MASTER

The design and evaluation of control solutions for dynamic light effects in consumer homes

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The Design and Evaluation of Control Solutions for Dynamic Light Effects in Consumer Homes

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“Everything should be made as simple as possible, but not simpler.”

- Albert Einstein
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Home Ambience Creation, Dynamic Light Effects, Light Control, Light Customization, LED, User Satisfaction, Perceived Control.

Preface

This Master Thesis is the product of my graduation project, which is part of the Master’s program in Human-Technology interaction. This project was executed in collaboration with Philips Research, on the topic of user interaction with dynamic ambient lighting systems for consumer homes. During this project I investigated the effects of types of dynamic lighting effects and control solutions on user satisfaction. More specially, this research addressed the following research questions: 1) Which of the tested control interfaces (i.e. varying in the amount of control options on the user interface) was preferred by users to interact with different dynamic light effects? 2) For the different dynamic light effects, which of the tested control interfaces resulted in the higher user satisfaction? 3) How do perceived system features affect user satisfaction? Furthermore, at the end of the study, I reflected and proposed several design suggestions for future user interaction designs in the relevant areas. I got excellent supervision and very valuable advice from my supervisors at Eindhoven University of Technology and Philips Research. I would like to thank Wijnand IJsselsteijn and Antal Haans, and my supervisors at Philips Research, Bernt Meerbeek and Pieter Seuntiens. Furthermore I would like to thank the colleagues from Philips, Dragan Sekulovski and Ramon Clout, for their contribution in the creation of the dynamic light effects and the light source. I would like to thank Jettie Hoonhout, for her important and helpful advice on the questionnaire design. Finally I would like to thank all my friends and my family for their support during this project.

Yefan Wang

Eindhoven, September 2015
Summary

In this study, we evaluated three control interfaces (varying in the amount of control parameters on the user interface) with three dynamic light effects (mimic nature: Candle, Fire and Water) in a home-living lab environment. It was found for different dynamic light effects, people differed in the preferences of the control interfaces. But in general people tended to prefer more detailed control at parameter level rather than an integrated control predefined at effect level in the ambience creation with dynamic light effects. Suggested by the data, people seemed to be more satisfied with Fire and Water effects than Candle effect. Moreover, we found the importance to have personal control over various parameters of the light effect also different. The hue, brightness and speed options were rated as more important to have personal control over, compared with the parameters size and saturation regardless of the types of light effects. Finally we found perceived attractiveness and perceived control play an important role in determining user satisfaction with dynamic ambient lighting systems.

The results suggest that for ambience creation using dynamic lighting, people are willing to put more effort in creating their satisfactory lighting conditions. To simplify the user interaction using integrated control (controlling multiple underlying parameters with single key parameter) is quite challengeable at the moment since it may lead to a lack of control felt by users and less satisfactory results people could achieve. It is desired by users in looking for a simple and quick way to create a satisfactory lighting condition, however the simplicity of the interaction should not be at the sacrifice of the results people could achieve to meet their needs, especially for ambience creation. Several design implications are provided at the end of the thesis, aiming to inspire more effective designs of control to support dynamic ambient lighting systems in maximizing the user satisfaction.
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Chapter 1

Introduction

Advancements in the modern lighting technologies such as Light Emitting Diodes (LEDs) offer increased possibility in controlling a variety of light parameters such as intensity and color, opening up a wide range of lighting opportunities in enhancing the human experience of light and benefiting people's everyday life. It is now possible to create various ambiences and atmospheres for homes simply through dynamic lighting scenes. For example, Philips Hue as one of the first smart bulbs on the market that offers flexible light setting to users and allows people to adapt their home lighting to various needs and moods.

However, it also introduces new challenges in the user interaction with these highly flexible lighting systems. The increased degrees of freedom creates a huge amount of parameters to control, which requires us to rethink the existing interaction paradigms for lighting control. The current lighting controls such as on/off centralized switches or dimmers no longer seem suffice to support these dynamic lighting services. It calls for new control strategies that can effectively support dynamic ambient lighting systems in maximizing the user comfort and satisfaction while simplifying the user interaction with the system or the environment (Aliakseyeu et al., 2014).

Control over such novel lighting systems can be automated. However, many studies also show that giving people control over the lighting in their workspaces can increase productivity and satisfaction (Newsham & Veitch, 2001; Boerstral, Beuker, Loomans & Hensen, 2013). Furthermore, studies show that increases in perceived freedom and perceived control (i.e. the available options and the belief that one is capable of influencing and making a desired difference on the situations) increase satisfaction with the built environment (Barnes, 1981). Moreover, it can be argued that control over lighting levels in our environment is part of the basic human needs of competence and autonomy, as postulated by one of the basic theoretical frameworks on human motivation, the self-determination theory (Deci & Ryan, 1985), together with relatedness, competence and autonomy offer the highest quality forms of motivation and engagement for activities. The competence dimension in SDT relates to the need to control outcomes in one's life, leading to an experience of mastery. The autonomy dimension reflects the need to be a causal
agent in one’s own life, and integrate experiences in harmony with one’s self. Even though one may argue that control over interactive lighting constitutes only a tiny fraction of the aforementioned basic human needs, not having an appropriate level of interactive control over one’s immediate home environment may significantly frustrate the needs for autonomy and competence. Both these empirical findings and theoretical insights seem to suggest that giving people control over their lighting system, and consequent atmosphere, can increase users’ feeling of being in control, thus enhancing user comfort and satisfaction.

However, most of research related to this topic has been focused on the contexts of office working environments. Though it is logical to assume that in home environments, the desire of personal control over ambient lighting would be much higher than in the office environments, it is also expected that the interaction with the lighting system should be as simple as possible for the daily use. There seems to exist a tradeoff between control freedom and ease of use, and a tradeoff between user control and automation. Parasuraman (2000) proposed a model of human interaction with automation and indicated that automation clearly can play a positive role in simplifying the interactions with a system, however, at the expense of user control. User control may still be implemented at a more aggregate or supervisory level, but exactly how much control users are willing to sacrifice is an empirical question.

In conclusion, it is still unclear about people’s preferences of control solutions (e.g. digital vs. tangible, integrated vs. detailed vs. hybrid, user control vs. automated) that can obtain higher satisfaction with dynamic ambient lighting systems (DALS). This lack of knowledge may inhibit the application development of next-generation dynamic lighting concepts for the homes of the future. And there is a need for new control solutions to support DALS in maximizing the user satisfaction and more research is required to investigate user control preferences for DALS.

In this study, we therefore aimed to identify people’s desires and preferences regarding DALS in consumer homes and investigate the factors contributing to user satisfaction. More especially, we focused on a pixelated colored RGB LED strip, which can be easily to be digitally controlled, and can create dynamic light effects with more natural patterns in the light content such as fire and water, more than just adjustable colored lighting. Ultimately we aimed to provide relevant design implications and contribute to the development of more effective control solutions that can open up opportunities of dynamic light effects to consumer homes.
In this thesis, we first introduce several research studies that related to our research (Chapter 2). Then, we describe the process of concept development, including the design of dynamic light effects and controls, and the definition of the control mappings (Chapter 3). Third, we explain the methods that we used for the study (Chapter 4). Last, we report the results together with the analysis (Chapter 5), and the design implications and reflections (Chapter 6) and finally the conclusions and discussion (Chapter 7).
Chapter 2

Theoretical Background

2.1 Introduction

This chapter provides the background knowledge for the current study. Section 2.2 introduces our prior research, in which we explored the possibilities and challenges for adopting dynamic lighting in consumer homes and the findings useful to this study are presented. Section 2.3 to section 2.7 will expand on several research findings and theories that cover different aspects of the current study. Section 2.8 present our research framework outlining the scope and structure of this study. Finally, section 2.9 defines the main research questions and hypotheses.

2.2 Prior Research on Dynamic Lighting for Consumer Homes

Before starting this project, we conducted a 9-day cultural probes research exploring the possibilities and challenges for dynamic lighting systems in consumer homes (Wang, Meerbeek, Seuntiens & IJsselsteijn, 2015). The results indicated that people vary on their needs and preferences of lighting for different occasions, which are highly dependent on the characteristics of the context (e.g. activities, time of the day, location) and the individuals (e.g. personal taste and beliefs). For instance, some people wanted dimmed lighting in their bathrooms at night for relaxation, while in the morning, they preferred bright lighting for energizing. It was found that in general people appreciated natural light effects such as sunrise, as well as the lighting scenes that could bring the feeling of nature. However, once people perceived the light effect as a fake imitation, their satisfaction decreased. Therefore, we expected the perceived naturalness of the light effect to be one important factor that affects satisfaction. Other factors observed from the prior research includes perceived usefulness of the system (e.g. whether the lighting system can bring extra values to homes), perceived beauty/pleasantness of lighting (e.g. whether the light effect is beautiful and pleasant), perceived coherency with the context of use (e.g. whether the lighting system can fit the interior), the level of arousal required by lighting, and perceived consistency with the individual characteristics (e.g. personal taste).
When asking people about their concerns on the adoption of dynamic lighting systems in their homes, many mentioned they could not see the benefits of using dynamic lighting in their homes (especially when they need to invest more money on it). And they were afraid that dynamic lighting would dominate the space (e.g. disco light effect) and the operation of these lighting systems would become complex. As for the opportunities, many participants were willing to have more control options, such as to dim and/or to change the color temperature of the light (e.g. warmer or colder), and to have dynamic lighting scenes adapted to the present situations and support different purposes (e.g. relaxation, activation, romance).

In conclusion, the prior research suggested that 1) people's needs and preferences on lighting were dependent on the characteristics of the context and the individuals, and 2) several factors were found likely to affect user satisfaction with the system (e.g. perceived naturalness, perceived beauty, perceived usefulness), and 3) people were willing to have more control over their environmental lighting, but 4) they were worried about the increased complexity in the interaction with these novel lighting systems and 5) they did not want too much arousal in lighting.

In this study, with a particular interest on the interaction aspect, we wanted to further study user preferences regarding DALS in home environments, and we wanted to examine some of the factors suggested by the prior research (i.e. perceived naturalness, perceived beauty of the light effect, perceived usefulness and perceived ease-of-use of the system) and investigate to what extent they play a role in determining user satisfaction with DALS.

### 2.3 Study in User Interaction with Everyday Lighting in Homes

Very few studies have been performed on the user experience and preferences of the interaction with dynamic light effects in the context of home environments. However, we noticed one related study done by Offermans, Essen and Eggen (2013), in which they conducted a user study aiming to understand user desires regarding the lighting in homes and the interaction with it. They concluded that it was important to support the user with varying levels of control, depending on the context of use. Most often people wanted quick control when the lighting is functional, however in some cases, more subtle and detailed control was desired, for example, while in creating an atmosphere people were willing to put more time and effort. Moreover, they noticed
that the control interface itself played an important role on the user motivation to interact with lighting, mainly from the aspects of the degrees of freedom and availability in control, the level of automation and other interaction qualities (e.g. experiences of fun, magic and competence). They defined two main parameters that determines the level of control freedom: the number of adjustable parameters per light and the amount of lights that could be controlled by the user. And they demonstrated that the availability of control (determined by whether the adjustment is available in the light itself and whether the controller to support the adjustments is available) may be even more important than the obtained results. As for the intuitiveness of the user interface, they noted that when the control mappings were consistent such as sliding for more or less light, was considered intuitive.

