in a vertical position

Figure 6. Grabbing a cast light by closing the hands near its perimeter

Figure 7. Moving a cast light by moving the hands

Designing the Interactions

The interactions designed provide a set of interconnected actions for manipulating the light setting. Actions include spawning, selecting, deselecting, moving, scaling, and removing lights. To simplify the interactions, we draw inspiration from known daily life actions such as grabbing, holding onto a plate or cup. We have explored different interaction alternatives requiring both one and two hands, as the number of hands is found to possess different qualities, which will be explained in the following. On-going evaluations have helped shape the interactions to their current form as presented here.

Spawn gesture
It is possible to create a new illuminated region by holding two hands in a vertical position as if holding onto a physical bowl (Fig. 5). This hints that the lights can be physically contained within the circle enclosed by the hands.

Grab and move gestures
A cast light is selected with two hands by "grabbing the light" near its perimeter as if it was a physical steering wheel (Fig. 6). This interaction, of course, yields no physical feedback as when grabbing an actual steering wheel. The grab gesture can also be performed with one hand, as two hands could yield a problem when carrying objects such as dishes, plates and cup. In use, the one-handed grab often allows for quicker positioning than the two-handed grab. The one-handed grab is initiated near the center of the cast light on the table and can be viewed in Fig. 3. Once grabbed, the newly spawned and existing cast lights can be moved according to the position of the hands in a 2D plane above the tabletop (Fig. 7).

Scale gesture
When selected, cast lights can be scaled up and down in size. The user can resize the lights to highlight physical objects on the table, e.g. dishes, cups, plates, plants etc. When interacting with two hands it might seem natural to just move the hands away from each other (Fig. 8), building on experience from the real world. Here, flexible objects such as bags, rubber bands, fabric, etc. can be expanded by grabbing and pulling hands in opposite directions. For scaling with one hand we seek inspiration in the behavior of a flashlight. Moving it closer or further from a surface results in a smaller or larger cast light, respectively (Fig. 11).

Release gesture
In Tangible Lights, releasing (i.e. unselecting) an already grabbed light is implemented as the reverse grab gesture. In other words, when not intending to manipulate a cast light anymore, the person extends her fingers. The final hand posture for two-handed interaction can be seen in Fig. 9.

Remove gesture
Lastly, to remove a cast light completely from the table, the light is pressed (squeezed) together with two hands or reduced in size with one hand moved very close to the table. Essentially, this is the scale gestures being used to make the light continuously smaller until it disappears (Fig. 10).

Initial Evaluation Results

Based on our current lab and contextual evaluations with 21 people, we have categorized our initial findings.

Tangibility of Cast Lights
As our set of gestures is conceptualized based on tangible phenomena, we want to understand how people

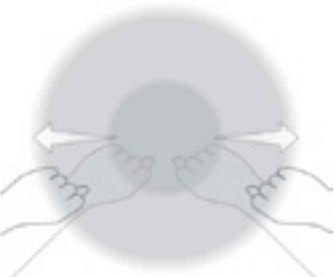

Figure 8. Scaling of a cast light by pulling in both directions

Figure 9. Releasing a grab by extending the fingers (reverse grab gesture)

Figure 10. Removing a cast light from the table by squeezing it together

feel when using them, and how they learned and understood the suggested tangible qualities. Thus far, we have mainly had people trying different gesture variations when selecting and have asked them to reflect upon the differences. Our current evaluations suggest that the grab and release gestures are generally an accepted and straightforward way of selecting and deselecting a cast light. As one person explained *"it [grabbing the lights] just came natural to me… I had totally forgotten about last time"*. For him, grabbing was an unconscious action.

Contextual Implications

An important part of our evaluation is to reflect upon the context for which our design is intended. A first impression is that users are able to start highlighting objects on the table as soon as the grabbing concept is explained. During contextual evaluations, one of the house residents stated, "*I can see this being used in practice, now when we do all this other stuff [setting the table with napkins and candles]*". This category is subject to further contextual evaluations.

Direct Mapping and Alignment

The alignment of hand and cast light was, for many people, an intuitive way of selecting light, and was expressed by one participant, "*it is easy to just move my hand in [above the table] and, like, interfere with the light beam*". However, when not instructed or demonstrated, we also observed a tendency to reach out directly above the cast light trying to select a light (exemplified with one hand in Fig. 12). Following a quick how-to demonstration, people were able to adapt to our intended mapping. It would be interesting to collect more detailed information on how the two mapping alternatives are understood.

