Adaptive Lighting for Knowledge Work Environments

A Pilot Design

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Adaptive lighting technologies and control of lighting by users provide new possibilities for lighting design in the context of knowledge work environments. In our research project, we study innovation supporting knowledge work environments and their features, such as lighting. In this paper, we present and reflect the design of a pilot intervention, where the use of adaptive lighting was tested. We discuss how different forms of data and knowledge can be applied as a rationale for adaptive lighting behaviour which as an ambient feature in office environment supports knowledge workers’ well-being and supports different working situations. In addition, we present the data-based evaluation methods with which we could gain feedback from users’ experiences and their way of using the lighting and the pilot office environment. The potential of this kind of real-world data for future design processes is discussed.

Keywords: knowledge work environment, adaptive lighting, dynamic lighting, user-controlled lighting, lighting design

INTRODUCTION

Adaptive lighting is defined as a wide concept referring to lighting, which adapts to information about environment and its users or to other information relevant to intended lighting behaviour. This information can be, for example, sensor-based data, or the information can be obtained from different databases, such as meteorological data. On the other hand, the control of lighting behaviour can be based on some idealized natural process, such as the model of daylight’s temporal changes of intensity and spectral characteristics, which support human biological rhythms and is, thus, employed in biodynamic lighting. Additionally, one approach to adaptive lighting is direct or indirect control of lighting by users of environments. The essential common features in all the cases described above are, firstly, that lighting is not static but an altering element of environments, and, secondly, the designer has defined the light’s behaviour to follow some reference information, knowledge or logic. (Pihlajaniemi 2016) In this paper, we present a case study concerning the use of adaptive lighting in knowledge work environments. We describe a temporary pilot intervention in a real world office environment and reflect the design, which applies different forms of information and knowledge as a base for adaptive lighting behaviour.

Contemporary knowledge work environments are designed to support multiple work situations, which range from individual concentration intense
work to collaborative knowledge creation situations (Wohlers and Hertel 2017). Knowledge work occurs through mental processes and varies from mundane tasks, such as storing and retrieving information, to high-level cognitive tasks, for example, designing, developing and creating new products (Heerwagen et al. 2004). In today’s knowledge work organizations, collaboration is highly valued. Therefore, new offices are often designed as multi-space offices (Boutellier et al. 2008) or activity-based offices (Appel-Meulenbroek et al. 2011). Both of these office types aim to provide spaces that support both individual, concentration intense working and spaces that support collaboration and teamwork. Shared workstations and work areas enable more efficient use of space, but may also increase distraction and decrease the sense of comfort (Wohlers and Hertel 2017).

Knowledge work environments have several ambient features, such as lighting, temperature and noise. In combination with office layout, ergonomics and organizational factors, the ambient features have remarkable influence on knowledge workers’ work performance and satisfaction of their environment, and importantly, on occupants’ well-being and health. Functional and comfortable workspaces support users’ task performance, whereas uncomfortable design leads to users’ stress when they need to expend their energy on overcoming environmental impediments to perform their tasks, for example, when lighting is insufficient or too bright. (De Korte et al. 2015, Vischer and Wifi 2017). Numerous studies have assessed the influence of lighting on knowledge workers. One of the published studies of user-controlled lighting in real office environment (Moore et al. 2003) revealed nearly tenfold differences in individual preferences for lighting when individual work plane illuminance was measured during a long-term study. The preferred work plane illuminance levels ranged from 91 lx to 770 lx, with average of 288 lx (Moore et al. 2003). Results from mock-office studies and laboratory experiments have revealed even larger scale of individual preferences (Newsham et al. 2004). These results implicate that fixed illuminance levels do not optimally support all individuals’ preferences and needs in shared spaces.