However, they did not provide more insights on how to approach the control mapping problem between the human and technical parameters, and through which control parameters the customization should be offered, these were yet unclear. And the parameters of the light effect studied in previous research were quite limited. Thus they confirmed the need for further research on exploring the solutions that support more degrees of freedom and control availability. The data they collected were the result of thirteen participants' subjective reflections during the workshop sessions, which were quite self-motivated and design oriented. No quantitative measurements nor statistical analysis were used to indicate to what extent their findings could be generalized.

Therefore in the current study, we decided to evaluate different control interfaces with various dynamic light effects in a controlled but still naturalistic environment, and we collected the user feedback via questionnaires and interviews. We wanted to figure out at how much control was desired by users for different dynamic light effects and on which parameters of the dynamic light effect the personal control should be provided.

### 2.4 Perceived Naturalness and Naturalness Bias

In our prior research, it was found that people preferred natural light effects or light effects that could be associated with nature. This so-called naturalness bias - a cognitive bias towards preferring the natural option is actually not new and has been observed in other fields. For instance, people prefer cosmetics that are directly taken from nature; people purchase products that appear more natural (e.g., use more natural materials). Consistent with our previous finding,
Haans (2014) concluded in his study that such kind of naturalness preferences existed as well in the people’s appraisal of light. The results from his research has indicated that naturalness has a consistent meaning related to light, and is influenced by the light source (e.g., artificial light bulbs or sun) and the way the light enters a space (e.g., through a window or a hole in the wall). Therefore, in this study, we considered perceived naturalness of the light effect as a factor that may play a role in user satisfaction with DALS.

2.5 Perceived Control and Satisfaction

The absence of control, even in situations that are not stressful, may lead to feelings of unhappiness and powerlessness (Averill, 1973; Burger, 1989). Many studies have shown that perceived control seems to be very important to construct satisfaction, which was already discussed in the previous chapter. Here we want to present more notions regarding perceived control.

In the definition given by Paciuk (1990), perceived control is one of three components that constructs personal control; the other two are available control (i.e., the degree and type of control made available by the system) and exercised control (i.e., the relative frequency in which people engage in the interaction with the system). Paciuk (1990) found that perceived control was related to both available and exercised control, and had a strong impact in shaping both the thermal comfort and satisfaction with a thermal environment. Exercised control seemed to exert a negative effect on satisfaction. We argued the causal chain may be reversed. For instance, if you are uncomfortable (e.g. not satisfied with the thermal environment), you are more likely to exercise control to change the condition. It was also found in his study that the available control enhanced perceived control and indirectly influenced satisfaction with a thermal environment.

However, such a conclusion is contradictory to the findings of Boerstral, Beuker, Loomans & Hensen (2013), which was also in the domain of thermal control. In their study, overall no significant correlations were discovered between available control and perceived control except the interventions of type of solar shadings. An increased in the availability of temperature controls (e.g. local vs. central or individual control vs. automatic) did not enhance perceived control over temperature. But they also pointed out that perceived control is especially important to the user comfort with the building performance. Hinds (1998) found that the extent to which a user feels in
control (i.e. perceived control) when using an interface is influenced by a variety of factors, including characteristics of the task, the context in which the task is being performed and the individuals. Furthermore, Newsham & Veitch (2001) found that participants who made the biggest changes to lighting conditions after the control was given tended to experience the biggest improvements in mood, satisfaction and those who made few changes showed no improvements.

Additionally, according to Hind's (1998) study, it appears that cultural background moderates the relationship between choice and perceived control regarding an interface. It was found that Westerners responded more positively to increased choice feeling more in control when more options were available whereas Asians responded negatively to increased choice feeling less in control when they had more choice. Furthermore, Westerners who were given more choice also reported the system was more difficult to use, while no significant difference was found in the responses of Asians on perceived ease-of-use regarding to increased choice, suggesting that controlling for culture, a tradeoff might exist between available control and perceived ease of use.

In conclusion, several research studies have suggested that perceived control seem to be very important in constructing satisfaction via interaction with a system. However whether there is a relationship between the actual available control and perceived control is still not fully clear and requires further investigation. Additionally, a tradeoff seems to exist between the amount of control choice and perceived ease of use, although these findings may be attenuated by cultural influences.

2.6 User Acceptance towards New Technologies

In addition to user comfort and satisfaction, we considered user acceptance towards new technologies as a premise to construct satisfaction. Therefore in this section, we will introduce the model of Davis et al. (1989), which they predict user acceptance and usage behavior by perceived usefulness and perceived ease of use. Perceived usefulness is likely to be influenced by perceived ease of use. Perceived usefulness is defined as ‘the extent to which a person believes that using a technology will enhance his/her productivity’ and perceived ease of use as ‘the extent to which a person believes that using a technology is free of effort’. Venkatesh (2000) proposed a theoretical framework that extends the original technology acceptance model by adding an anchoring and
adjustment perspective on the construction of perceived ease of use, see *Figure 1*. Perceived enjoyment represent 'the extent to which the activity of using a specific system is perceived to be enjoyable in its own right, aside from any performance consequences from system use'. It was found that perceived ease of use had a direct effect as well as an indirect effect via perceived usefulness, on intention to use the system showing that perceived ease of use is an important determinant for accepting new technology. Moreover, perceived usability, perceived control and perceived enjoyment from system use were found to play a role on perceived ease of use of new system through interaction. And with increasing experience, beliefs on computers and computer use were still a crucial factor in determining perceived ease of use.

![Diagram of Venkatesh's model (2000)](image)

*Figure 1: Venkatesh's model (2000)*

However, all these were discussed in terms of information systems. In the domain of light, things may be different because people can get instant visual feedback through direct experience with the light, hence the perceived control of a lighting system seemed to be obtained not only through
system operation (i.e. user manipulation of the lighting system), but may also be influenced by the created lighting condition. Therefore in the domain of DALS, the factors that will most strongly affect user acceptance and satisfaction with the system are still unknown and needs to be further investigated.

2.7 Understanding User Experience

Moving beyond usability and ease of use, Hassenzahl (2003) proposed to focus on the broader conception of defined user experience, which emerges as a consequence of a user’s internal state, the characteristics of the designed system and the context within which the interaction occurs. He proposed a model that used both pragmatic and hedonic attributes as key factors for determining appealing and thus satisfaction. Pragmatic qualities are defined as the “manipulation of the environment requires relevant functionality (i.e. utility) and ways to access this functionality (i.e. usability)”. Hedonic qualities were defined as “qualities of a product to be enjoyable and or pleasant and are not directly related to the task a user wants to achieve, but rather the originality and beauty of the product”. The model consisted of three layers: 1) objective quality 2) cognitive appraisal consisted of perceived quality and system evaluation 3) consequences of appraisal, see Figure 2.

Figure 2: Hassensahl's Model (2003)
2.8 Research Plan and Framework

Customizing home ambience using dynamic lighting is likely to become a common feature in homes of the future. However, only a few studies exist on user experience and individual preferences for such kind of lighting systems. And from the current literature study, we captured several factors that are likely to play a role in determining user satisfaction with dynamic lighting systems, namely perceived naturalness of the light effect, perceived beauty of the light effect, perceived attractiveness of the system, perceived control, perceived ease of use, perceived enjoyment, and perceived usefulness of the system. In this study, we wanted to further investigated to what extent these factors contribute to user satisfaction and capture the user desires and preferences regarding DALS for consumer homes. Therefore we designed and developed different dynamic lighting systems (Chapter 3), and evaluated the user experience during a controlled experiment (Chapter 4). Following this, we analyzed the data collected from the experiment and addressed our research questions (Chapter 5) and finally proposed the design implications and suggestions for future study (Chapter 6). To clarify our approach, we adapted the model of Hassensahl's (2003) and from which we developed a research framework (Figure 3) integrating the following aspects: 1) Two objective system features: types of dynamic light effects and types of control interfaces, in our case were three dynamic light effects related to nature and three control interfaces varying in the amount of objective control; 2) Measures of perceived system features about the light, the control and the overall system; 3) Measures of user attitudes, including satisfaction and willingness to recommend.
2.9 Research Questions and Hypotheses

In this study, we aimed to address the following main research questions, all in the context of dynamic ambient lighting systems (DALS) in consumer homes.

1. Which of the tested control interfaces (i.e. varying in the amount of control options on the user interface) was preferred by users to interact with different dynamic light effects?

   *In our case, we tested three types of dynamic light effects (i.e. Candle, Fire and Water), and three types of control interfaces varying in the amount of control options enabled by the user interfaces (i.e. an integrated control option at effect level or more detailed control options at parameter level), in a living room environment.*

2. For the different dynamic light effects, which of the tested control interfaces resulted in the higher user satisfaction?

3. For the different dynamic light effects and control interfaces, which parameters (e.g. speed, brightness, size, saturation and hue) were rated as more important to have personal control over?

4. How do objective system features (e.g. types of dynamic light effects and control interfaces) affect user satisfaction?

5. How do perceived system features (e.g. perceived enjoyment, perceived control) affect user satisfaction?

   *In particular, we would like to examine:*

   5a. Whether there is a positive correlation between perceived naturalness of the light effect and user satisfaction?

   5b. Whether there is a positive correlation between perceived control and user satisfaction?
5c. Whether there is a positive correlation between perceived ease-of-use and user satisfaction?

5d. Whether there is a positive correlation between perceived usefulness and user satisfaction?

Our hypotheses are:

**H1.** People prefer the interface that offers more control options.

*Rational:* People want more control over the lighting in homes for ambience creation.

**H2.** With the interface that offers more control options, people achieve higher satisfaction with DALS.

*Rationale:* Giving more control to users is more likely to contribute to higher perceived control of the system, thus leading to higher user satisfaction. Moreover, previous research has indicated that for atmosphere creation, people are willing to put more effort and time in obtaining better results.

**H3.** People want personal control over speed and brightness.

*Rationale:* From prior research, it was found that people preferred dimmable lighting for relaxation and disliked fast changing lighting that may dominate a space. We expect these two parameters are rated as most important ones people want to have control over.

**H3a.** The type of dynamic light effect has a main effect on user satisfaction. More particularly, people are more satisfied with Candle or Fire effects, than Water effect.

*Rational:* Based on the results of previous context-mapping study, people preferred warm and cozy light effects such as candles, fire and sunrise, in a living room environment for relaxation. And the water effect seemed to be more suitable for a bathroom.
**H3b.** The type of control interface has a main effect on user satisfaction. More particularly, higher user satisfaction can be obtained with the interface offering more control options. *Rationale* is same as we described in H2.

**H4a.** Perceived naturalness positively affects user satisfaction.

**H4b.** Perceived control positively affects user satisfaction.

**H4c.** Perceived ease of use positively affects user satisfaction.

**H4d.** Perceived usefulness positively affects user satisfaction.

**H4e.** Both hedonic and pragmatic aspects of the system perceived by users plays an important role in determining user satisfaction.

*Rationale:* H4a – H4d are implied from the findings of our prior research and other related research work as we explained in the section 2.2 to section 2.6. And H4e is supported by Hassensahl’s model (2003).
Chapter 3

Concept Development

3.1 Introduction

This chapter presents the concept development for three types of dynamic light effects, and three types of control interfaces. Section 3.2 describes the concept generation and content creation of the three dynamic effects, and section 3.3 presents the prototyping for different light control interfaces. Last in section 3.4, the mappings underlying the control options for individual parameters of the dynamic light effect are introduced and explained.