Although we intended to provide a smooth interaction experience, we encountered some technical challenges, which affected the perceived mapping. When observing interaction sessions, the largest technical breakdown occurred when people continuously reached out for a specific cast light, but did not get in contact with it. This was caused by system instabilities of either not recognizing the hand, the gesture, or by the mapping being misaligned in the software. Beyond technical improvements, the question is, how can we help the user to understand the mapping?

Gestures and Functionality

Once shown or told how to select and move lights, people were able to independently explore the scaling functionality by moving the hands apart (or up and down if one hand). Scaling actions were almost always performed during the very first interaction and can arguably be contributed to the system behavior of being reactive to changing distances between hands (or height if one hand).

When interacting, the light is visible on the hands. Once selected, the instantaneous visual feedback of the cast light moving according to hand movement provided an easy way for people to control the light around the table. However, approaching the table, new users do not know that it is possible to reach out for lights with the hands unless the functionality is explained. In the near future we will explore how the use of different feedforward techniques [9] can help to communicate the functionalities and provide suggestions for use. We intend to explore a number of iterations focused on how subtle behavior such as movement and pulsation of cast lights can invite interaction.

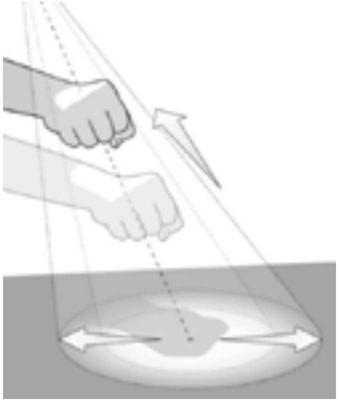

Figure 11. One hand scaling of a cast light by varying the height of the hand

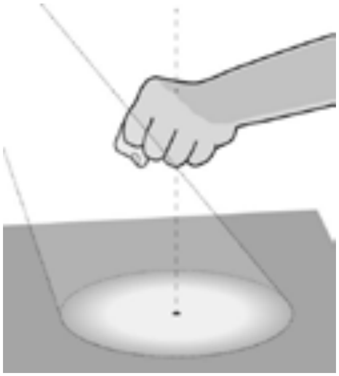

Figure 12. We observed a tendency to grab lights directly above the cast light instead of interfering the light beam

Discussion and Future Work

Tangible Lights requires a relatively high amount of interaction effort. By integrating gestures for color and brightness control, the interaction effort is intensified. In contrast, it is interesting to explore use cases where the user is not likely to put in much effort beyond a focus on satisfying the functional needs, e.g. study or office work, where the lighting need is task-oriented rather than customization.

Tangible Lights is designed as individual, manipulatable spotlights inspired by the tangible interaction paradigm. To keep this effect, it is necessary to perceive the edges of a cast light. As the living environment often uses diffused lighting, we have sought to make each light appear more natural by adjusting the projector by softening the focus adjustment and applying a gradient to the edges of the cast light. As a result, we found a balance between blurring the edges and yet still support the recognition of individual spots.

Through evaluations we have observed several users adding elements of playfulness, such as sliding or "throwing" cast lights around the table or by other means adding some "life" to the lights. We agree that this might allow for delightful experiences. Thus, in the near future we wish to explore how implementing subtle behaviors might add to the interaction experience. Further, we will explore the social dimension of the interface, as current evaluations have already hinted at various opportunities to support interesting and playful experiences.

Lastly, we see a potential in exploring how controlling the lights via gestures at the table can be integrated with the existing home lighting. This includes outlining how gestures performed above the tabletop can affect other areas of the home, which arguably accounts for a large part of setting an atmosphere. Moving the in-air control away from the table and into other areas of the home provides yet another path for further exploration.

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Appendix 2. Contextmapping, sensitisation activity

Dear *[participant]*,

Thank you for participating in our workshop as a part of our master's thesis.

The workshop will be held at *[anonymised location]* Aarhus N between 10 – 12 am, at *[date]*.

The subject for the workshop will be lighting in the home, and the situations where light is used. During the workshop, there will be activities regarding situations with light. However, as a small warm-up exercise, we ask you to do the following activity prior to the workshop:

1. Take pictures of all your light sources (lamps, candles, mood lighting, etc.) found in your home and their controls (switches, regulators, dimmers, etc.)
2. In a few sentences, express where the light source is being used, in which occasions, social contexts, time of day, location in the home, or other considerations relating to this light source. If the light source is used in various situations, please note these. Afterwards, please email us the pictures with the accompanying text, e.g. in a Word-document or Google Docs, before the workshop on Friday *[emails]*

Thank you in advance.

