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Context-based presets for lighting setup in residential space

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A B S T R A C T

This study aims to derive context-based lighting setup presets in residential space by exploring the multilateral relationships among household activities, affects, and lighting setups. Three procedures were involved: First, sixty affective words were evaluated through which seven affect factors were extracted to facilitate the evaluation of colored illumination in the subsequent experiment. Second, in the user study, seven affect factors and thirty household activities were used to evaluate 147 lighting setups extracted from combinations of twelve hues, six illuminance levels, and three purity levels. As a result, twenty lighting setup presets were derived that were not only activity-based, but affect-based as well. Lastly, the twenty presets were prototyped as a set of testbed to further explore potentials and limitations. This study demonstrates that intuitive, context-based presets can help users explore the effects of colored illumination in creating a diverse range of user experiences.

1. Introduction

As illumination technology rapidly progresses each year, the role of artificial illuminations is changing to become more meaningful and dependent on user context (Nawyn et al., 2012). One of the light sources that have made such changes to the illumination industry possible is the Light-Emitting Diode (LED). LEDs have become particularly popular for because they are physically small, highly efficient, and allow users to manipulate the brightness and colorific characteristics of light to generate highly optimized illumination according to specific user activities and preferences (Chen et al., 2013).

Previous studies have shown that illumination can affect both the physical and mental conditions of humans (Juslén et al., 2007; Leichtfried et al., 2015). As one of the earliest studies of colored illumination, Gerard (1958) measured physiological reactions to show that red light increases arousal level. In a more recent research, the effects of hue, lightness, and saturation of colored illumination on arousal and valence have been studied through subjective evaluations (Rajae-Joordens, 2011). To further highlight the potential of using colored illumination to improve everyday life, some researchers have expanded their scope of research to investigate the psychological and physiological effects of a wider range of colored illumination (Lee and Suk, 2012).

Another research trend in illumination is investigating 'affect' as an important element of user experience (Park et al., 2013). Affect, also known as the perception of affective quality, indicates the subjective feelings or impressions that users experience (Han and Hong, 2003). Variable illumination color temperatures and intensities exert a potential advantage indoors with respect to subjective mood (Hoffmann et al., 2008). Park et al. (2011) investigated how LED illumination hues influence the rating and recognition of affective stimuli. Moreover, as an attempt to develop a theoretical basis of affective illumination, Woo et al. (2013) proposed a dimensional model of affectiveness by evaluating the affective quality of an illumination with different color temperatures. In response to these findings, it has become accepted that colored LED illumination can be effectively used to positively improve users' mood and their well-being (Suk, 2013).

Highly flexible in color and brightness manipulation, LEDs are not only being used as light sources in decorative spaces, like retail shops and restaurants, but have shown the most market growth for ambient illumination in the residential sector (Price, 2003). Ambient illumination refers to the general illumination in a space that illuminates a room in a uniform, unfocused, and indirect manner with no visible direction of light. Although it can come in different types, ambient illumination generally takes the form of ceiling lamps installed in the center of a room (Leslie and Conway, 1996). Because ambient illumination, in residential spaces in

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0003-6870/

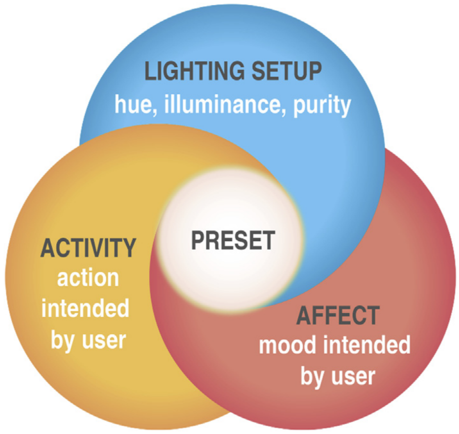


Fig. 1. Structure of a complete context-based preset for residential space. The term 'activity' refers to the action or behavior the users intend to perform, such as reading or meeting; 'Affect' refers to the subjective mood intended by the users, such as relaxing and energizing; and 'lighting setup' refers to the three color components of illumination (hue, illuminance, and purity).

particular, often requires high functionality, users must be able to control lighting setup so as to best serve their needs depending on the contextual situation.

2. Related research

2.1. Affect as a contextual variable

Affect is often a favorable variable for defining user context and user needs (Park et al., 2013). Some recent works that explore context-aware lighting setup recommendations have shown the effectiveness of affective states as contextual variables (Vandewalle et al., 2010; Zheng et al., 2013). These studies have agreed that the colors of illumination influence the way that the brain processes perception; therefore, incorporating affective states in controlling the lighting setup can help users make better decisions in creating the intended atmospheric mood.

In support of this argument, Ku et al. (2012) proposes "IlluMe," software that processes natural language from instant message logs to analyze the affective state of users and to create personalized ambient environments by means of illumination and music. The "Emotional Impact Slider" is another example of incorporating affect as a parameter for controlling the lighting setup (Liew, 2007). It is an interface concept for cinematic and theatrical lighting setup that uses emotion-based abstractions as communicative functions to generate entertaining environments. However, the affective states covered by these studies are rather limited or do not go hand in hand with the residential context.