Subsequent studies, such as Veitch et al. (2013), have linked lighting appraisal to increased workplace satisfaction and work engagement. Daylight is typically perceived as a positive factor in the knowledge work environments. It is dynamic by its nature, it changes intensity, color temperature and direction throughout the day. (Leslie 2003). The positive effects of dynamic changes in color temperature and intensity (Van Bommel and Van den Beld 2004) can be applied into knowledge work environments with luminaires and lighting control systems. This is particularly important in knowledge work environments where amount of daylight is insufficient. Furthermore, the color temperature of polychromatic white light has been shown to affect alertness levels. Higher correlated color temperature (CCT) levels, such as 4000 K and above, promote alertness by affecting the circadian rhythm (Kraneburg 2017). Also, shorter periods of brighter and cooler light positively affect alertness, work memory and performance (Smolders et al. 2012, Huiberts et al. 2016). The level of satisfaction can be elevated through user-controlled personal lighting (Veitch et al. 2013). Although technology is unlikely ever to be able to simulate natural daylight and its properties completely, today’s lighting technology is, however, able to display dynamic lighting changes in terms of illuminance levels and color temperature of white light. Dynamic changes can be applied to knowledge work environments by pre-programming dynamic light scenes or, alternatively, by giving users a choice to adjust their personal lighting through different control methods, such as lighting control applications that are installed in their personal smartphones.

The aim of our research project InnoStaVa is to study and develop knowledge work environments in startup-companies in the Oulu region in order to support their innovation. Our object is to gain deeper understanding of the connection between space, in-
novation and collaborative knowledge creation processes. The aim of this specific paper is to present and reflect the design of one pilot intervention, where the use of adaptive lighting was tested. We discuss how different forms of data and knowledge can be applied as a rationale for adaptive lighting behaviour which as an ambient feature in office environment supports knowledge workers’ well-being and supports different working situations. In addition, we present the data-based evaluation methods with which we could gain feedback from users’ experiences and their way of using the lighting and the pilot office environment. The potential of this kind of real-world data for future design processes is discussed.

METHODS OF RESEARCH
This research was carried out in a real world environment as part of our ongoing case study. The complete setup of this case study was to study innovation supporting knowledge work environment in a local startup company. In addition to lighting, other central elements of knowledge work environment were researched. These included spatial layout of office, acoustic elements and collaboration supporting elements. The research followed a four-phase process: observation - design - intervention - evaluation. The outline of the study has been described in more detail elsewhere (Markkanen 2017). The pilot study was divided into two phases: First, dynamic lighting was programmed and users had no control over lighting control. Second, dynamic lighting was programmed and users were able to control illuminance level, color temperature of light and dynamic changes of lighting using an application in smartphones.

Pilot environment and context of research
During the intervention phase, a complete redesign and implementation was constructed in the premises of the participating startup company. The research area comprises of a two-room office of 65 m2. The office was occupied by 10 participants, including the co-founders of the company and employees, during the study. As an outcome of observation and design phases, the two-room office was redesigned into two teamwork areas and a brainstorming area during the intervention phase of the study. It should be noted that participants of the study preferred assigned workstations and that they also perform their individual tasks in the teamwork areas. The workstations were organized into groups to support short communication events and a brainstorming area was separated from another office room to support longer collaborative knowledge creation events.

The office space is in an attic of a wooden building constructed in 1900, thus the windows in the research area were very small and in comparison to contemporary office buildings, this severely limits the levels of natural daylight in the research area. Furthermore, the startup company is in Northern Finland, thus the length of day varies greatly throughout the year, from less than 4 hours to over 22 hours. The research was completed during the calendar weeks of 7 to 18, during which time the daylight increased from 8 hours to nearly 18 hours.

Lighting design and lighting control
Lighting in the research area was studied and designed with 3D modelling and rendering software 3ds Max. LED luminaires with digital addressable lighting interface (DALI) control and colour temperature control were used used in this study (Fagerhult). The dynamic lighting was programmed using programmable DALI lighting system DIGIDIM (Helvar). The control of lighting was constructed using two different methods. Due to the temporary nature of the pilot intervention, no physical lighting control was installed to the research area. First, the lighting was turned on using passive infrared (PIR) motion detectors, which were installed to ceiling-mounted acoustic boards. Lighting was programmed to turn off after 30 mins of inactivity of motion detectors. Second, the individual luminaires or groups of luminaires were controlled using SceneSet smartphone application (Helvar). During the first phase of the pilot (pilot weeks 1 to 5) users had no control over lighting. Dur-
ing the second phase of the pilot (pilot weeks 6 to 12) users were able to control the lighting with SceneSet smartphone application (Helvar).