3.2 Designing Dynamic Light Effects for Specific Context

- Defining Design Goals and Context of Use

The results from previous context mapping study showed that a living room is a multi-functioned space where different user activities might take place, for example, watching TV, playing games, reading, and socializing with visitors and such. Moreover, it was reported as a place where different moods and atmospheres were needed for a variety of purposes, such as relaxing after work, socializing with friends, etc. The multi-functional nature of the living room make it suitable for introducing dynamic light effects to create richer and adaptive ambiences that support various activities. Therefore we decided to design a dynamic ambient lighting system for a living room environment.

- Designing Contents of Dynamic Light Effects
Literature has suggested that people tend to prefer nature related concepts. The results from our previous research (the results from video and photoset evaluations) supported this view as well. Specially, people appreciate natural scenes or natural light effects (e.g. milk way, water, candlelight, sunrise, fire) more than effects that appeared artificial or induced negative associations (e.g. disco lights, or moving shadows). Figure 5 shows the light scenes appreciated by people for a living room with associated atmospheres specified. In which people demonstrated a preference for natural sunlight, romantic candle lights, harmonious colorful lighting scenes and fireplaces. In general, people wanted natural, warm and cozy lighting for their homes.

Figure 4: Desired dynamic lighting scenes for a living room

Given users’ preferences for natural effects and the effects we could make with our LED lighting, we decided to develop three dynamic light effects for this study – Candle light effect, Fire effect and Water effect. The reasons why we chose these three specific effects were: 1) candles are often used when people need some romantic and cozy atmosphere in their homes such as when having a romantic dinner; the effect can be mimicked with an LED light source; and since it can be controlled digitally, it has more possibilities and can be more convenient and safer than a candle. 2) The concept of fire or fireplace is familiar to people since many people install fireplaces in their homes, because it gives the feelings of warmth and coziness; it was expected fire effects on an LED lighting
device can be an alternative to a real fireplace. 3) Many people believe that water has calming effect that can help clear one’s mind and relax, thus it seemed also suitable for a home environment.

Three dynamic light effects were implemented on a pixelated RGB LED strip (a length of 150 cm and a width of 1 cm approximately). The Fire and Water effects were basically rendered by behavior models learned from the footages of real natural effects (Sekulovski, Clout, Kater & Overbeek, 2009). The Candle effect was adapted from the Fire effect, with some adjustments made in the color scheme and the effect size. In particular, the Candle effect consisted of five separate candles with a ball shape flame, aligned in one line horizontally with an equal spacing in between (Figure 5). The Fire effect created a continuous flame pattern, just like an open fire (Figure 6). The Water effect presented a natural scene of rain falling on a pond and cause a ripple in the water (Figure 7). The codes that generated the dynamic light effects were uploaded to a Teensy board connected to the light source and could be further controlled via programs.

Figure 5: Candle Lights Effect

Figure 6: Fire Effect

Figure 7: Water Effect
3.3 Designing Control Solutions and Prototyping Control Interfaces

As an explorative study in searching for effective control solutions that could facilitate users in the interaction with different dynamic light effects and achieve higher satisfaction, we were interested to first address the following questions: 1) at what level of freedom and availability in control is required by users for various light effects and furthermore, 2) on which parameters of the dynamic light effect do people want personal control. Therefore the general design direction was to deliver control interfaces with different levels of control freedom and availability.

In order to have a clean comparison between different controls for our experiment, we decided to minimize the potential impact from the visual and aesthetic aspects of the user interface. Therefore we standardized the visual part, keeping all presentation aspects of the tested control interfaces consistent. Finally we designed three control interfaces, ranging from integrated control over the overall effect to detailed control over individual parameters. That is, from one control slider labelled with “Effect”, to three control sliders labelled with “Speed”, “Brightness”, and “Size”, and to five control sliders labelled with “Speed”, “Brightness”, “Size”, “Hue” and “Saturation”, hereinafter these control interfaces are referred to as Control A, Control B, and Control C respectively. The user interfaces thus varied on the amount of control options displayed on the control panel, see Figure 8, 9 and 10.
Figure 8: Control A

Figure 9: Control B

Figure 10: Control C
Besides the control sliders, we also included two buttons “RESET” and “SAVE”. The RESET button enabled users to restore a default setting with all values set to the middle (50 % of the range) of the control slider. And the SAVE button allowed users to save their own designs to the database, however, the saved user defined schemes were only stored on the back-end for our analysis, they were not visible for users.

All these graphic user interfaces were created by the software Processing and were exported to a standalone executable that could directly run on a Windows platform. In our experiment, we used a touchscreen Windows tablet PC (Fujitsu STYLISTIC Q550, 10.1”, capacitive multi-touch, resolution selected: 1280*800) and it was connected with the light source via a long USB cable so that the participants could sit on the couch and held the tablet in their hands or put it on their knees as they preferred. By running different control applications, the corresponding user interfaces were displayed on the provided tablet as the control for participants to interact with the light effect (Figure 11). And all these control sliders and buttons were pretested to ensure that they were easy to operate for users with big fingers as well.

![Figure 11: Tablet control](image)
We also created some other designs on platforms (e.g. control from a mobile or a website) and using different control strategies (e.g. group the control panels for different light effects into one interface), however, based on the final design of our experiment, and considering both the issues of device responsiveness and naturalness in the interaction, we used the three interfaces described before for the test. The other design ideas are presented in Appendix A.

3.4 Defining the Control Mappings

The Control A (i.e. one control slider labelled with "Effect") was designed to allow users to control the light effect with one single key parameter in a holistic and highly integrated way, from very a very subtle to a much more obvious effect, changing several underlying parameters (e.g. speed, brightness, size and color) in the light dynamics simultaneously. For example, for Candle effect, the participants could control a line of five individual candles simultaneously, from a dimmed reddish and relatively static lighting condition to a brighter yellowish and flickering effect. For Fire effect, it was similar to the mapping for the candle but bigger in the effect size, more like an open fire, from very subtle and small to more wild and big flames. For Water effect, the effect could transfer from a very calming and peaceful water surface to more lively scene that had more ripples on the surface caused by an increasing amount of raindrops.

The Control B (i.e. three control sliders labelled with “Speed”, “Brightness” and “Size”) enabled people to have separate control over the individual parameters of the light effect, namely speed, brightness and size. With these three control options, the individual could adjust the speed of effect transition, light intensity and size of the effect (for Candle and Fire effects the slider ‘size’ was controlling the flame size and for Water effect it was controlling the amount of the raindrops).

The Control C (i.e. five control sliders labelled with “Speed”, “Brightness”, “Size”, “Hue” and “Saturation”) added the color change option, compared with Control B. Hue is one of the color parameters representing the “degree to which a stimulus can be described as similar to or different from stimuli that are described as red, green, blue and yellow” (in the CIECAM02 model), and saturation is the colorfulness of a color relatively to its own brightness, which is determined by a combination of light intensity and how much it is distributed across the spectrum of different wavelengths. See Figure 12 for more intuitive understandings of the concepts.
We designed Control A with a goal that by adopting a single key parameter control, which was highly integrated inherently but appeared just as intuitive as a traditional light dimmer, simplifying all detailed tuning what should otherwise be a complicated process. The objective for designing Control B was to provide more control possibility over the individual parameters that could be adjusted by users themselves, however, to keep the effect as natural as we designed, we did not give the color change option to users. With Control C, we authorized the color control to users so that the light effect could vary in a full range of colors, for example from reddish to blueish, which could be more colorful but maybe less natural. Table 1 shows the control mappings between the user interface (UI) and the technical parameters of the light effect, the actual values for these mappings are not reported in this thesis for the confidential reason.

<table>
<thead>
<tr>
<th>Control A</th>
<th>Control B</th>
<th>Control C</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Effect”</td>
<td>“Speed”</td>
<td>“Speed”</td>
</tr>
<tr>
<td></td>
<td>“Brightness”</td>
<td>“Brightness”</td>
</tr>
<tr>
<td></td>
<td>“Size”</td>
<td>“Size”</td>
</tr>
<tr>
<td></td>
<td>hue</td>
<td>hue</td>
</tr>
<tr>
<td></td>
<td>Saturation</td>
<td>“Hue”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Saturation”</td>
</tr>
<tr>
<td></td>
<td>speed</td>
<td>speed</td>
</tr>
<tr>
<td></td>
<td>brightness</td>
<td>brightness</td>
</tr>
<tr>
<td></td>
<td>size</td>
<td>size</td>
</tr>
<tr>
<td></td>
<td>hue</td>
<td>hue</td>
</tr>
<tr>
<td></td>
<td>Saturation</td>
<td>saturation</td>
</tr>
<tr>
<td></td>
<td>Default values for hue and saturation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: control mapping between the UI and technical parameters of the light effect
Chapter 4

Methods

4.1 Experiment Design and Manipulations

A three (3 dynamic light effects: Candle vs. Fire vs. Water) by three (3 control interfaces: Control A vs. Control B vs. Control C) mixed design was run with types of control interfaces as within subjects variable and types of dynamic light effects as between subjects variables, thus in total we had 9 tested conditions (Table 2). With more of interest in individual preferences on the interaction with dynamic light effects, we designed types of control interfaces as a within subjects variable. And to minimize the fatigue and/or boredom in the participants, we designed types of dynamic light effects as a between subjects variable.

<table>
<thead>
<tr>
<th>Types of dynamic light effects between subjects</th>
<th>Types of control interfaces within subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Candle (20 subjects)</td>
<td>Control A</td>
</tr>
<tr>
<td>Fire (20 subjects)</td>
<td></td>
</tr>
<tr>
<td>Water (19 subjects)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Overall design of the experiment

The participants were randomized due to the nature of the recruitment process and were assigned to one of the three light effect groups. We first tested with the Candle effect, followed by the Fire effect, and lastly the Water effect. The three control interfaces were experienced by all participants, and the test order was fully counterbalanced (e.g. Control A- Control B- Control C, Control A- Control C- Control B, or Control C- Control B- Control A etc.). Therefore the manipulations in this experiment were the three types of light effects that mimic nature (i.e.
candle vs. fire vs. water) and the three types of control interfaces that vary on the available control options on the user interface (i.e. 1 slider vs. 3 sliders vs. 5 sliders).

4.2 Participants

In total 59 participants participated in the experiment. They were recruited by an external agency (i.e. CG Selection) and each participant received €50 for participating. All participants were from outside the company, balanced in gender (25 females and 34 males) and ages (mean=38 yrs., SD=13 yrs., min=20, max=60), with different backgrounds (e.g., product manager, teacher or student). All participants were Dutch citizens living in the Netherlands so as to avoid the potential effect of culture background on individuals' preferences. All of them indicated to have good English skills and be able to understand the questionnaire and interview in English.

4.3 Experimental Room

The experiment was run in the living room of Philips HomeLab, which is a fully functional home laboratory space. We chose HomeLab as the location of our experiment for two prime reasons: 1) it provides sufficient information of the context of use and could evoke the experience of users connected with their daily life more naturally and, 2) it is possible to have some control over the experiment and make data collection much easier than in field tests in real consumer homes. Simply speaking, in HomeLab we could conduct user testing with prototypes in a controlled but still naturalistic environment.