2.2. Lighting setups for residential space

The range of activities that take place within a home can vary greatly. Depending on the activity, people may wish to encounter different affective states that can help enhance those everyday experiences. For example, when listening to music, people may want to feel a sense of relaxation; whereas, when studying, they may prefer a sense of alertness and focus. As RGB LEDs become available to homes, it has become possible to use colored LED illumination to accommodate these different affective needs for various user contexts by creating optimal lighting setups that are both fitting for the activity and evoke the desired affective state. As mentioned earlier, there are some researches that take into consideration the user context (Ku et al., 2012; Liew, 2007; Vandewalle et al., 2010). However, there is yet to be any research that investigates colored illumination with the context of a residential environment in mind, specifically concentrating on the diverse range of activities and affective states that take place in a home. Hence, with the lack of studies on the affective responses of colored illumination, this study aims to examine the users' affective responses and preferences for colored illumination as well as derive optimal lighting setups for residential spaces.

2.3. Benefits of using context-based presets

Using manual controls to change the settings of high dimensional systems can be difficult and time consuming. For

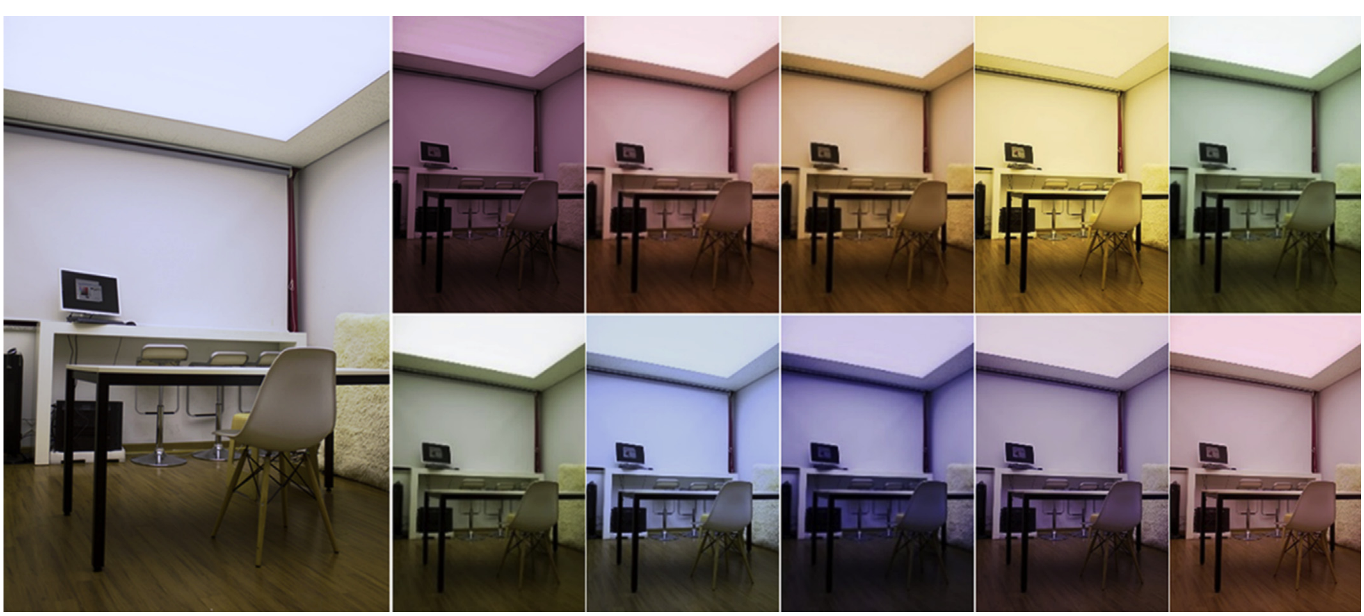


Fig. 2. Experimental room equipped with LED luminous ceiling. The walls and majority of the furniture placed in the room were white, as white reflects environmental illuminations most properly. All curtains were closed to block off other light sources.

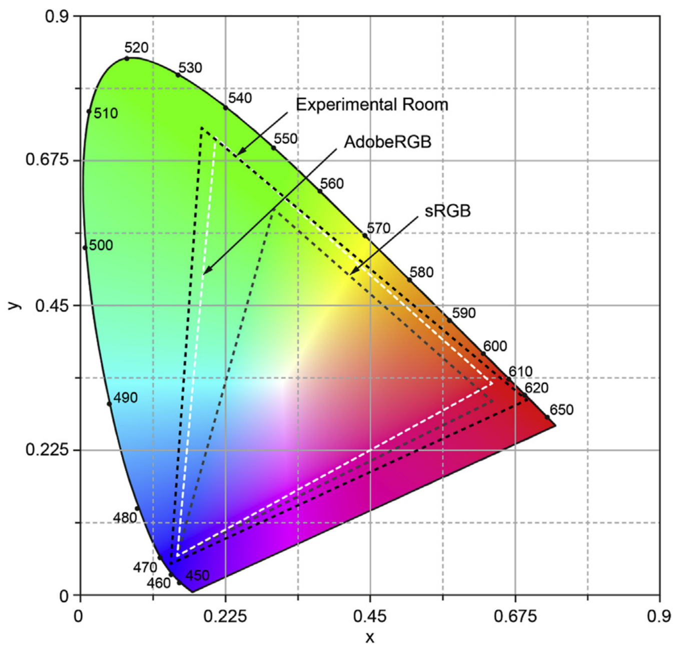


Fig. 3. The color gamut of the experimental room is compared with AdobeRGB and sRGB. The area of each triangle is the entire range of possible chromaticities.