**Data gathering methods for user-generated knowledge of work environments lighting**

Understanding the individuals’ and organizations’ daily routines provides designers important information when and where different light-generated atmospheres should be used with dynamic changes of light intensity and color temperature. During observation phase we gathered knowledge on users’ daily situation through interviews and a participatory design workshop. We will outline different ways to collect data on user experiences of dynamic lighting and personal lighting control in this paper. Results of evaluation will be discussed elsewhere (Markkanen and Pihlajaniemi, unpublished results). We used following methods in our research to evaluate participants’ experiences of piloted dynamic lighting and the use of personal control of lighting: evaluation probes (Luusua et al. 2015), workshop, experience sampling method (ESM) (Hektner et al. 2007; van Berkel et al. 2016) and data collection of lighting control through DIGIDIM lighting control system (Helvar).

**RESULTING DESIGN FOR ADAPTIVE LIGHTING BASED ON KNOWLEDGE**

Our lighting pilot research was part of a larger case study in which the layout of the studied knowledge work environment was redesigned and piloted.
Therefore, we were able to build genuinely user-controllable lighting on a personal level. As the layout of office and lighting were designed simultaneous, each workstation was designed with an individually controllable luminaire. Furthermore, we chose LED luminaires with DALI control and colour temperature control properties to enable dynamic lighting setup in the research area.

Lighting in the research area was studied and designed with 3D modelling and rendering software 3ds Max. During the design process of adaptive lighting behaviour the following aspects were considered:

1. Circadian rhythm - dynamic changes in illumination levels and colour temperature of daylight
2. Adaptivity on organizational level - programmed lighting supports daily routines
3. Adaptivity on individual level - daily routines and personal user-control of lighting

The outcome of the lighting design is described in Figure 1 and it consists of three main features: workstation lighting (1) and wall lighting (2) in teamwork and individual work areas and general lighting (3) in brainstorming area.

**Dynamic lighting supports organization’s daily activities**

Understanding the organizational routines of a typical workday can be used to enhance the lighting design to support knowledge workers’ well-being and productivity. Organizational routines may include daily meetings, breaks and other designated periods of activity, such as brainstorming sessions. These routines can be supported programming changes of light intensity or color temperature with varying length. For example, during daily morning meetings, the alerting effects of bright and cool light can be implemented during pre-defined times through programmed pulses (e.g. 30 mins) of light with dynamic increase of illuminance and change of color temperature of light. On the other hand, to support creativity and innovation during brainstorming ses-
sion, it has been shown that dim illumination supports exploration and creative processes better than bright light (Steidle and Werth 2013). These situations can be supported through programmed situations, which users can activate through lighting control system. In this case study, we implemented brief pulses of high illuminance with cool color temperature in pre-programmed dynamic workstation lighting during morning and afternoon periods. The combination of daylight simulation changes and organizational routine supporting changes were programmed using programmable DALI lighting system DIGIDIM (Helvar) and the designed lighting was implemented to research area during pilot weeks 1 to 12.

**Individual control of lighting enables personal lighting**

At the end of week 5, we explained participants about the dynamic changes in color temperature of light and in illuminance levels, which were used in pre-programmed lighting. They were also instructed how to use SceneSet application installed in their smartphones to control lighting during the following weeks of pilot (pilot weeks 6 to 12). The application contained both pre-programmed changes and manual lighting control. Participants were able to override the programmed dynamic lighting by applying static lighting settings to teamwork and brainstorming areas. The lighting control was divided as follows:

**Personal workstation lighting.** Personal preferences for lighting in work environment have been shown to differ greatly in terms of illuminance level and color temperature (Moore et al. 2003). In our pilot study, participants were able to control their workstation lighting individually. The pre-programmed options included static lighting scenes if 250 lx, 500lx and 1000 lx with color temperatures of 3000 K, 4000 K and 5000 K, respectively. In addition, there were a dynamic lighting scene of pulse of high illuminance with cool color temperature for one hour. Furthermore, there was a possibility to set manually both illuminance level and color temperature.

**Wall lighting in teamwork area.** The wall lighting and workstation lighting function together to create the office lighting. Wall illuminance has been shown to effect on workplane illuminance level preferences (Chraibi et al. 2017). Wall illuminance has more impact on the atmosphere when compared to illuminance at workstations. In this study, participants were able to control the group of spot luminaires creating wall lighting in similar fashion as their workstation lighting. In addition, a pulse of high illuminance with cool color temperature was implemented in wall lighting options during the second phase of pilot.