The basic lighting condition for the whole room was a cozy evening mode set by seven spot lights on the ceiling (Philips Hue GU10) and three on the TV cabinet (two LivingColors and one warmish desk lamp). The light source to be tested was fixed and placed on a low cabinet and slightly skewed, so that the dynamic light effect could be properly presented on a blank white wall behind the cabinet. See Figure 13, 14 for an overview of the experiment setting.
4.4 Measures and Dependent Variables

Two types of questionnaires were used for the study: one was titled ‘Importance Rating Questionnaire’ (IRQ) to measure the level of importance of having each control slider or the control parameter (e.g. brightness, hue) on the control panel, which was done on a 7-point Likert scale ranging from “not at all important” (1) , via ‘Neutral’ to ‘extremely important’ (7), see Appendix B for the IRQ for Control C; the other was titled ‘Dynamic Lighting System Evaluation Questionnaire’ (DLSEQ) for measuring user experience and satisfaction with the system, including 21 questions measuring nine variables. These were perceived beauty of the light effect (1 item), perceived naturalness of the light effect (1 item), perceived attractiveness of the system (3 items), perceived ease-of-use (3 items), perceived control (3 items), perceived enjoyment (3 items) and perceived usefulness of the system (3 items), satisfaction with the system (3 items) and the willingness to recommend (1 item). When we studied user experience, they were treated as dependent variables, while we investigating the factors contributing to user satisfaction, they became independent variables as possible predictors except the variables User satisfaction and Willingness to recommend. See Appendix C for the complete questionnaire. Since there is to our knowledge no existing questionnaire for assessing user experience with dynamic lighting systems for consumer homes, we adapted related existing evaluation questionnaires and developed a questionnaire that meets our research objectives. We adapted the questions developed by Venkatesh et al. (2000) to
measure the variables perceived ease-of-use, perceived control and perceived enjoyment of the system. We defined three items measuring the variable perceived usefulness, as well as for the variable perceived attractiveness of the system. For variables perceived naturalness and perceived beauty of the light effect, these were measured by one single item, as well as for the variable willing to recommend the system to others. We piloted the DLSEQ with two volunteers for better usability and had it checked by one expert in questionnaire design to make sure that everything was done in a proper way. Because of the modifications, the reliability coefficients for the scales were tested. The scales were composed of the following items:

- **Scale Perceived attractiveness:** ‘I find the system pleasant/ attractive/ inviting’ (Cronbach’s $\alpha = .845$).

- **Scale Perceived ease-of-use:** ‘The interaction with the system is clear and understandable/ does not require a lot of my mental effort; I find the system easy to use’ (Cronbach’s $\alpha = .707$).

- **Scale Perceived control:** ‘I felt I was in control of the system; I find it easy to get the system to do what I want it to do; I was able to operate the system in my own way’ (Cronbach’s $\alpha = .876$).

- **Scale Perceived enjoyment:** ‘I find using the system to be enjoyable; I find the actual process of using the system pleasant; I have fun using the system’ (Cronbach’s $\alpha = .900$).

- **Scale Perceived usefulness:** ‘I felt by using the system the atmosphere in the room was enhanced/ my mood was improved; I find the system useful in a home environment’ (Cronbach’s $\alpha = .765$).

- **Scale User Satisfaction:** ‘How satisfied were you with the light effect/ control interface/ overall system’ (Cronbach’s $\alpha = .757$).

### 4.5 Procedure

Before the formal experiment, we conducted two pretests: one was to estimate the appropriate length of the experiment, including the phases of an experience session, questionnaire evaluations, and an interview session; and the other one was to check the process of the experiment and whether it was clear to the subjects. During the courses of the trial runs, we also fixed some bugs in the coding and improved the responsiveness of the control device several times to ensure instant reactions and a smooth interaction with the light effect during the real experiment.
The experiment mainly consisted of two parts: the first part was an experience session including trials of different control interfaces with the light effect, and questionnaire evaluations; the second part was a face-to-face interview to further understand user perspectives. During the experience session, the participants were asked to sit on the couch and to use the provided control interface to interact with the DALS. The task was to explore the lighting system freely and to create a satisfactory lighting condition while experiencing the lighting from the couch. After the participants noted they were done with the task, they completed the questionnaire. After completion of the questionnaire, the two trials of the other control solutions followed the same procedure as just described. After the completion of the experience session, a face-to-face interview was conducted with the participant to discuss more in details about their experience during the whole experiment. The interviews were semi-structured, and consisted of questions on the experience of users with the system (e.g. their preferences on the three provided controls or associations with the light effect) and possible improvements of the system. Table 3 shows an overview of the complete experiment procedure. Figure 15 shows a typical scenario of the user testing.

<table>
<thead>
<tr>
<th>Welcome</th>
<th>Experience Session with Questionnaire Evaluation included</th>
<th>Interviews</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>UI 1 -&gt; Questionnaire</td>
<td>UI 2 -&gt; Questionnaire</td>
<td>UI 3 -&gt; Questionnaire</td>
</tr>
<tr>
<td>1 min</td>
<td>1st trial</td>
<td>2nd trial</td>
<td>3rd trial</td>
</tr>
</tbody>
</table>

Table 3: An overview of the experiment procedure
Figure 15: User testing Scenario
Chapter 5

Data Analysis and Results

5.1 Data Preparation

- **Reliability Check**

  As we mentioned before, for variables measured by multiple items, internal-consistency reliability was checked, and if Cronbach’s alpha is larger than 0.70 is considered as acceptable. In our case all are acceptable. However, for the variable *Perceived Usefulness*, it was a bit controversial to include the item on the mood improvement into the average calculation for perceived usefulness score within the project group. It was argued that people’s mood may not be influenced by the environmental lighting thus to use the mood item measuring the usefulness of the system may be debatable. Therefore these three items were decided to be analyzed and interpreted separately.

- **Potential Outliers Detection**

  There is no precise statistical definition of an outlier. However, the common method to detect outliers is to use a criterion based on z-scores assuming the data follow a normal distribution. Based on the recommendation by Cousineau (2011), a Bonferroni correction based on the sample size \( n \), and with a conservative decision criterion \( 1 - \alpha / (2n) \) was used. The level 0.01 was chosen. Table 4 lists some critical Z-score as a function of the decision criterion, referring by Cousineau in his review. Therefore, the data with a Z-score larger than 3.481 or smaller than -3.481 was treated as an outlier.

<table>
<thead>
<tr>
<th>DECISION CRITERION</th>
<th>SAMPLE SIZE IF CORRECTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>0.10</td>
<td>2.576</td>
</tr>
<tr>
<td>0.05</td>
<td>2.807</td>
</tr>
<tr>
<td><strong>0.01</strong></td>
<td><strong>3.291</strong></td>
</tr>
<tr>
<td>0.005</td>
<td>3.481</td>
</tr>
</tbody>
</table>

Table 4: z-score as a function of the criterion and a Bonferroni correction
After applying this criterion to all measured variables for each experimental condition, one participant (id=31) was detected as an outlier for the variable ‘perceived control’ (in the fire effect group with the control C, z-score= -3.64), and one participant (id=53) was detected as an outlier for the variable ‘perceived ease-of-use’ (in the condition Water effect with Control A, z-score= -3.72). Therefore, they were excluded only for the analysis relevant to the corresponding variable.

In addition, one participant (id=54) was detected as an outlier for the importance rating on the parameter Speed (in the condition Water effect with Control B, z-score= -3.56), and one participant (id=6) was detected as an outlier for the importance rating on the parameter Hue (in the condition Candle effect with Control C, z-score= -3.53).

## 5.2 Addressing our Main Research Questions

**Q1.** Which of the tested control interfaces was preferred by users to interact with different dynamic light effects?

--- For Candle and Water effects, people preferred Control C most (89.5% for Water, 70% for Candle and 50% for Fire), which supported for H1. While for Fire effect, half of the participants preferred Control C and half preferred Control B for its simplicity in support the satisfactory lighting conditions.

We addressed this question directly based on the user feedback during the interviews. The results suggest that for Candle and Water effects, the majority of participants preferred Control C most (i.e. 14 out of 20 in Candle effect group and 17 out of 19 in Water effect group). Especially for Water effect, only two participants prefer Control B, the remaining all preferred Control C. For Fire effect, half of the participants preferred Control B and the other half preferred Control C most. Therefore, for Candle and Water effect, it was noticed that people preferred to have more control over the light effect, while for Fire effect, half of the participants were already satisfied with the three control options over speed, brightness and size, and with no particular need in color change options.

**To conclude,** the results suggested that most people preferred Control C mainly due to the reasons that with more control, they could impact more on the light effect and had more possibilities to create what people wanted. While for Fire effect, Control B was also preferred by half of the participants,
We furthermore summarized the advantages and disadvantages for each type of the control interface (Table 5). Please note that the numbers in the brackets were the amount of responses from the three light effects Candle (C), Fire (F) and Water (W) respectively. More user remarks see Appendix D.

<table>
<thead>
<tr>
<th></th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control A</strong></td>
<td>• Easy and quick. ( (C: 1+ W:1) )</td>
<td>• Very limited control to impact the effect. ( (C: 1+ F: 6+ W:2) )</td>
</tr>
<tr>
<td></td>
<td>• Very limited control to impact the effect. ( (C: 1+ F: 6+ W:2) )</td>
<td>• Cannot control parameters separately. ( (C: 2+ F: 2+ W:4) )</td>
</tr>
<tr>
<td></td>
<td>• Cannot achieve what you want. ( (C: 3+ F: 1) )</td>
<td>• Cannot achieve what you want. ( (C: 3+ F: 1) )</td>
</tr>
<tr>
<td><strong>Control B</strong></td>
<td>• Simple and easy ( (C: 5 + F: 7+ W: 2) )</td>
<td>• Cannot change color ( (C: 1+ F: 8) )</td>
</tr>
<tr>
<td></td>
<td>• Sufficient to get what you want. ( (C: 2 + F: 3) )</td>
<td></td>
</tr>
<tr>
<td><strong>Control C</strong></td>
<td>• Can influence more and have more possibilities to create what you want. ( (C: 8 + F: 12 + W:16) )</td>
<td>• Many ways to influence. It takes time and effort. ( (C: 3+ F: 1 + W: 6) )</td>
</tr>
<tr>
<td></td>
<td>• Can customize the color for more moods. ( (C: 9 + F: 7 + W:10) )</td>
<td>• A bit hard to understand ( (F: 1+ W:1) )</td>
</tr>
</tbody>
</table>

Table 5: Advantages and disadvantages of the tested controls

From the feedback collected we noticed that most people preferred Control C due to its increased control possibility and influence on the effect, which could allow them to create a more satisfied condition. Especially it offered the color control option that many participants believed could bring various atmospheres. People who preferred Control B mainly because they felt it was a balance between too limited and too complicated to operate, which provide just proper amount of control and relatively important options that were sufficient to create what they liked. People
disliked Control A because they felt limited control influence the effect and second they found it was impossible to control some of the parameters independently especially for speed and speed and brightness. Besides, we noticed that only for Fire effect, Control B was as competitive as Control C when we explicitly asked their preferences face-to-face. And more participants felt Control B was the easiest way and already sufficient to satisfy them in creating the effects as they wanted, compared with the other two light groups.

**Q2.** For the different dynamic light effects, which of the tested control interfaces resulted in the higher user satisfaction?

---  For Candle effect, with Control B or C higher user satisfaction was gained, than with Control A. For Fire effect, with Control B people achieved higher satisfaction than with Control A. And for Water effect, with Control C people obtained highest satisfaction. No support was found for H2 that an increased in control possibility did not always lead to higher user satisfaction.
Figure 16: Clustered boxplot of satisfaction scores for all experimental conditions

The boxplot (Figure 16) shows a large variation in the responses for Candle effect while it indicates more consistent feedback on Water effect. Between Candle and Water effects the trend was similar that with increasing available control options, satisfaction was increased as well. Only for Fire effect, participants seemed to be most satisfied when given Control B. In addition, satisfaction scores on the system were always lower with Control A than with Control B and Control C regardless of types of light effects. These observations it were further investigated using statistics.