illumination control systems, manual controls can often lead to wrong selection of light intensity and moods, making users feel annoyed and fatigued (Steffy, 2008). Contrary to manual controls, presets provide users with an easy and natural way of changing multi-dimensional parameters (van Wijk and van Overveld, 2003). With that said, one of the main advantages of using context-based presets is that the presets are not only activity-based, but affect-based as well. In other words, the context-based presets reflect optimal lighting setups for various household activities and the affective state users want to experience for those activities. This user-centered, rather than technology-centered, approach can help make the task of selecting optimal lighting setups more simple and relatable to execute.

2.4. Objective

The main purpose of this study is to explore the multilateral relationships between household activities, affects, and lighting setups in order to derive context-based presets in residential space, as shown in Fig. 1. A context-based preset denotes an optimal lighting setup that accommodates both activity-based and affective needs of users. The context-based presets are expected to provide users affordance in selecting optimal lighting setups in residential homes. These findings will be applied as the basis for designing a user-centered LED illumination control interface for future illumination systems.

3. Preliminary study: extraction of affect factors

Depending on the medium and context, the set of affect factors representing the affective state experienced by users can vary (Desmet, 2012). This implies that the factors for evaluating affective responses to colored illumination can be different from the factors used to evaluate product colors. The purpose of this preliminary study was to extract affect factors of colored illumination to evaluate ambient lighting setup in the main user study for deriving context-based presets.

3.1. Extraction of affective words

In order to extract the affect factors for evaluating the affective responses to illumination, numerous adjectives were extracted from existing papers related to the evaluation of affective illumination (Park et al., 2011; Shin et al., 2009; Woo et al., 2013). Affective adjectives with negative valence were removed to keep the context-based presets focused on the positive well-being of users, and adjectives which were synonyms were combined as one. Hence, a total of sixty affective words were derived for the preliminary study.

3.2. Illumination stimuli

The examination was conducted in a room equipped with a LED luminous ceiling, as shown in Fig. 2. The colorific properties of

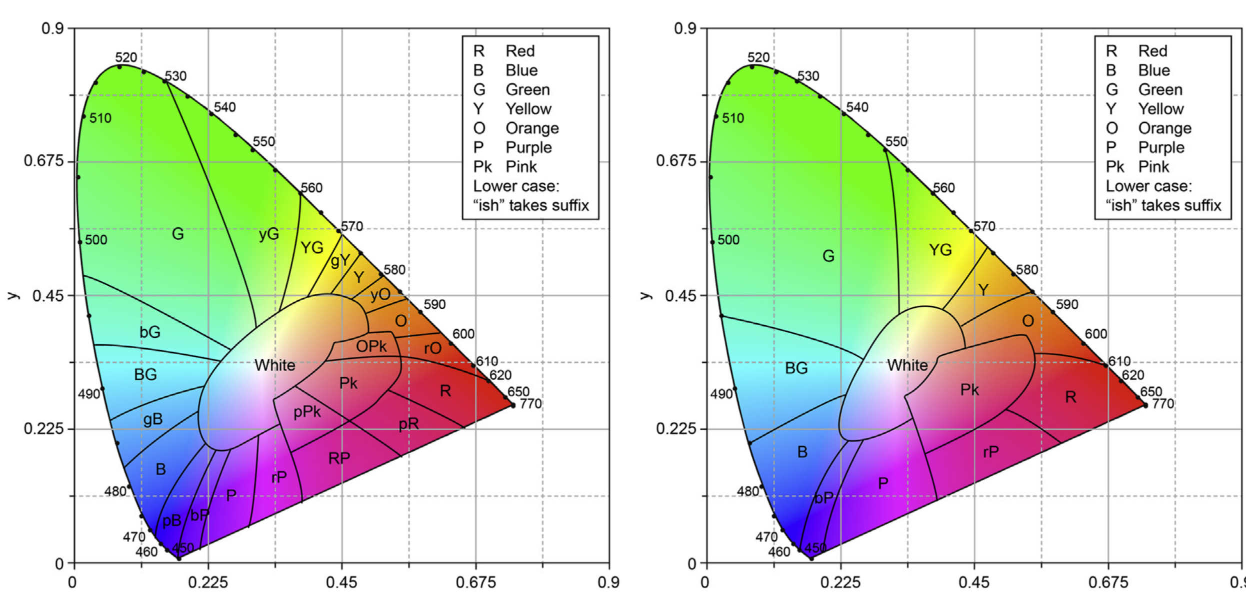
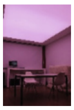
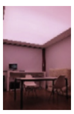
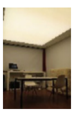
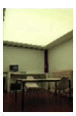
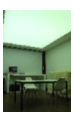
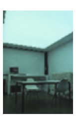
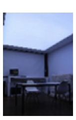
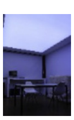
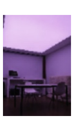
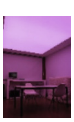
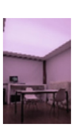
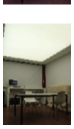


Fig. 4. Left: Approximate color regions on CIE 1931 x, y chromaticity diagram (Gage et al., 1977); Right: Color names of light sources from KS A 0012 (2013) standard.