**General lighting in brainstorming area.** The luminaires in brainstorming area had fixed color temperature of 3000 K or 4000 K. Participants were able to adjust the lighting in brainstorming area from pre-programmed option of 3000 K luminaires only, 4000 K luminaires only, or both group of luminaires, resulting in three different atmospheres in space. This enabled participants to find the suitable atmosphere for group activities and individual working in the brainstorming area.

**Data collection methods for evaluation and improved lighting design**

To understand the effect of lighting for participants of the study and their experience of light and personal lighting control, we collected data through evaluation probes and workshops, ESM and direct data from light control situation through a gateway tool that accesses the DIGIDIM lighting control system. The results of pilot evaluation will be published elsewhere (Markkanen and Pihlajaniemi et al. 2017, unpublished results). In this pilot, we used evaluation probes to collect data during the intervention. At the end of pilot, we also organized a workshop to discuss with participants their experiences of pilot, including dynamic lighting and user-control of lighting. These methods generated rich qualitative data on participants’ experiences of piloted adaptive lighting. Gained knowledge is beneficial in developing lighting design in forthcoming knowledge work environment pilots. Importantly, such qualita-
tive research methods often generate design inspiration from the users of the environment and point out events and experiences designers and researchers may not be aware of.

In this pilot, we also applied ESM method (Visuri and van Berkel et al. unpublished results) to study the users’ motives to control the lighting. This was organized by giving participants smartphones with application that opened a short query every time participants used SceneSet application to control the lighting. Furthermore, we also used a gateway tool developed by Helvar to collect data of each individual participant.
lighting control event applied by the participants of the study from DIGIDIM lighting control system.

**DISCUSSION AND CONCLUSIONS**

When lighting design of knowledge work environment is based on standard recommendations, it relies on knowledge that has not been adapted to the specific needs of users and the restrictions the architecture or the environment provides. The lighting technologies that enable adaptive lighting are still relatively novel and not yet commonly used. Occupancy based lighting control and daylight sensors are considered import energy saving options. However, creating atmospheres that support different tasks and situations in knowledge work environments should be also considered important, as they promote users well-being and comfort. Contemporary knowledge work environments promote collaboration and shared desk policies. Noise and lack of assigned desk have been shown to decrease users’ satisfaction towards their environment (Wohlers and Hertel 2017). Adaptive user-controlled lighting provides knowledge workers an opportunity to control their own surroundings, which has positive effects on mood, well-being and productivity and increases users’ satisfaction to their environment (Veitch et al. 2013).

In this paper, we present an user-centric approach to design adaptive lighting in knowledge work environment, which combines design and evaluation of implemented lighting design. The used evaluation methods facilitate iterative lighting design process that enables genuine user-centric design by means of gaining knowledge of users’ experiences and motives to adapt lighting to their desired needs. Our approach is presented in Figure 3.

The daily situations of researched case organization were determined using qualitative research methods and taken into account when designing lighting for implemented pilot intervention. Three levels of adaptive lighting were considered in the lighting design process: First, the positive features of natural daylight were implemented in dynamic lighting design of piloted work environment. These included dynamic change of illuminance levels and color temperature. Implementing positive qualities of daylight in interior is specifically important for environments where natural daylight is scarce and during months, when the length of day is short. Second, organization’s daily activities were analyzed and alertness promoting brief light pulses were implemented to dynamic lighting design for workstation lighting in teamwork area. Third, participants were able to control the lighting of shared environment and their assigned workstations in the second phase of the pilot study. In addition to enhanced user satisfaction to their environment (Veitch et al 2013), the user-control of lighting provides means to collect data on the lighting situations generated by the users. Furthermore, we applied ESM method to make inquiries on participants’ motives to apply changes to dynamic lighting.

The design and evaluation set-up presented here provides tools for lighting designers that enable reaction to users changing needs and preferences. The presented pilot case system gives user control of their work environment and also creative means to explore and test how lighting can support their daily situations. Importantly, evaluative methods serve as communication tools between the users and designer. Both ESM data and lighting control event data are available through remote online access for designers and researchers. In future systems, online access to such a system would enable modifications to lighting design. Lighting designer is able to make changes into previously programmed dynamic lighting and pre-defined user-controllable lighting situations. In addition, based on gained knowledge and user-controlled situations, the designer would be able to create new dynamic lighting situations. Learning from our pilot, the critical point in system described above, is the users’ readiness to use the system and to actively modify the lighting to support different daily situations. New research and development of easy to use and intuitive user interfaces are deemed necessary.
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