Satisfaction scores on the system for Fire effect with Control C condition were found not normally distributed (skewness=-.954, kurtosis=-.385; Shapiro-Wilk=.844, p=.004). In order to be more robust with the reported results, both parametric (paired t-test) and nonparametric analysis (Friedman followed by Wilcoxon Signed Ranks test) were performed, and the results were found to be consistent. Here we reported the results from the nonparametric analysis. Figure 17 shows an overview of the results (the ranking and the lines indicating the importance and whether they are significantly different).
Figure 17: An overview of the results for Q2

<table>
<thead>
<tr>
<th>Satisfaction with the Dynamic Lighting System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
</tr>
<tr>
<td>Candle</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Fire</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Water</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
</tr>
</tbody>
</table>

For **Candle effect**, the results indicated that the satisfaction scores for the condition with Control A (M=4.4, SD=1.54, SEM=.34) was statistically significantly lower than the condition with Control B (M=5.35, SD=1.09, SEM=.24), Z= -2.576, p<.010, and the condition with Control C (M=5.45, SD=1.10, SEM=.25), Z=-3.232, p< .001. This result suggested that users obtained higher satisfaction with the system when given detailed control at parameter level, than the condition with a single integrated control at effect level.

For **Fire effect**, the results showed that the satisfaction scores for the condition with Control A (M=5.5, SD=.95, SEM=.21) was statistically significantly lower than the condition with Control B (M=6.05, SD=.82, SEM=.18), Z= -3.639, p<.001. No other significant differences were found. Hence for Fire effect, highest satisfaction seemed to be achieved with Control B, statistically significantly higher than the condition with Control A, but not statistically significantly higher than the condition with Control C (M=5.56, SD=1.23, SEM=.27). This suggested people required separate control over individual parameters, however an increase in the amount of control options did not guarantee an increase in satisfaction with the system. More explanations would be provided in the later sections.

For **Water effect**, the results showed that the satisfaction scores for the condition with Control C (M=5.74, SD=.65, SEM=.15) was statistically significantly higher than the condition with Control A (M=5.10, SD= 1.24, SEM=.29), Z= -3.146, p<.002, and the condition with Control B (M=5.58,
SD = .69, SEM = .16, Z = -2.583, p < .010. It revealed the fact that people achieved highest satisfaction with the system when using Control C in the effect creation, statistically higher than conditions with the other two control interfaces.

**Conclusion:** For **Candle effect**, people achieved higher satisfaction with interfaces allowing for separate control at individual parameter level (**Control B or C**) than only given integrated control at effect level (Control A). For **Fire effect**, an increase in the amount of available control would not always guarantee an improvement in user satisfaction with the system, that giving the extra color changing option (Control C compared with Control B) did not lead to higher satisfaction, and people seemed to be more satisfied with the system when using **Control B** in the interaction with the system. For **Water effect**, people achieved **highest satisfaction** with **Control C**. One possible explanation was that many people mentioned they liked the dynamic pattern, the type of the movement in the effect, however if they preferred more warmish colors rather than blue, the color options were very important.

**Q3:** For the different dynamic light effects and control interfaces, which parameters (e.g. speed, brightness, size, saturation and hue) were rated as more important to have personal control over?

--- Overall, parameters **hue, brightness and speed** were rated as more important than saturation and size. For Candle and Water effects, the ranking order is same (1st to 5th: hue, brightness, speed, saturation and size). For Fire effect, the ranking order is speed, hue, brightness, size and saturation. Speed and brightness were important, which supported H3, However, hue was also rated as a very important parameter that we could not neglect.

We evaluated the importance of different control sliders on the user interface for Control B (3 sliders: speed, brightness, and size) and Control C (5 sliders: speed, brightness, size, hue and saturation). We did not evaluate the importance for the single “Effect” slider on Control A. In the following paragraphs, we report the results for Control B first, followed by the results for Control C.
A Friedman test followed by a Wilcoxon Signed Ranks test were performed to investigate if there was any statistically important difference between any parameters allowed by Control B for the three tested dynamic light effects. See Figure 19 for an overview of the results (the ranking and the lines indicating the importance and whether they are significantly different).

Figure 18: Clustered boxplot for importance rating on different control parameters enabled by Control B

Figure 19: An overview of results for the importance ratings for Control B
For Candle effect, no statistically significant differences were found between the three parameters (Speed: M=5.90, SD=1.373, SE=.31; Brightness: M=5.85, SD=1.46, SE=.33; Size: M=5.35, SD=1.42, SE=.32) enabled by Control B, which suggested that these three parameters of the dynamic light effect might be equally important to provide control over.

For Fire effect, the results indicated that the importance scores for Size (M=5.45, SD=1.32, SE=.29) were statistically significantly lower than Speed (M=6.30, SD=.73, SE=.16), Z= -2.346, p<.019, and Brightness (M=6.20, SD=.70, SE=.16), Z= -2.828, p<.005. This suggested that parameters Speed and Brightness seemed to be more important for personal control than the parameter Size.

For Water effect, it was found that the importance scores for the parameter Brightness (M=6.37, SD=1.01, SE=.23) were significantly higher than Speed (M=5.63, SD=1.30, SE=.30), Z= -2.546, p<.011, and Size (M=4.11, SD=1.70, SE=.39), Z= -3.536, p<.001. And the importance scores for the parameter Speed were found statistically significantly higher than Size, Z= 2.998, p<.003. Hence, for Water effect in terms of Control B, the parameter Brightness seemed to be the most important one that required personal control, followed by the parameter Speed, and the parameter Size was rated as least important.

Same kind of analysis was performed again to investigate if there was any statistically important difference between any parameters allowed by Control C in terms of the three tested dynamic light effects. Figure 21 shows the overall results.
Figure 20: Clustered boxplot for importance rating on different parameters enabled by Control C

<table>
<thead>
<tr>
<th>Importance to provide personal control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Candle</strong></td>
</tr>
<tr>
<td>1st 2nd 3rd 4th 5th</td>
</tr>
<tr>
<td>Candle Hue Brightness Speed Saturation Size</td>
</tr>
<tr>
<td>Hue &gt; Saturation Brightness &gt; Size</td>
</tr>
<tr>
<td><strong>Fire</strong></td>
</tr>
<tr>
<td>1st 2nd 3rd 4th 5th</td>
</tr>
<tr>
<td>Fire Speed Hue Brightness Size Saturation</td>
</tr>
<tr>
<td>Speed &gt; Size Hue &gt; Saturation</td>
</tr>
<tr>
<td><strong>Water</strong></td>
</tr>
<tr>
<td>1st 2nd 3rd 4th 5th</td>
</tr>
<tr>
<td>Water Hue Brightness Speed Saturation Size</td>
</tr>
<tr>
<td>Hue &gt; Saturation Brightness &gt; Saturation Speed &gt; Size</td>
</tr>
</tbody>
</table>
For Candle effect, the parameter Hue (M=6.05, SD=1.15, SE=.26) was found to be significantly more important than the parameter Size (M=5.60, SD=1.54, SE=.30), Z=-2.667, p<.008, and the parameter Saturation (M=5.5, SD=1.47, SE=.33), Z=-2.154, p<.031. And the parameter Brightness (M=6.05, SD=1.1, SE=.25) was detected as significant more important than the parameter Size, Z=-2.547, p<.011. Considering both the statistics and the information reflected from the boxplot, it was suggested that the parameter Hue seemed to be most important to provide personal control, then the parameters Brightness and Speed (M=5.6, SD=1.54, SE=.34), though no statically significantly differences were found between these three. Then might be followed by the parameter Saturation and the parameter Size (smaller variation in the Saturation), although no statically significantly differences were detected between these two.

For Fire effect, the parameter Speed (M=6.25, SD=0.55, SE=.12) was found to be statistically significant important than the parameter Size (M=5.45, SD=1.36, SE=.30), Z= -2.390, p<.017, and the parameter Saturation (M=5.25, SD=1.62, SE=.36), Z= -2.620, p< .009. And the parameter Hue (M=6.05, SD=1.23, SE=.28) was significant more important than the parameter Saturation, Z= -2.355, p< .019. Considering both the descriptive data and the statistical results, it appeared that the parameter Speed was a crucial one that required for personal control, and then the parameters Hue and Brightness (M=5.85, SD=1.35, SE=.30), though these three were not detected as statistically significantly different. The parameters Size and Saturation might be considered as less important parameters that required customization.

For Water effect, the parameter Hue (M=6.26, SD=0.99, SE=.23) was found to be significantly more important than the parameter Saturation (M=5.32, SD=1.67, SE=.38), Z=-2.106, p< .035, and the parameter Size (M=4.21, SD=1.93, SE=.44), Z=-2.922, p< .003. The parameter Brightness (M=6.21, SD=0.79, SE=.18) was discovered to be statistically significant important than the parameter Saturation, Z= -2.534, p<.011, and the parameter Size, Z= 3.345, p< .001. And the parameter Speed (M=5.79, SD=0.86, SE=.20) was found to be statistically significant important than the parameter Size, Z = -2.956, p<.003. The results suggested that the parameters Hue and Brightness seemed to be very important parameters to have personal control over, as well as the parameter Speed. And the parameters Size and Saturation seemed to be less important ones.
Conclusion: The results suggested that in general the parameters hue, brightness and speed appeared to be more important to provide personal control over than the parameters size and saturation. One explanation is that these three parameters seemed to have bigger influence on the created light effects. For instance, a change in brightness or speed could make an effect either dominating or calming. The hue option allowed people to choose their favorite colors and very important to support different moods. Moreover, as we noticed for Fire effect, color control seemed to be less important than for the other two effects. One explanation suggested by the interviews is that Fire effect was mostly recognized by the participants, and most people tried to mimic a fire effect during the interaction. Many people did not find a full range of colors necessary, mostly they would only need those warmish colors to make a fire look effect, and Control B seemed to be an easy and quick way to achieve that goal.

Q4: How do objective system features (e.g. types of dynamic light effects and control interfaces) affect user satisfaction?

Figure 22: Mean satisfaction scores over all experimental conditions
A repeated measures GLM was used to address this question. However, as mentioned before in Q2 the satisfaction scores for Fire effect in Control C condition were not normally distributed (skewness=-.954, kurtosis=-.385; Shapiro-Wilk=.844, p=.004). Therefore the reported results here were not robust. The results indicated that both within-subjects factor - types of control interfaces (F (2, 112) = 19.635, p< .001) and between-subjects factor - types of dynamic light effects (F (2, 56) = 5.469, p< .007) significantly affect user satisfaction with the system. No interaction effect of these two factors was discovered (p= .185). We then performed post-hoc pairwise comparisons to further investigate the effect based on estimated marginal means. A statistically significant difference was found between Candle effect and Fire effect (p<.002) and between Candle effect and Water effect (p<.024). Besides, a statistically significant difference was discovered between Control A and Control B (p< .001), and between Control A and Control C (p< .001) as well.

**In conclusion**, people were more satisfied with Fire and Water effects than with Candle effect, which partly supported H3a that the types of light effects has a main effect on satisfaction. However, the direction was not fully supported, people did prefer Fire effect, but not for Candle effect, compared with Water effect. And for the first experience with such kind of dynamic lighting systems, people preferred to have detailed control at parameter level (e.g. hue, brightness and speed) more than an integrated control predefined at effect level, which supported and H3b.

**Q5: How do perceived system features affect user satisfaction?**

First we checked the correlations using Spearman test to examine the hypotheses H5a to H5d, and then we performed several linear regressions for different interfaces (to keep observations independent) to explore key factors in determining user satisfaction.