Table 1
The dominant wavelength (nm), illuminance (lux), and excitation purity (%) of the twelve illumination stimuli. 'c' indicates the complementary dominant wavelength for the colors on the line of purples. Due to the camera's self-corrective function, the colors appear darker and more vivid than in reality.

Photo	Color	Dominant wavelength (nm)	Illuminance (lux)	Excitation purity (%)
	Red (R)	625	602	28.21
	Orange (O)	595	533	25.65
	Yellow (Y)	580	567	28.83
	Yellow Green (YG)	570	566	23.40
	Green (G)	525	608	27.66
	Blue Green (BG)	495	552	24.27
	Blue (B)	475	513	21.34
	Bluish Purple (bP)	380	550	22.14
	Purple (P)	565c	520	27.54
	Reddish Purple (rP)	525c	509	29.02
	Pink (Pk)	500c	533	24.14
	White (Wh)	–	548	7.07

ambient illumination could be controlled by adjusting the *R*, *G*, *B*, and *W* (White) input values. The color gamut of the experimental room is compared with two standards (AdobeRGB and sRGB). A color gamut refers to the range of colors which can be accurately represented by a certain output device. A larger area inside a triangle is regarded to represent a capability of displaying more colors. As shown in Fig. 3, the LED luminous ceiling of the experimental room could achieve a wide color gamut, which in turn is capable of displaying a wider span of colors. The LED ceiling was covered with Barrisol® diffusers (officially registered trademark of PVC translucent) to distribute uniformly the greatest amount of light without causing glare problems (Martins Mogo de Nadal,

Table 2
Seven affect factors for colored illumination were identified, labelled as 'gentle,' 'affectionate,' 'inspiring,' 'entertaining,' 'alert,' 'elegant,' and 'nostalgic' (N = 30).

Factor label	Included affective keywords	Cumulative value of factor loading (%)
Gentle	tranquil, gentle, clear, pure, cool, calm, safe, soothing, relaxed, modern, refreshing, holy, natural, neutral	18.15
Affectionate	happy, warm, sweet, loved, kind, soft friendly, generous, comfortable, lyrical	29.18
Inspiring	intriguing, creative, unique, mystical, intense, luxurious	35.53
Entertaining	humorous, exciting, playful, energetic	41.65
Alert/Attentive	radiant, focused, bright vivid, dazzling	47.40
Elegant	elegant, beautiful, pretty, romantic, classy, quality	52.58
Nostalgic	dreamy, contemplative, majestic	56.96

2005). A uniform and soft illumination environment was realized in the room, which illuminated the entire space, ensuring that the participants fully adapted to the surrounding environment.

The illumination stimuli were created using three quantitative parameters that make up the colorific components of light sources: dominant wavelength, illuminance, and excitation purity, which are analogous to hue, brightness, and saturation, respectively (Malacara, 2002). The dominant wavelength, which represents the perceptual notion of the hue, is denoted by nanometers (nm). Illuminance, which corresponds to the brightness of the lit environment, is expressed as lux (lx). Excitation purity is a quantitative measure of the saturation that ranges between 0 and 100%. The larger the purity, the more saturated the color appears, or the more similar the color is to its spectrally pure color at the dominant wavelength. The smaller the purity, the less saturated the color appears, or the more white it is (Erdogan, 2013).

As for the illumination stimuli, the twelve light source colors as stipulated by the Korean Standard Association (KS A 0012, 2013) were selected as hues to represent the different colored illumination, as shown in Fig. 4. The twelve color names were red (R), orange (O), yellow (Y), yellow green (YG), green (G), blue green (BG), blue (B), bluish purple (bP), purple (P), reddish purple (rP), pink (Pk), and white (Wh). The illuminance and purity were kept relatively constant. The illuminance range for all stimuli was between 500 and 600 lux, which is a recommended illuminance for tasks with medium visual requirements for indoor (ISO 8995, 1989; Karwowski, 2006; KS A 3011, 1998). Because this study focuses on the context of ambient residential illumination, the purity of the lights were preserved at a relatively low level within the range of 20–30%, with the exception of white (0%), so that they would seem practical for residential space. The colorimetric values of each stimulus were measured with a chroma meter (Konica Minolta CL-200), at the center of the experimental room from a height of a table around which participants were seated, as shown in Table 1.

3.3. Procedure

A total of thirty college students (sixteen females and fourteen males) were recruited in the preliminary study. The average age of the participants was 21.93 years, with a standard deviation of 2.33 years. All participants were paid volunteers. Prior to the experiment, all participants were tested for color detection deficiencies using Ishihara Test for Color Blindness. No significant color deficiencies were observed. All participants had normal or corrected-normal visual acuity. Experiments were conducted in an experimental room, under the following conditions: ambient temperature = 23.8 ± 2 °C; ambient humidity = 39 ± 5%; and ambient noise 44.6 ± 10 dB(A). The ambient conditions of the room were maintained for human comfort (ISO 7730, 1993; Parsons, 2000). An ethical approval was obtained from the Korea Advanced Institute of Science and Technology (KAIST) Institutional Review Board prior to the commencement of all studies concerning human participants (Approval No.: KH2015-23).