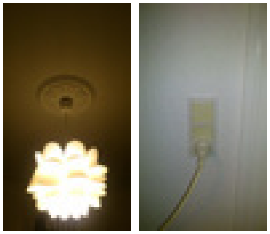
PS. There will be coffee, tea, and cake at the workshop.

Regards,
Tor and Oskar

Appendix 3. Contextmapping, sensitisation responses

Participant 1, male, 25

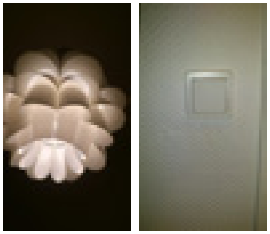
Ceiling lamp in the living room (regular on/off switch near door). Used daily when watching tv, read, surf on my computer. If having visitors, it supports the feeling in the room. Not always necessary to have it turned on, but it becomes easier to see and it feels pleasant with light in the room



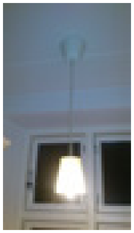
Tea light in designer in candlestick in the window (matches/lighter). Has not been in use yet, but is used to create a good feeling in the room. The candlesticks is made of glass and can contain different things of your choice, and also the tea lights, even though I have not used them yet.

The ceiling lamp in my flatmate's room (regular on/off switch near door). Used if we are watching something together on the computer or having a beer, if we have mutual guests, or whatever activities taking place

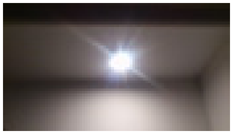
Ceiling lamp in the hallway (regular on/off switch near door). Almost never used because the room is so small and the light from the rooms are enough to light up the room anyway.



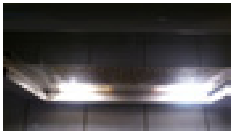
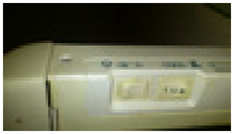
Ceiling lamp in the kitchen (regular on/off switch near door).Used only while cooking and/or eating + cleaning




Spotlights near the small dinner table in the kitchen. (regular on/off switch near door).Used only for eating or if you forget which switch controls the lamp, and which controls the spotlights, and you end up switching on both

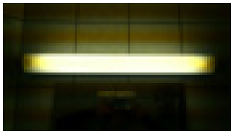


Light below the cooker hood (on/off button on the side of the cooker hood). Used for cooking.

Light in the oven (automatic when on). Used for cooking.

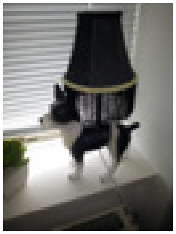
Light in the fridge (automatic when on). Switches on every time you open.



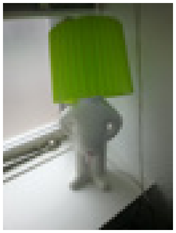

Ceiling lamp in the bathroom. (regular on/off switch in the kitchen!!!). Used when you are in the shower or on toilet

Participant 2, male, 27

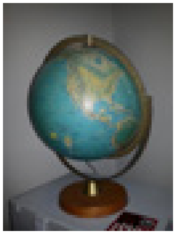
Lamp in the living room. It is used to provide a cosy atmosphere. I gave it to my girlfriend. Turn the button to use it.



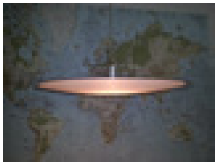
Lamp in the living room. ”Mr. P”. It is used to provide a cosy atmosphere. I received it as a gift from my girlfriend. On/off switch is his …. yeah.



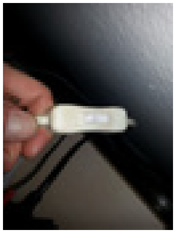
Lamp in the living room/Globe. It is used to provide a cosy atmosphere. Found in a rubbish dump in my neighbourhood and brought it home as I thought it was OK. A switch to turn on its lamp.



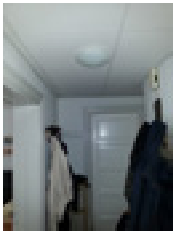
Lamp above the dining table. Used daily for normal lighting in the living room. My girlfriend and I have received it from her mother. Just a normal switch is used to turn on the lamp.

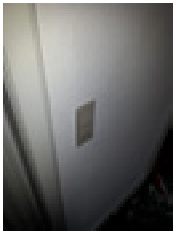


Lamp in the living room. Often used every day to give light to the living room as it can power a bigger bulb, and it was cheap when I bought it as a student back in 2006. I bought 2 of the same lamp but only one still works. On/off switch for the lamp.