With Control A, perceived naturalness and satisfaction were moderately positively correlated, r (57) = .407, p < .001, which supports H5a. Perceived control and satisfaction were moderately positively correlated, r (57) = .466, p < .001, which supports H5b. Perceived ease-of-use did not found significantly correlated to satisfaction, so for Control A no support was found for H5c. H5d was supported as perceived usefulness and satisfaction were moderately positively correlated, r (57) = .456, p < .001.
With Control B, perceived naturalness and satisfaction were weakly positively correlated, $r (57) = .317$, $p < .007$, which provides support for H5a. Perceived control and satisfaction were moderately positively correlated, $r (57) = .565$, $p < .001$, which supports H5b. Perceived ease-of-use and satisfaction were found moderately positively correlated, $r (57) = .494$, $p < .001$, which supports H5c. And finally, H5d was also supported as perceived usefulness and satisfaction were found moderately positively correlated, $r (57) = .511$, $p < .001$.

With Control C, H5a was supported as perceived naturalness and satisfaction were weakly positively correlated, $r (57) = .231$, $p < .040$. Perceived control and satisfaction were moderately positively correlated, $r (57) = .580$, $p < .001$, which supports H5b. Perceived ease-of-use and satisfaction were found moderately positively correlated, $r (57) = .476$, $p < .001$, which supports H5c. Finally, H5d was also supported as perceived usefulness and satisfaction were found moderately positively correlated, $r (57) = .448$, $p < .001$.

**To conclude,** the data provided support for hypothesis H5a-H5d showing positive correlations between the perceived system features (perceived naturalness, perceived control, perceived ease of use, perceived usefulness) and satisfaction with the system for all three control conditions. Only for Control A, the hypothesis H5a was not supported as we did not found a significant positive correlation between the variable perceived ease-of-use and satisfaction scores with the system. This might be explained by the fact that Control A was evaluated as very easy to use by most of the participants, thus a ceiling effect might occur here.

We did several regressions for the control interfaces exploring the key factors that predict user satisfaction, we found perceived attractiveness and control were always suggested as important predictors for all the control interfaces. Then we did the regressions exploring the factors that could explain these two factors.

Figure 23 shows the results for Control A, we combined the results for three regressions in the same figure, with the standardized coefficients shown as well. More statistics please see Appendix D1.
For the condition with Control A, a stepwise multiple linear regression was calculated to predict user satisfaction. A significant regression equation was found ($F (2, 56) = 33.051, p< .001$), with an $R^2 = .541$. The estimation equation was $\text{User Satisfaction} = 0.63 + 0.467 \text{ (perceived attractiveness)} + 0.325 \text{ (perceived control)}$, where all variables were measured in a 7-point Likert scale, and all were significant predictors of satisfaction, $p< .001$. Same technique was performed to explore the factors that could predict perceived control and attractiveness. A significant regression equation was found ($F (2, 56) = 33.051, p< .001$), with an $R^2 = .541$. The estimation equation was $\text{Perceived attractiveness} = -0.470 + 0.616 \text{ (perceived beauty)} + 0.467 \text{ (perceived enjoyment)}$, where all variables were measured in a 7-point Likert scale, and all were significant predictors of satisfaction, $p< .001$.

Figure 24 shows the results for Control B, again we combined the results for three regressions in the same figure with the standardized coefficients shown as well. More statistics please see Appendix D2.
For the condition with Control B. A significant regression equation was found \( F (4, 54) = 36.07, p < .001 \), with an \( R^2 = .728 \). The estimation equation was \( \text{User Satisfaction} = -0.689 + 0.218 (\text{perceived attractiveness}) + 0.445 (\text{perceived control}) + 0.264 (\text{perceived beauty}) + 0.159 (\text{perceived usefulness}) \), where all variables were measured in a 7-point Likert scale, all predictors were significant, \( p < .038, .001, .001, .018 \) respectively.

Figure 25 shows the results for Control B, again we combined the results for three regressions in the same figure with the standardized coefficients shown as well. More statistics please see Appendix D3.
For the condition with Control C, a multiple linear regression was calculated to predict user satisfaction with the dynamic lighting system based on the perceived attractiveness and usefulness of the system. A significant regression equation was found (F (2, 56) = 45.399, p< .001), with an $R^2 = .619$. The estimation equation was $User Satisfaction = 0.404 + 0.307 (perceived attractiveness) + 0.408 (perceived control) + 0.198 (perceived enjoyment)$, where all variables were measured in a 7-point Likert scale, and all were significant predictors, p< .002, .001 and .034 respectively.

To conclude, the results suggested that both pragmatic (e.g. control, usefulness) and hedonic aspects (e.g. attractiveness, enjoyment) of the perceived system features affect satisfaction with the dynamic lighting system, which supported H5e. And more specially, perceived attractiveness and control were always found as crucial factors in determining user satisfaction. Furthermore, it was suggested by the models that perceived attractiveness of the system seemed to be mostly influenced by perceived beauty of the light effect and perceived enjoyment of system use. And perceived control seemed to be mostly influenced by perceived ease of use and perceived enjoyment of system use. Interestingly, we found that perceived control was always an important predictor in predicting satisfaction, even with same kind of control interface. This suggested that perceived control was not only dependent on objective control (the available control) but might be more influenced by the individuals.

5.3 Other Results and Findings

5.3.1 Questionnaire

In order to exploit more from the data, we analyzed all variables measured by questionnaires separately and only reported the significant findings below (Table 6). More statistics see Appendix E.

<table>
<thead>
<tr>
<th>NATURALNESS</th>
<th>FIRE</th>
<th>WATER</th>
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</thead>
<tbody>
<tr>
<td>CANDLE</td>
<td>Control C &gt; Control A</td>
<td>Control C &gt; Control B</td>
</tr>
<tr>
<td>FIRE</td>
<td>Control C &gt; Control A</td>
<td>Control B &gt; Control A</td>
</tr>
<tr>
<td>WATER</td>
<td>Control C &gt; Control A</td>
<td>Control C &gt; Control A</td>
</tr>
</tbody>
</table>
For Candle effect, with Control C, the light effect was perceived as more beautiful and the system was perceived as more attractive than the condition with Control A, as well as perceived enjoyment and perceived usefulness. With Control A, perceived control of the system was evaluated as lowest. For Fire effect, with Control C, the system was perceived as most difficult to use. With control B, most control of the system was perceived and more enjoyable than the condition with Control A. With control A, the light effect was perceived as least beautiful.

For Water effect, with Control C, the light effect was perceived as most natural and most beautiful, and atmosphere in the tested room was felt being significantly improved by using the system. People were most willingly to recommend the system. With control A, the system was perceived as easiest to use but least attractive and enjoyable.

5.3.2 Interviews

"Does the light effect remind you of anything? "

Table 6: Overview of other results
For Candle effect, seven people associated the effect with candles while six participants associated the effect with fire/ fireplace. Other sporadic associations include flashing lights on the highway, wave of the sea, northern light, disco light, LivingColors and HUE lamps.

Some of the user remarks:

“Very comfortable, a feeling of relaxation, reminds me of northern light, a little bit with sea. With yellow or red, it looks like candle light, but in a very strange way, not that romantic. For example, when I have dinner, I put candles on the table, but with this light, just with a switch, the feeling gets less.”

“It gives you a natural feeling of natural light, candle with wind.”

“Really natural, not distracted, and create nice atmospheres. A bit like candle light, cozy evening at home.”

“Very beautiful, especially in winter, like open fire when with the right color on it. A little bit like the wave of the sea that you can dream.”

For Fire effect, fifteen people successfully recognized the effect as open fire/ fireplace/campfire. Other sporadic associations were sunrise, northern light, light through the trees.

Some of the user remarks:

“With the movement, it reminds me of fireplace.”

“Nice and cozy fire, relaxed, cheering a bit by playing with light.”

“With reddish color, reminds you of fire.”

For Water effect, seven people associated the effect with fire, seven people said the effect reminded them of water or aquarium and two people thought of candle lights. Other sporadic associations were sunshine, AmbiTV, and disco light with music.

Some of the user remarks:

“Really pretty, it reminds me of the raindrops on the water, it is flickering, also looks like leaves on the tree, or light in the woods.”

“Remind me of gas heater, flames, fire, a bit like small candles.”
“It is nice, reminds me of the candle light with the yellow color, and if the color set to blue reminds me of a fish tank.”

In conclusion, we found that most people successfully recognized the intended Fire effect during the experiment. For Water effect, surprisingly we found many people also connected the effect with fire or candle, and when asking the reasons, they indicated that it was mainly because of the movement in the effect, and if you could choose the warmish color it would make the effect even appear like fire. For Candle effect, evoked associations were more diverse. Some clearly recognized the effect as several candle lights while others could only vaguely described the effect as fire or others.

“What kind of atmosphere or mood have you experienced in this room with this kind of light effect?”

For Candle effect, it was described as relaxing, cozy, peaceful, warm and cheerful. For Fire effect, it mostly reflected as calming, restful, quiet, relaxing, warm and cozy. While for Water effect, it was felt as soothing, peaceful, quiet and relaxing. We found that most people wanted to create a relaxing atmosphere during the experiment and they would use the combinations of different control options to optimize their goals in making the dynamic light effect appeared more relaxing and pleasant, such as setting the speed quite low or choosing a warmish color.

“Have you experienced any difficulties in using the system?”

Most people found the system was very easy to use and only a few difficulties were mentioned. The issues that were reported by some of the participants include: 1) they felt it was a bit hard to understand the terms ‘Hue’ and ‘Saturation’ at the beginning of their use, but if they kept playing they could get the feeling that they were related to color; 2) they felt it took some time to try different control options to reach the optimum, especially when you used Control C, you need to figure out how different control options could work well together. Moreover you did not have the option to go back to the previous setting that you might like best, this made the tuning even more timely and it costs effort. 3) Sometimes the responsiveness of the control device was a bit slower than the finger movement, this could be improved.
“Would you like to have this lighting system in your home? If yes, in what kind of situations?”

For Candle effect 16 people expressed they would like to try this kind of lighting system in their homes. The scenarios mentioned by the participants include 1) when having a romantic dinner or a family dinner; 2) while watching a film or TV; 3) when friends come over; 4) when resting in a couch or in a favorite chair; 5) when it is dark to give some warmth feeling; 6) when listening to music. More especially some people mentioned that the effect could be coupled with a fish tank or light a wall as a decoration, or used as a tool to get baby more sleep.

For Fire effect, 17 people said yes. Besides the common scenarios mentioned above, some participants also mentioned that it was safer to use this lighting instead of real fire and also good for environments but still could give the warmth feeling.

For Water effect, 13 people would like to have the system in their homes. The mentioned scenarios like watching a movie or having friends over. More especially, many people believed that the water effect might be effective for meditation use since it could calm them down and help clear mind. One participant expected the lighting could be more responsive and more aware of the environmental change such as temperature, and amount of people present in the room.

“Do you have any previous experience with dynamic lighting products? Is there anything changed in your attitude about applying dynamic lighting to your home?”

We did not notice any dramatically change in people’s attitude toward dynamic lighting. Most people indicated that they were neutral about dynamic lighting even though some of them expressed they were not quite sure about the definition of dynamic lighting. As for previous experience with dynamic lighting products, many people mentioned about AmbiTV, LivingColors and Hue lamps.

“Would you recommend this lighting system to anyone you know? Why?”