During the experiment, the twelve illumination stimuli were exposed to the participants in random order. For each stimulus, participants were asked to evaluate how appropriate each of the affective words were in expressing their affective state based on a seven-point Likert scale, where seven was most appropriate in expressing the affective state, whereas one was the least appropriate. The participants were asked to observe diffuse light reflected from furniture and walls instead of directly observing the light source. The walls and majority of the furniture placed in the room were white, as white reflects environmental illuminations most properly. To allow some chromatic adaptation to take place prior to each evaluation, participants were asked to close their eyes for five seconds, reopen their eyes, and observe the environment for a minimum of another five seconds before evaluating the stimuli. The stimuli were changed while the participants' eyes were closed. The experiment lasted approximately thirty minutes.

Table 3
The thirty activities were grouped into five primary categories through promax rotation (N = 210).

Group	Included activities
Group 1	cleaning, studying, ironing/laundry, read novel, eat breakfast, dress up, wake up, planning, eat lunch, work(analogue), sewing/handcraft, drawing, gardening, cooking, washing dishes
Group 2	meditate, sleep/nap, listen to music, tea/coffee break
Group 3	watch movie, watch TV, use electronic devices, work(digital)
Group 4	socializing, face to face conversation, phone conversation, play card games, play instrument
Group 5	dining, eat dinner

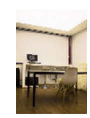
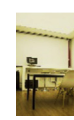
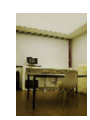
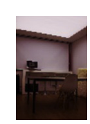
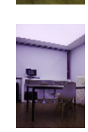
4. Results and analysis

The adequacy test of the evaluation of the twelve stimuli produced a Kaiser-Mayer-Olkin (KMO) value of 0.91, and the Bartlett's test yielded a significant value of less than 0.05. This denoted that the assessments for the affective words were correlated and were appropriate to perform a factor analysis. Through factor analysis, seven affect factors for colored illumination were identified, labelled as 'gentle,' 'affectionate,' 'inspiring,' 'entertaining,' 'alert,' 'elegant,' and 'nostalgic.' Table 2 shows the selected factors, which account for 56.96% of the data.

5. User study: derivation of context-based presets

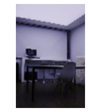
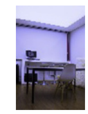
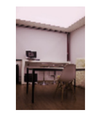
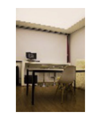
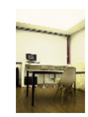
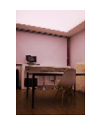
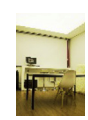
The purpose of the user study was to find and establish the multilateral relationships between household activities, affects, and lighting setups, and thereby derive context-based presets that could be applied as the basis for designing a user-centered LED illumination control interface.

Table 4
List of the twenty complete context-based presets. The lighting setup is denoted by hue/purity/illuminance. Due to the camera's self-corrective function, the colors appear darker and more vivid than in reality.

Preset name	Household Activity	Affect	Lighting setup	Photo
Mindful reading	Read Novel	Alert/Attentive	YG/L/1500	
Cozy reading	Read Novel	Affectionate	O/M/900	
Food centric	Eat Breakfast, Eat Lunch, Cooking	Alert/Attentive	Wh/900	
Gentle meal	Eat Breakfast, Eat Lunch, Cooking	Gentle	YG/L/300	
Wakeful morning	Wake up, Dress up	Alert/Attentive	O/L/1500	
Cognizant tasking	Planning, Studying, Work, Drawing, Gardening, Sewing/Handcraft	Alert/Attentive, Not Affectionate, Not Nostalgic	bP/L/900	
Focused cleaning	Ironing/Laundry, Cleaning, Washing Dishes	Alert/Attentive	Wh/1500	
Warming rest	Listen to Music, Tea/Coffee Break	Affectionate	Y/M/900	
Nostalgic rhythm	Listen to Music, Tea/Coffee Break	Nostalgic	Y/M/300	
Easy listening	Listen to Music, Tea/Coffee Break	Gentle	G/L/600	
Hypnotic sleep	Sleep/Nap	Not Alert/Attentive, Not Entertaining	R/L/30	
Reflective meditation	Meditate	Nostalgic, Gentle	YG/L/600	
Elegant cinema	Watch TV, Watch Movie	Elegant	P/L/600	

(*continued on next page*)

Table 4 (*continued*)

Preset name	Household Activity	Affect	Lighting setup	Photo
Chillin' TV	Watch TV, Watch Movie	Gentle, Not Alert/Attentive, Not Affectionate	bP/M/30	
Tech alert	Uses Electronic Devices, Work (Digital)	Inspiring, Not Affectionate	bP/M/900	
Friendly company	Socializing, Face-to-face Conversation, Phone Conversation, Play card games	Affectionate	Pk/L/600	
Graceful discussion	Socializing, Face-to-face Conversation, Phone Conversation, Play card games	Elegant	O/L/900	
Passionate musician	Play Instrument	Affectionate	Y/L/900	
Romantic dining	Eat Dinner, Dining	Affectionate	R/L/600	
Luxurious dining	Eat Dinner, Dining	Elegant	Y/M/1200	

5.1. Extraction of user activities in residential space

Through literature reviews on studies of daily life activities in the home, a list of common household activities was extracted (Dey, 2009; Naeem and Bigham, 1990; Lee et al., 1990). Activities that overlapped or were relatively similar to one another were combined together for a total extraction of thirty different household activities (e.g., 'cooking' and 'preparing food' were combined and labelled simply as 'cooking').