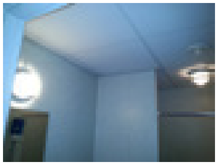


Lamp in the hallway. Was installed when we moved in and it is used daily. Switch for the lamp.

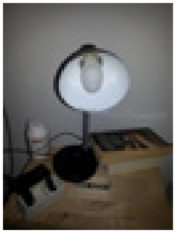




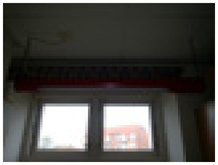
Bathroom lamp. Just some pictures of the bathroom lamps. They were there when we moved in. They are used when we visit the bathroom. Switch for turning on the lamps.

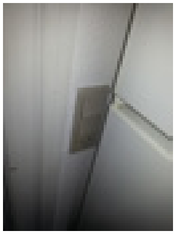


Bed room lamp. The only light source in our bedroom. It is turned on and off on its base. This lamp was bought in IKEA eight years ago because it was cheap but it still works.



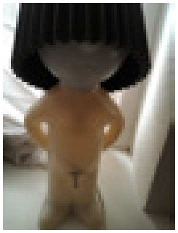
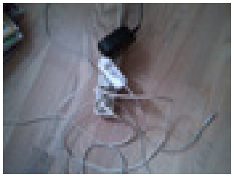
Lamp in the kitchen. Was installed when we moved in but is used every day. Switches for on/off.



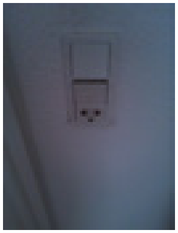


Participant 3, female, 24

My evening lamp. I use it if I read before going to sleep.

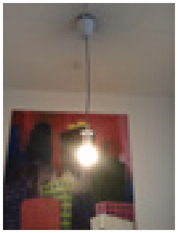



The lamp in my room. I use it when it is dark ;)

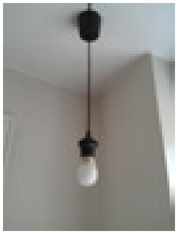



Lamp in the living room. Cosy light when we watch TV.

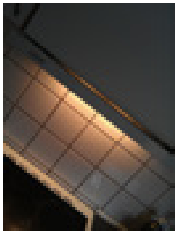

Lamp above our dining table in the living room. Used when we eat, have guests, have parties, etc.



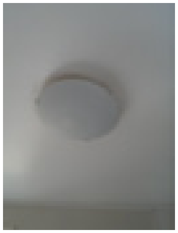

Lamp in the kitchen. Used when we are doing the dishes, cooking, and so on.



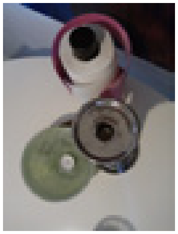

The cooking hood is used to give a cosy atmosphere in the kitchen, because the other lamp is slow to provide a proper light.



Lamp in the bathroom, used when it is dark ;)

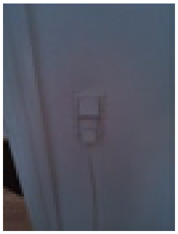
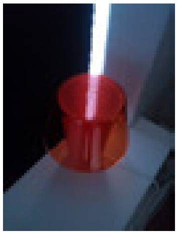
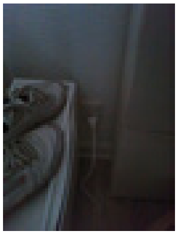



Candlelight in the kitchen, used when we are having a good time by cooking food, or having guests. This way, the whole flat gets a cosy atmosphere, even though we are probably only staying in the living room.

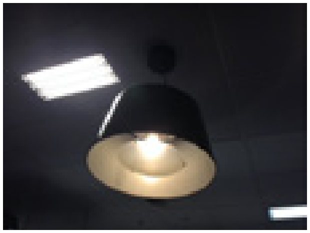


Candlelights on the dining table, used for cosy domesticity.

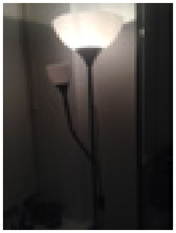
Louise's (flat-mate) lamps, which I do not use that much.

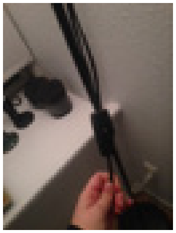





Lights in a family restaurant (workplace).We use the lights in the kitchen and in parts of the restaurant, as we have a large window section surrounding the restaurant, which also lights up the restaurant. The first button can turn all lights on at the same time, while the next three buttons turn different individual lights. The rest is for the kitchen appliances.