For Candle and Water effects, around 12 people expressed that they would like to recommend it and for Fire effect, around 17 participants recommend it. But most considerations are about price and the type of the house. The main reason for recommendation was because such kind of lighting system could create more atmospheres.
“Any suggestions that we could improve with the current lighting system?”

During the interviews, many suggestions were proposed by the participants, and we grouped their views into following categories:

- **Control Setting & Options**
  - Provide the options that could save user defined lighting schemes into the database and could allow users to select from all their stored designs easily during the future use.
  - Provide more presets or shortcuts to user defined modes.
  - Make users informed of the current state of the lighting condition such as with exact values shown for each control parameter they make.
  - Hide/ extend detailed control from the main control.
  - More customization choices on the effect size (e.g. adjustment in the height of the effect), color (e.g. more gradually change or resolution in warmish colors), position (e.g. project the effect higher or from another direction), pattern (e.g. customize the direction of the movement for water or the shape of the flame).
  - Support static light as well as dynamic light effect (i.e. an option that you could minimize the dynamics or you can choose to turn on/off the dynamic lighting)

- **Transition**
  - Smooth the transition and make the change such as in colors more gradually, especially for those common colors or warmish colors, allowing for more precise tuning.

- **Interface**
  - Provide a physical and tangible interface, just like a TV remote, or the control for the LivingColors

- **Intelligence**
  - Make the lighting system learn user preferences and improve the performance over time.
• **Installment**

  - Easy installation, just like a click on hat you could integrate the light source into existing objects in your homes.

• **Design**

  - More fashioned design for the user interface and the light fixture. For example, the light source could be hidden behind some plants or embedded in other furniture
Chapter 6
Design Implications and Reflections

Based on the user feedback, results and reflections from this study, we identify the following design implications that might be helpful for future designs of user interaction with such kind of dynamic lighting systems.

♣ How to make users “feel in control”? Make those key parameters of the effect in control.

The perceived control is not guaranteed by the actual amount of control options, it is more important to provide sufficient control that can support users to create their satisfactory lighting conditions. The impact of different parameters of a light effect on the gained results may be different, people need those key parameters that play an important role on the resulted effect to be in control, such as speed and brightness. If there are some innovative features of the system that might not be consistent with previous user preferences, then it is better to provide a backup option to restore a conventional option. For example, provide warmish colors if you deliver a lighting system for homes. Also provide an option to stop or slower down the speed of the dynamics.

♣ User control, the more the better? Not the case, but make the system cooperative.

As mentioned before, more control options given to users does not always lead to higher satisfaction. This means sometimes or more times, the system can help people create better lighting conditions. However, most of the time, a lack of trust and confidence in the system operation and system performance may obstruct users to adopt more automatic lighting systems. Thus if the system could learn users’ needs, behaviors and their preferences, and keep improving the performance to benefit people’s everyday life and work, then people are more likely to be willing to put effort and time in training the system and gradually give more control to the system. However, before that, the system needs to be flexible, humble and cooperative.

♣ Make things as simple as possible? Or think in another way, make it enjoyable.
It was found in our study that people tended to prefer more detailed control at parameter level rather than integrated control at system level for the interaction with dynamic light effects. This suggests that people are willing to put more effort in achieving better results for ambience creation as we can understand. For the future user interaction design, we can also think from another perspective, that instead of perusing simplicity in the interaction, maybe we can also think more about the enjoyment and fun of the system use. Those hedonic qualities sometimes could make things more attractive.
Chapter 7

Conclusions and Discussion

In this study, we tested three control interfaces (varying in the amount of control parameters on the user interface) with three dynamic light effects (mimic nature: Candle, Fire and Water) in home-living lab environment. Both qualitative and quantitative analysis were performed in detecting the difference in individual preferences of control solutions for various light effects and the factors that may play an important role in determining user satisfaction. Three models for the control interfaces in predicting user satisfaction with dynamic lighting systems were proposed as well.

**Detailed Control at Parameter Level vs. Integrated Control at Effect Level**

As result, we found that for different dynamic light effects, people differed in their preference for the control interfaces. In general people tend to prefer more detailed control at parameter level rather than an integrated control at effect level in the ambience creation using dynamic light effects. More specifically, for Candle and Water effects, people seemed to prefer more control options to adapt the light effect. In particular, for Water effect, people preferred the hue control option so that they could choose warmish color as well to better suit their environments. For Fire effect, having detailed control over some of the parameters such as brightness, speed and size already meet user requirements in achieving their satisfactory lighting conditions. The hue option seemed to be not that necessary, compared with Water effect. One possible explanation could be that the Fire effect was recognized by users and many people were familiar with the concept of having a fireplace in their homes. Therefore compared with Candle and Water effects, they had clearer expectations on what they would like to achieve in the light effect, mostly they tried to mimic an open fire or a fireplace. With Control B, the color was already set to a warmish color similar to fire flames, and many people were satisfied with the predefined color and did not want to spend too much time playing with all kinds of colors. All these seem to suggest what people look for is a simple and quick way to create a satisfactory lighting condition, however the simplicity of the interaction should not be at the sacrifice of the results people could achieve to meet their needs, especially for ambience creation.
Potential Effects of Evoked Associations on User Experience and Interaction

It was found that in general people were more satisfied with Fire and Water effects. For Fire effect, it was mostly recognized, and gave people feelings of warmth and coziness, and relaxation. For Water effect, either was associated with water or fire by most participants, both were quite relaxing as reported. For Candle effect, people liked the concept of candles if it was recognized. However, some participants also mentioned the effect could be a bit restless and artificial. Moreover, some participants associated the effect with the highway flash lights, which seemed not suitable for home environments. This results was consistent with the finding we found in our prior research that possible associations evoked by the light effect whether it was positive or negative, familiar or not familiar, may affect user experience. As we also mentioned before, that with different associations, and with clear or ambiguous connections, might determine the users’ behavioral types in the interaction, whether is goal-oriented (i.e. have clear expectations in the results) or explorative (i.e. more open in the results and the interaction). However, this requires further investigation.

Perceived Control and Perceived Attractiveness and User Satisfaction

From the models, it was found that both hedonic aspects (e.g. perceived attractiveness and perceived enjoyment of system use) and pragmatic aspects (e.g. perceived control and perceived usefulness) of the system play an important role in determining user satisfaction with dynamic lighting systems, which supported Hassensahl’s notions on evaluating user experience. However, different from his model and TAMs, we found perceived control and perceived attractiveness play an important role on user satisfaction. And with Control C, perceived control even play a role on perceived attractiveness. In our models, we found that it is perceived ease of use and perceived enjoyment of use mainly influence perceived control, while in Venkatesh's model (2003), it is reverse where perceived ease of use contribute to perceived control. Furthermore we found perceived attractiveness of the system is influenced by perceived beauty of the light effect, perceived enjoyment of use, and perceived usefulness of the system. We suggest that to maximize user satisfaction with DALS, on the one hand the system should make users feel in control and on the other hand the light should be beautiful and pleasant, and enjoyable to use.

Limitations and Future Work
There are several limitations about current study. First, only one task was included in the user testing that we asked the participants to create a lighting condition as they preferred most at present moment. We might have found different results if we change the task such as creating a lighting condition while having a party or playing a game. Future research could include more types of tasks that vary on required amount of focus in the scenario testing. Second, the experience time was still too short, the users’ preferences of control might change when they have more experience of such systems. Third, in this study we only included Dutch participants, the results might be different with other cultural background. Forth, some scales measured by the current questionnaire have not been well validated, and some variable is measured by a single item such as perceived beauty of the light effect, in the future research, these could be improved and more items could be added to increase the reliability of the measurements. In the current study, we did not specify the characteristics of users in our experiment design, however from the results we noticed it would be interesting to study different types of users such as their goals, expectations and preferences on customizing the ambient lighting in their homes. Last but not least, in this study, we only tested limited control mappings, there might be some other ways of mapping that could obtain better user experience.

We actually recorded the user behaviors while they were playing around with the system, from which we can learn what parameters were used a lot and therefore might be of interest of particular users. When we learn from control/usage behavior, we can suggest automatically the control parameters on individual bases, such as self-learning system, which would be very useful in simplifying the interaction while maximizing user satisfaction.


Appendices

Appendix A: Other designs for the user interface

![Diagram of AmbiDance interface with options to select candles and lighting control.](image-url)
Appendix B: Importance rating questionnaire (IRQ)

<table>
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</table>
Appendix C: Dynamic lighting system evaluation questionnaire (DLSEQ)

Dynamic Lighting System Evaluation Questionnaire

Please express your opinion by ticking the circle. Please note that in questions below with "system" we mean the whole dynamic lighting system, both the light effect and the light control.

<p>| | | | | | | | | |</p>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>I find the light effect beautiful.</td>
<td>Strongly Disagree</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Strongly Agree</td>
</tr>
<tr>
<td>2.</td>
<td>I find the light effect natural.</td>
<td>Strongly Disagree</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Strongly Agree</td>
</tr>
<tr>
<td>3.</td>
<td>I find the system pleasant.</td>
<td>Strongly Disagree</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Strongly Agree</td>
</tr>
<tr>
<td>4.</td>
<td>I find the system attractive.</td>
<td>Strongly Disagree</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Strongly Agree</td>
</tr>
<tr>
<td>5.</td>
<td>I find the system inviting.</td>
<td>Strongly Disagree</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Strongly Agree</td>
</tr>
<tr>
<td>6.</td>
<td>The interaction with the system is clear and understandable.</td>
<td>Strongly Disagree</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Strongly Agree</td>
</tr>
<tr>
<td>7.</td>
<td>I find the system easy to use.</td>
<td>Strongly Disagree</td>
<td></td>
<td></td>
<td></td>
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<td>Strongly Agree</td>
</tr>
<tr>
<td>8.</td>
<td>Interacting with the system does NOT require a lot of my mental effort.</td>
<td>Strongly Disagree</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Strongly Agree</td>
</tr>
<tr>
<td>9.</td>
<td>I find it easy to get the system to do what I want it to do.</td>
<td>Strongly Disagree</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Strongly Agree</td>
</tr>
<tr>
<td>10.</td>
<td>I felt I was in control of the system.</td>
<td>Strongly Disagree</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Strongly Agree</td>
</tr>
<tr>
<td>11.</td>
<td>I was able to operate the system in my own way.</td>
<td>Strongly Disagree</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Strongly Agree</td>
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### Appendix D1: Regression results for predicting satisfaction for Control A

<table>
<thead>
<tr>
<th></th>
<th>Question</th>
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<th></th>
<th></th>
<th></th>
<th>Strongly Agree</th>
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<tbody>
<tr>
<td>12</td>
<td>I find using the system to be enjoyable.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>13</td>
<td>I find the actual process of using the system pleasant.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>I have fun using the system.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>I felt by using the system the atmosphere in the room was enhanced.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>I felt by using the system my mood was improved.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>I find the system useful in a home environment.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>How satisfied were you with the presented light effect?</td>
<td>Not at all</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Completely</td>
</tr>
<tr>
<td>19</td>
<td>How satisfied were you with the provided control interface?</td>
<td>Not at all</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Completely</td>
</tr>
<tr>
<td>20</td>
<td>How satisfied were you with the overall system?</td>
<td>Not at all</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Completely</td>
</tr>
<tr>
<td>21</td>
<td>How likely would you recommend the system to your friends?</td>
<td>Not at all</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Very Much</td>
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*This completes the questionnaire. Thank you for your time and cooperation.*
### Model Summary