5.2. Illumination stimuli

The examination was conducted in a room equipped with an LED luminous ceiling, as described in the preliminary study. To create the illumination stimuli, twelve hues, six illuminance levels, and three purity levels were taken into consideration. The hues were derived from the KS A 0012 standard, as it was done in the preliminary study (KS A 0012, 2013). The illuminance levels ranged from 30 to 1500 lux based on the ISO 8995 and KS A 3011 recommendation of interior illuminance levels for different types of visual tasks (ISO 8995, 1989; Karwowski, 2006; KS A 3011, 1998). The illuminance was divided into five levels (30, 300, 600, 900, 1200, and 1500 lux). Lastly, the purity levels were divided as low (L) purity (<30%), medium (M) purity (>30%, <60%), and high (H) purity (>60%). However, due to the technological limitations of the LED ceiling, some combinations could not be produced. Hence, a total of 147 different lighting setups were extracted. All measurements were taken at the center of the experimental room from a height of a table around which participants were seated around and using a chroma meter (Konica Minolta CL-200).

5.3. Procedure

A total of 210 college students (113 males and 97 females) were recruited for the experiment, with an average age of 22.95 years and a standard deviation of 2.15 years. All participants were paid volunteers. All participants had normal or corrected-normal visual acuity with no significant color deficiencies. During the experiments, each experimental group was exposed to 20 to 25 different lighting setups in random order depending on the pace of their evaluation. Specifics of the experimental setup, namely the LED ceiling, the furniture arrangement, and the ambient conditions of the experiment room were similar as in the preliminary study.

Participants were asked to complete two types of evaluation for each lighting setup: 1) affective evaluation and 2) activity evaluation. For the affective evaluation, participants were asked to determine whether the lighting setups were appropriate for experiencing the seven affective states ('gentle,' 'affectionate,' 'inspiring,' 'entertaining,' 'alert,' 'elegant,' and 'nostalgic') derived from the preliminary experiment. During the activities evaluation, participants were asked to determine if the lighting setups were appropriate for performing the thirty common household activities. Similar to the preliminary study, participants were asked to close their eyes for five seconds, reopen their eyes, and observe the environment for an additional five seconds before starting the evaluation to accommodate for the time that it takes for chromatic adaptation to occur.

5.4. Results and analysis

Based on the assessments on the activities, a factor analysis was performed. The KMO value was 0.94 and the Bartlett's test was statistically significant ($p < 0.05$). A promax rotation, one of the non-orthogonal rotation methods, was applied, as the household activities could be correlated with one another. Thus, based on the analysis, the thirty activities were grouped into five primary categories, as shown in Table 3. Each activity group had a Cronbach's alpha value greater than 0.66, which is an acceptable range for internal consistency within each factor. The correlation analysis within each group yielded statistical significances at the 0.05 level.

In order to provide users with a diverse palette of context-based presets, the five primary activity groups were subdivided by the following strategies. First of all, to derive the most appropriate lighting setups for the different activities, the five lighting setups with the highest mean scores were observed. One-way ANOVA showed that there were no significant differences between the top five lighting setups ($p > 0.05$), indicating that they were all equally preferred by users and could all be used to represent the optimal lighting setup for the given activity. Hence, the top five lighting setups were taken as being potentially the most appropriate lighting setups for each activity.

Secondly, while analyzing the top five lighting setups, it was observed that some activities within each activity group showed similar lighting setup preferences (if more than three lighting setups were interwoven) compared to others within the same group. As such, these activities where further divided into smaller groups, based on their similarity. For instance, among fifteen activities in Group 1, the top five lightings setups for the ‘Dress Up’ activity were: W/1500, B/L/900, O/L/1500, YG/L/300, W/1200; and for the ‘Wake Up’ activity: B/L/900, O/L/1500, B/L/1500, W/1500, Y/M/1200. Therefore, ‘Dress Up’ and ‘Wake Up’ activities were separated as a single group. Consequently, Group 1 with fifteen activities was further divided into five groups, Group 2 into three groups, Group 3 into two groups, and Group 4 into two groups. A total of thirteen activity groups were formulated.

To determine which affective responses participants want to experience for different activities and to see if there are relationships among household activities, affects, and lighting setups, the affective state with the highest mean from each of the top five lighting setups for each activity were observed. If the mean values for the affective states were in the upper third quartile, the affective states were considered to be associated with the lighting setup and the activity that the lighting setup is intended for. Through this process, a total of twenty context-based presets were selected and given representative names that express both the nature of the activity group and its associated affect. Each preset is affiliated with distinctive household activities, affects, and lighting setups defined by hue, purity, and illuminance. The results of twenty context-based presets are shown in Table 4.