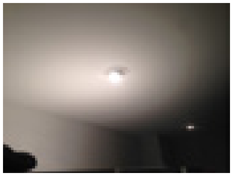


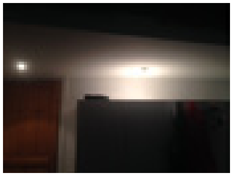
Light in my room. Used daily as my spotlights can't even light up half of my room. I live in the living room and thus lights from the windows are not an option unless sharing my daily life with peeping Tom.





The light in the other half of my room. Almost never used as my cupboard blocks most of the lights anyway. The top switch is used to turn on the lights. The two switches below have no purpose.





Appendix 4. Contextmapping, session outline (workshop)

Note, this is the researchers' outline for the workshop (2 hours planned activities)

Intro

- Greeting and welcoming the participants
- Welcome speech
    - Calm people down, ensuring how the focus of the workshop is not to test the participants in any ways
    - Say Thank you for you participation in our workshop on situations with light in the home.
    - Provide coffee and biscuits
- Inform participants about the agenda
    - Exercises 1, 2, 3
    - Debriefing

Exercises

Exercise 1 – Warm-up

Present a print-out of the received responses (images and accompanying text) following the home exercise (sensitisation stage). Discuss the following aspects for a selection of the images

- Practical considerations regarding this light
- Mobility. How often do you move the light or is it in a fixed location?
    - If so which situations and for what purpose?
    - What if it is not being used?
- Situations when this light is used.
    - Categorise situations (everyday activity, party, etc.)
    - Number of person and their relationship to you
    - How do this/these person(s) affect the situation?
    - Have you used different light sources in similar situations (alternatives)?
    - Is it used for different purposes/activities?
    - When do you turn off the light? (sleeping time, fire hazard, safe money, too hot)
    - Any last concerns or stories about this particular light source?

Exercise 2 – Preparation phase

Special situations for interaction with existing lighting systems.

- In groups of two, create two imaginative scenarios for each group
    - First, where family members OR friends are invited for dinner (choose)
    - Second, where celebrities (Gustav and Linse) OR the Queen of Denmark is invited for dinner (choose)
- For each scenario, consider the light arrangements
    - Which lamp? Why this kind of lamp?
    - Where the lamp should be placed?
    - What colour would suit the situation?
    - Use the cut-out inspiration pictures to exemplify light settings for the scenarios

Exercise 3 – Future ideas for a Philips Hue controller

Show off the Philips Hue system and let the participants get a first-hand impression of novel lighting interaction.

Grounded in knowledge on this system, now redesign the Philips Hue system for your home where you cannot use an app (e.g. it is broken).

- Obstruction assignments
    - Only using feet, speech, tangibles - no smartphone interaction
- "Inspiration cards", available at the session
    - Cut-outs of controllers, dimmers, sliders, buttons, etc.
    - Cut-outs of colour charts, colour pickers
    - DIY lamps and visual effects
- Props and crafting material, available at the session
    - Lamps (Floor lamps, table lamps, wall lamps)
    - Bulbs (Incandescent, fluorescent, painted, power-saver, Philips Hue)
    - Wires (Arduino)
    - Cut-outs of controllers, dimmers, sliders, buttons, etc.
    - Electronic switches (Arduino)
    - Tape

Debriefing

- Thank you for your participation
- Sum up important and interesting findings identified throughout the workshop

Appendix 5. Interview guide, long-term Philips Hue users

Semi-structured interview guide

- What meaning does light generally carry in your home?
- How much do you know about light theory?
- What was the motivation for acquiring the Philips Hue system?
- What was the solution before Philips Hue?
- How often is the Philips Hue system used during the day/week?
  - Manual and automated?
- In which situations are the Philips Hue presets used?
- In which situations are the Philips Hue automatically controlled?
- Can you give us a step-by-step guide of how you interact with the Philips Hue app?
- Are there any issues relating to the app? Can you compare it to the traditional wall switch?
- Which situations does the Philips Hue fit? And which does it not fit to? What is the reason for this?
- Do you see any conflicts when having two ways to interact with the lights? (Hue and traditional switches)
- (if relevant) How do you experience the fact that the lighting now both provides a means of general illumination, and the next moment it conveys external information, such as weather, time, notifications, etc.? (IfThisThenThat integration)

Reflection

on the lighting use

Take a picture of the activity that takes place around the table. Afterwards, please answer the questions below, shortly. Send the picture and text in an MMS to

[phone number]

- Which activity does the picture describe?
- Who/how many participated in the activity?
- Which role did the light serve in the activity?
- (Other? Please specify)

Thanks for your help,
Tor Sørensen & Oskar D. Andersen