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<th>Adjusted R Square</th>
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<th>df1</th>
<th>df2</th>
<th>Sig. F Change</th>
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- a. type_control = controlA
- b. Predictors: (Constant), attract
- c. Predictors: (Constant), attract, control
- d. Dependent Variable: satisfaction

### ANOVA

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- a. type_control = controlA
- b. Dependent Variable: satisfaction
- c. Predictors: (Constant), attract
- d. Predictors: (Constant), attract, control

### Coefficients

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<th>Collinearity Statistics</th>
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<tr>
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- a. type_control = controlA
- b. Dependent Variable: satisfaction
Appendix D2: Regression results for predicting satisfaction for Control B

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- type_control = controlB
- Predictors: (Constant), attract
- Predictors: (Constant), attract, control
- Predictors: (Constant), attract, control, beautiful
- Predictors: (Constant), attract, control, beautiful, useful
- Dependent Variable: satisfaction

---

ANOVA

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<th>Model</th>
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</table>

- type_control = controlB
- Dependent Variable: satisfaction
- Predictors: (Constant), attract
- Predictors: (Constant), attract, control
- Predictors: (Constant), attract, control, beautiful
- Predictors: (Constant), attract, control, beautiful, useful

---

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### Appendix D3: Regression results for predicting satisfaction for Control C

#### Coefficients\(^{a,b}\)

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<th>Model</th>
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<th>Collinearity Statistics</th>
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<td>2.107</td>
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\(^{a}\) type_control = control\(C\)

\(^{b}\) Dependent Variable: satisfaction

#### Model Summary\(^{a}\)

<table>
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<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
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<th>Change Statistics</th>
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<td>0.664(^{a})</td>
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<td>3</td>
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\(^{a}\) type_control = control\(C\)

\(^{b}\) Predictors: (Constant), control

\(^{c}\) Predictors: (Constant), control, attract

\(^{d}\) Predictors: (Constant), control, attract, enjoyment

#### ANOVA\(^{a,b}\)

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<th>Model</th>
<th>Sum of Squares</th>
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<th>Mean Square</th>
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</table>

\(^{a}\) type_control = control\(C\)

\(^{b}\) Dependent Variable: satisfaction

\(^{c}\) Predictors: (Constant), control

\(^{d}\) Predictors: (Constant), control, attract

\(^{e}\) Predictors: (Constant), control, attract, enjoyment
Appendix E: Some of the user remarks for interview Q1

1. Candle effect

**Control C (14: C1, C2, C5, C6, C7, C8, C10, C12, C13, C14, C17, C18, C19, C20):**

- **More control possibility to achieve what you want (8), and more especially it provides the color control (9)**

  + With more options you feel more in control of the system and can adapt the lighting to different moods and activities, and can achieve what you want. (C1, C5, C8, C10, C13, C18, C19, C20)

  + C5: You have more control, you can choose more. You can pick color and size for yourself, choose your own color for the room, and use different colors to fit in your house. So many choices are important, because you may have different colored walls.

  + C6: I think color and speed very important, brightness is not that important.

  + C10: it gives more control of the system and has more advanced options, gives you the feeling that you are in control of the system, quite pleasant to adapt to the setting you like.

  + C12: with color option, you can change more in the light effect compared with other parameters

  + C18: you can play more and adjust it to the environment on your own. In the evening, you can have different colors, for more atmospheres.

- **Takes time and effort to reach the optimum (3)**

  - C3: It is hard to find the right setting. Each option you have the optimum, and once you changed one, the light changed a lot, like ‘Hue’, and you couldn’t find an optimum with all the control options. The interaction between components are too difficult.

  - C9: It is more difficult to see what kind of light I like, it takes more time. And if there is no possibility to save previous setting that I like, and I need to readjust it every day, I will definitely not use that.
- C15: When you control one, it only change one aspect of the effect, and you need to switch several times between different control options to get best result

**Control B (6: C3, C4, C9, C11, C15, C16)**

- **Simple and easy (5)**
  + It is simple and easier way to get your optimum. (C3, C9, C11, C15, C16)
  + C3: You have some options, and it is intuitive and simple to use. It is easier to find my optimum solution.
  + C11: For home cinema, with 3 sliders, it is easiest way to use and most satisfying, and I like the light effect best with this control
  + C16: easiest to control the light

- **Provide sufficient control options (2)**
  + C4: I like to control the speed and brightness, it is too fast, and that would be distractive. And I don’t feel it necessary to change the colors, but if it is purple/blue, would be distractive.
  + C15: The three options are the most important ones for me to achieve you wishes, and it is easy to do, and can bring the atmosphere to the environment.

- **Miss the control over color (2)**
  - C16: I missed the ‘hue’ and ‘saturation’ options, and I think that is important to have that control as well

**Control A:**

- **Easy and quick (1)**
  + C14: It is easy and quick, and when you back home, you want a quick way to get your preferred setting.

- **Could not create what you want (3)**
  - C1: With 1 control option, you couldn’t control it when you don’t like the light effect. And it seems the light is different but I am not sure about the difference.
  - C10: you couldn’t get the configuration you want, not very specific, and you doesn’t get any other options, just pull it up and down with one control slider.
  - C20: Either it is too much or too less, you cannot change the things in your way, it is the system to do the things.

- **Could not control over some of the parameters separately such as speed (2)**
  - C2: I like the light when it is quiet, not the movement part and you cannot control the speed separately.
  - C11: With 1 option you cannot control speed

- **Too less control possibility (1)**
  - C15: I feel everything is set, too less option

2. Fire effect
Control C (10: F2, F4, F5, F6, F8, F9, F13, F18, F19, F20)

- **Have more control possibility to impact more on the effect (12), more especially you can change the color (7)**
  
  + F2: you change a lot of things, and you have more influence.
  
  + F4: You can control a bit more things, for different emotions and moods, you can change the color, and it is different than the other two. I think the speed is most important, because I dislike disco.
  
  + F5: With 5 options, you can influence color, you can create more, like water, swimming pool, different atmospheres, like relaxing or party time.
  
  + F6: More possibilities to get more differences.
  
  + F8: With 5 options, you can choose colors, a lot of impact on how you feel about light and mood. Speed is very important, a little bit dimmed, I like slower speed, and with this pink make you relaxed.
  
  + F9: With 5 options, you can chose color.
  
  + F11: With 5 options, best for the effect.
  
  + F13: With 5 options, you have more options, and colors for different moods. With other controls, you cannot change colors.
  
  + F18: With 5 options, you control all the manners, choose the right color for atmosphere.
  
  + F19: You have hue option, and can tune it more.

- **Feel manual (1)**
  
  + F20: Very manual with 5 options, I do Photoshop a lot, so very familiar with HUE and saturation. Single control could be preset

- **Too many ways to influence, it takes time and effort to get what you want (6)**
  
  - F11: You need to try all the things, takes time and effort.
  
  - F1: With 5 options, a bit too many ways to influence. And when you are wrong with one, it changes a lot. Way too much, need mental effort, and you need to figure out where has to be changed.
  
  - F2: You need fine tune, sometimes you are very close but cannot get the effect you want to get.
  
  - F7: too many options, and when you changed the saturation, the effect changed a lot, so you need to go back to other sliders to tune it again to what you want., then you need more time.
  
  - F10: With 5 options, you will keep playing with color and saturation, it takes time.
  
  - F15: when you change one parameter, the effect changes a lot, and you need to switch several times to get best results.

- **A bit hard to understand (1)**
  
  - F17: a bit hard to understand

Control B (10: F1, F2, F7, F10, F11, F12, F14, F15, F16, F17)

- **Provide sufficient control options (3)**
+ F1: 3 is enough and I don’t need all that colors.
+ F15: you got most important options with the 3 sliders, and you can bring the atmosphere to the environment and easy to do.
+ F19: you can also adjust the speed, which is important, because if it is too fast, it becomes distracting.

- **Simple and easy (7)**
- F2: balance in the control options and it doesn’t take too much effort for that the result
- F10: With 3 options, quite simple way, the quickest way to get the effect you like most.
- F11: With 3 options, best for the control, it is between single option and 5 options.
- F12: 3 is simple, easy, no thinking, then finish. Actually for the use, I prefer in this order. Hue and saturation is difficult to get the right color. But for buying, I prefer control C because it is better effect with 5 options, that you can adapt it more for different moods.
- F14: With the 3 options, the color is already set, and I only need one color. With five options, you can adjust more to your preference, but you will only adjust them all at the first time, the beginning of use, and then you will use other two maybe to control every day.
- F17: it is in between, not too complicated and ok in control

- **Miss the color change option (1)**
- F8: With 3 options, you has speed, brightness and size. Saturation is important, but not that much important than Hue, and I think the brightness and size could be standard, while color you need more customization on that.

**Control A**

- **Too less control possibility to influence the effect (6)**
- F1: too less control
- F5: It is too simple to influence.
- F8: Single slider is the only one thing you can control, not too much customization
- F10: 1 option is too less options, you cannot configure speed.
- F17: The single slider is too simple to impact the effect
- F19: way too less

- **Could not control some of the parameters such as speed (2)**
- F9: With one option, you cannot change speed separately. I want it relaxing, so not so fast.
- F18: with 1 option you don’t have control on the movement.

- **Could not get what you want (1)**
- F11: With 1 option, you can’t get the effect you want.
3. Water effect


- **Have more control possibility to impact more on the effect (16), more especially you can change the color (10)**

  + W1: Most control with 5, can pick most things, most variety of the effect.
  + W2: Can change more, change more things about it.
  + W3: Can change the color with 5 options, like to have multiple options, especially on the color.
  + W4: More you can change yourself, the more you like. I feel I can control the system.
  + W6: You can change the color with 5 options I think hue, brightness and speed are most important.
  + W7: Have most control, you can decide what kind of color, what kind of effect you like, but needs time to understand hue and saturation, for the play is nice, for the real use, will need presets and press buttons.
  + W8: With 5 options, you have the option for color.
  + W9: With 5 options you have more chances to fine tune it especially the Hue gives most of the effect.
  + W10: More choices to manipulate the light.
  + W11: Can change the color for setting a certain mood.
  + W12: The color add something very important. You have more possibilities for more moods, you have control of what you are doing.
  + W13: With 5 options, you have more colors, and I think speed, brightness and hue are most important.
  + W14: With control C you can change the colors, hue is important.
  + W15: with 5 control options, you can adjust on the color.
  + W16: Adjust the colors, I hate blue, it's too cold. The more options you have the better. You can adjust everything as your wishes, it's tunable and more pleasant for your mood and your own feeling.
  + W17: More options for different moods, to make it personal and can set the effect to my favorite.

- **Too many control options and not clear with the term Saturation (1)**

  - W14: Too many options and not clear with 'Saturation' option.

Control B (2: W14, W18)

- **Easy and simple (2)**

  + W18: With 3 options, most easy way to customize the condition.
  + W14: Not too much control option, clear and simple.

Control A
• **Beautiful light effect (1)**
  + W15: With the single slider, effect like sort of beach wave, really enjoy that.

• **Could not control some of the parameters separately, such as color and brightness (4)**
  - W2: With only one slider you cannot change the color, and blue is cold not suitable for my home
  - W11: With a single slider, you cannot change separately, with different aspect of the effect.
  - W12: With 1 option, you cannot get low flames but brighter, you cannot change separately.
  - W17: With one slider, when the color is your favorite, you will find it becomes too bright.

• **The responsiveness of the slider could be improved (1)**
  - W13: The single slider sometimes not that responsive

• **Too less control possibility to impact the effect (2)**
  - W14: Single slider provides too less possibility in the control
  - W16: With one slider, you have only one thing change, too less.