5.5. Discussion

From the preliminary study, seven different affect factors were extracted. The representative lighting setup for the affect factors ‘affectionate,’ ‘alert/attentive,’ ‘elegant,’ and ‘gentle’ in this main user study were consistent with results in the preliminary study. Unfortunately, it was difficult to assess the lighting setup associated with the factors of ‘nostalgia,’ ‘inspiring,’ and ‘entertainment’ as there was only one activity-lighting setup relationship associated with each of these three affect factors. Moreover, the affective evaluation of lighting setup showed that the majority of activities and lighting setups are associated with the two main affect factors of ‘alert/attentive’ and ‘affectionate’ than with the other five remaining factors. It is interesting to note that these two affect factors show similar traits to the arousal and valence model, in which ‘affectionate’ represents the measure of valence and ‘alert/attentive’ represents arousal levels (Russell, 1980).

For this study, participants showed a tendency to prefer lighting setups with high illuminance levels (600 lux and above). This may be due to the fact that the windows in the experimental room were completely covered up with opaque curtains. Without the presence of any natural illumination, participants may have felt the space to appear darker. Additionally, colored illumination generally tends to have a low Color Rendering Index (CRI), and can make some colors appear darker than when they are viewed under white illumination. Hence, this could have led participants to perceive the room as being duller overall, causing them to favor lighting setups with high illuminances. It could be possible to conduct further research by keeping the curtains open, and adding the effects of the time of day and natural daylight as a variable of user context. Moreover, because this study investigates the ambient illumination of residential environments where everyday activities take place, it was no surprise that the purity of the lighting setups participants preferred were either low or medium.

6. Context-based presets for practical application

6.1. Testbed implementation

Using the twenty context-based presets derived in the user study, a set of testbed was prototyped: a smartphone application and a miniature model house. The objective of the testbed evaluation was to explore the potentials and limitations of the presets derived in the study. Fig. 5 illustrates the operational flow of the implemented application. Using a camera function, the application allows users to take a photo of the area for which they want to change the lighting setup. The application then uses photo filters to create renderings of what the lit environment would look like when the presets are turned on.

The smartphone application was then programmed to control Philips Hue LED light bulbs. The Hue light bulbs were installed in a miniature model house, approximately 1:10 in scale, so that users could experience the intended context of a residential home. Although it would have been ideal to carry out the evaluation in real life-sized rooms, this optimal experimental setup was difficult to implement due to its large scale and cost. The miniature model house was composed of three main areas: the kitchen and dining room, living room, and the bedroom, as shown in Fig. 6.

6.2. Procedure

Sixteen graduate students (eight females and eight males) with an average age of 24.06 years and a standard deviation of 1.73 years were recruited. All participants were paid volunteers without any color deficiency. During the evaluation, all other light sources, except the Philips Hue light bulbs, were turned off to avoid any external influences to the lighting setup in the miniature house. The ambient conditions of the experiment room were maintained similarly to the preliminary study and user study.

The presets in the application were labelled with numbers from one to twenty. During the evaluation, participants were given a set of context cards, titled with preset names together with information about the activities and affective state associated with each preset (e.g., title: cozy reading; activity: reading a novel; affect: affectionate). Participants were instructed to read the information

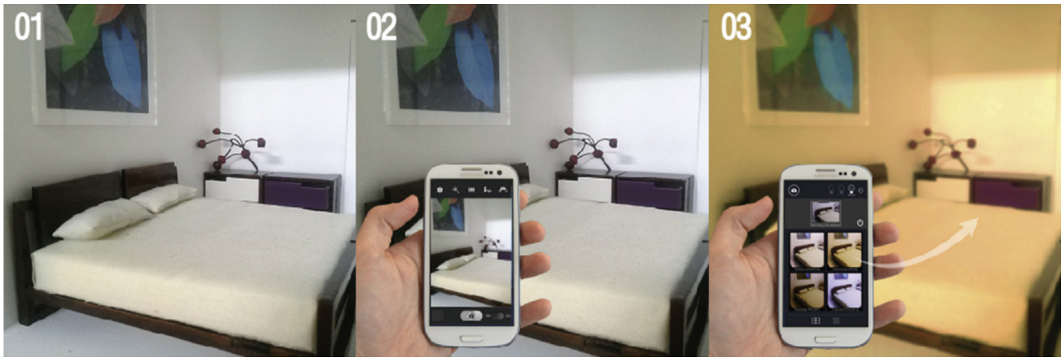


Fig. 5. Operation flow of the testbed: 1) want to comfortably read a book before going to bed; 2) take a photo of the space you want to preview (bedroom) using the application; and 3) select optimal lighting setup by viewing filtered images of presets.

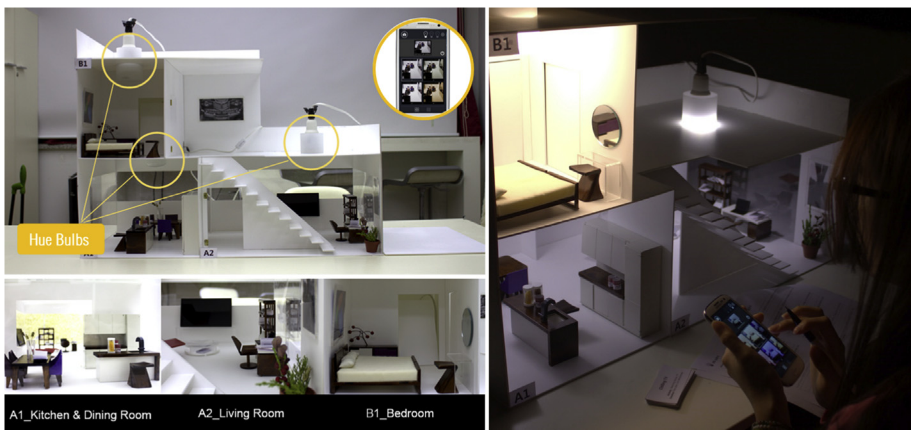


Fig. 6. Miniature prototype of a residential home. The miniature model house was composed of three main areas: the kitchen and dining room, living room, and the bedroom.

on the cards, select a space in the miniature model house where they would want to conduct the activity written on the card, take a picture of it, and write the preset number that best satisfies the user context in terms of both activity and affect. Upon completing the evaluation, a post interview was conducted.

6.3. Results and discussion

The participants' interviews proved that context-based presets have a lot of potential to be employed in the residential environment, as they give users intuitive information about optimal affective lighting setups. Participants also mentioned that it would help make everyday activities seem more interesting and meaningful. Among the twenty context-based presets, the top five presets with the highest frequency of successful match were: 'Cognizant Tasking,' 'Focused Cleaning,' 'Graceful Discussion,' 'Luxurious Dining,' and 'Nostalgic Rhythm'. The hue values for these five presets were within the natural color temperature range (white, yellow, orange, and blue). Because of the miniature representation of the lighting setup, there is a chance that there was an absence of chromatic adaption among the users during the evaluation, making the colored illuminations feel more saturated and unusual than when experienced in a large, full-scaled room. The dynamic in color and intensity of the ambient illumination was reported to bring advantages in health and well-being of users (van Bommel, 2006). The result of this study indicated that while colored illumination is effective in producing various affective responses from its users, people are not yet familiar with the concept of using colored illumination in residential environments. Therefore, the twenty context-based presets derived from this study should be selectively adopted in a real residential space by considering practical issues, such as user preferences and adaptability.

7. Conclusion

The purpose of this study was to identify context-based lighting setup presets for residential space, which can be applied as the basis for designing a user-centered LED illumination control interface. The multilateral relationships between household activities, affects, and lighting setups were explored to derive twenty context-based presets for the residential space, varying diversely in hue. Firstly, there were seven factors - 'gentle', 'affectionate', 'inspiring', 'entertaining', 'alert/attentive', 'elegant', and 'nostalgic'- that can be used to describe the positive affective experiences of users in colored illumination. Secondly, context-based presets for residential space can be derived by finding multilateral relationships between activities, affects and lighting setups. As such, the user-centered approach proposed in this study can be applied to develop lighting setup presets for other user contexts. Lastly, the role of colored illumination shows potential for growth in everyday activities. Although the concept of applying colored illumination to everyday living may not yet be widely accepted by the general public, this study demonstrates that an intuitive, context-based preset can help users progressively explore the effects of colored illumination in creating a diverse range of user experiences so that users will gradually develop an interest in integrating colored illumination into their lives.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.apergo.2015.07.023.

Table A.1
CIE *x* and *y* values, illuminance, purity, correlated color temperature (CCT), and color rendering index (CRI) measurements of the twenty presets.

	Color ID	*x*	*y*	Illuminance (lux)	Purity (%)	CCT (K)	CRI (Ra)
1	R/L/30	0.419	0.322	30.56	20.07	2539	20
2	R/L/600	0.449	0.321	596.63	28.43	2094	72
3	O/L/900	0.433	0.365	885.00	29.98	2718	72
4	O/L/1500	0.400	0.363	1511.00	23.63	3376	78
5	O/M/900	0.459	0.353	904.50	39.81	2243	43
6	Y/L/900	0.391	0.389	903.30	28.32	3818	79
7	Y/M/300	0.450	0.436	313.72	50.64	3020	58
8	Y/M/900	0.459	0.447	836.42	46.17	2971	79
9	Y/M/1200	0.428	0.420	1188.61	49.00	3275	81
10	YG/L/300	0.357	0.413	314.17	27.14	4825	74
11	YG/L/600	0.373	0.444	623.44	24.37	4544	76
12	YG/L/1500	0.378	0.423	1495.54	26.43	4338	83
13	G/L/600	0.287	0.396	613.40	18.94	7123	55
14	bP/L/900	0.276	0.262	901.17	27.04	13609	84
15	bP/M/30	0.239	0.209	17.40	36.12	–	–
16	bP/M/900	0.228	0.172	886.43	54.36	–	–
17	P/L/600	0.304	0.230	579.30	29.64	11794	85
18	Pk/L/600	0.356	0.282	589.03	21.51	3932	73
19	Wh/900	0.332	0.321	914.27	7.12	5513	83
20	Wh/1500	0.332	0.321	1523.18	7.04	5509	89

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