

Lighting User Experience (LUX) Cards: A Card-based Tool for the Design of Smart Lighting Solutions

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Abstract

Background The introduction of smart lighting technology, which has coincided with recent research on the psychological and physiological impacts of light, furnishes the practice of design with new opportunities. Despite such potential, design tools for smart lighting solutions are, to date, unavailable.

Methods In this paper, we introduce Lighting User Experience (LUX) Cards, created to support designers' innovation of human-centered smart lighting solutions. The LUX Cards consist of 103 cards, grouped into five categories: user, activity, input, emotion, and light. We evaluated the cards, using a workshop in which design students deployed the cards to address relevant design problems.

Results During the workshop, participants used the cards to acquire knowledge, draw inspiration, and foster group collaboration. Among these uses, the cards' greatest value arose from their ability to inform the participants, who generally lacked relevant knowledge on lighting. We observed a pattern of use of the light category that distinguished it from the other categories. While the other cards fostered divergent thinking, the light cards facilitated the refinement and convergence of ideas. In the later phases of design, participants depended primarily on the light category as they sought information. In contrast, the cards' ability to inspire participants and boost collaboration decreased over time, highlighting areas that required further improvement. Drawing on our observations, we redesigned the cards and provided guidance to promote card uses across a wider range of design contexts.

Conclusions In this study, we designed and evaluated the LUX Cards to support the idea generation of designers involved in the rapidly emerging smart lighting design industry. Design plays an essential role in assimilating new technologies into our lives, and this study's findings are expected to guide future development of similar tools to acquaint designers with the field's emerging issues, challenges, and opportunities.

Keywords Card-based Design Tool, Smart Lighting, Internet of Things (IoT), Human Centric Lighting

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1. Introduction

It is a thing of the past that light could only be turned on or off. The introduction of Internet of Things (IoT) technology has offered new interactive capabilities that extend the potential of traditional lighting design. In recent years, smart lighting, which refers to wireless lighting empowered by IoT technology and tuned to emit any color, has emerged as a rising trend (Higuera, Llenas, & Carreras, 2018).

Light is among our most powerful tools to affect change in our experience of the environment around us (Russell, 2012). Over a half-century, evidence has accumulated to show that light processed through the eye has a potent impact on users (Choi et al., 2019; Han & Suk, 2019; Jung et al., 2018; Lee, Ryu, & Lee, 2016; Oh & Kwak, 2015). However, such academically-oriented knowledge is not readily accessible to designers. Often, the user experience provided by several smart lighting solutions is, consequently, unsatisfactory.

Design researchers have created card-based design tools to render knowledge produced by design research, as well as information from areas that are fairly unfamiliar to designers. Existing research has found card-based design tools valuable across a range of uses (Markopoulos et al., 2016; Yoon, Desmet, & Pohlmeier, 2016). In the design context, cards were originally used as an inspirational tool. Halskov and Dalsgård (2006) developed *Inspiration Cards* and reported that using such cards can produce various sources of inspiration into the design process. Lucero and Arrasvuori (2010) created *PLEX Cards* to function as a source of inspiration in the context of designing for playfulness. Cards have also been used, by a number of researchers, to transfer scholarly knowledge. *DSD Cards* were created to disseminate age-specific knowledge about child development (Bekker & Antle, 2011). Deng and colleagues (2014) designed *Tango Cards* to inform the design of tangible learning games. Recently, cards are increasingly used to help designers grow acquainted with emerging issues. For instance, Luger and Colleagues (2015) designed *Legal Cards* to introduce data protection issues into the design process. *Tiles Cards* were developed to foster the design of novel IoT user experiences (Mora, Gianni, & Divitini, 2017).

Expansion of smart lighting products, in concert with the recent interest in light's psychological and physiological effects, has furnished new opportunities to design practice. Despite the paradigm shift this has engendered, no design tools for smart lighting solutions have been made available. In this paper, we introduce the design and evaluation of the Lighting User Experience (LUX) Cards created to support idea generation among designers involved in designing smart lighting solutions. The cards introduce IoT components and provide information on the extent to which lighting can impact the user experience. The reflections from the workshop are expected to serve as useful guidelines for the future development of similar design tools.

2. LUX Cards

A deck of LUX Cards consists of 103 cards grouped into five categories: user (15 cards), activity (27 cards), input (22 cards), emotion (16 cards), and light (23 cards). The cards are 55 mm wide × 85 mm high, color-coded by category, and numbered in the bottom right corner. One face of the card provides content unique to each card: a title, single image, and a brief caption communicating relevant information. The major sources of information were books and journal articles encompassing various disciplines. The contents were organized with the aim of making them understandable, even to users without a trace of background knowledge in lighting or technology. Each image was tinted with the color that represents its particular category. The opposite face of each card identifies the category to which it belongs. The initial version of the LUX Cards is shown in Figure 1 (Kim, Jeong, & Choi, 2019; Kim, Jeong, Choi, & Suk, 2018).



Figure 1 Initial version of the LUX Cards

User cards (Figure 1(a)) address diverse user groups who can benefit from the use of smart lighting, such as pregnant women, multi-person households, and pet owners. Activity cards (Figure 1(b)) provide daily routines and activities that may be performed in the major application areas of smart lighting. These cards include activities that take place in smart homes (e.g., reading, TV watching) and/or autonomous vehicles (e.g., drowsing, listening to the radio). Input cards (Figure 1(c)) cover data resources that can be applied to generate IoT solutions. Inputs depicted on cards belong to the following categories: internet services (e.g., mail, schedule), public application program interfaces (e.g., weather data, traffic information), sensors (e.g., sound sensor, posture sensor), and physical devices that provide or store information (e.g., activity trackers, smart furniture). Emotion cards (Figure 1(d)) cards address feelings or states of mind (e.g., enthusiastic, bored, lonely) caused by internal or external factors. Light cards (Figure 1(e)) describe the relative merits of different types of lighting based on their impacts on and benefits to the end user. For example, smart lighting can create a relaxing, cozy, and soft ambience by setting the light to a warm, yellow or orange color with low to medium brightness. Likewise, different types of lighting impact users in different ways, both psychologically and physiologically.

For each category, we provided blank cards, intended for personalization by users wishing to add relevant or specific information to each project. The final version of the cards are available for download at <http://color.kaist.ac.kr/LUXcards>.

3. Use Case Evaluation

We evaluated the cards through a workshop in which design students used the cards to address three design spaces where smart lighting may reside (Figure 2). Through observation, survey, and interviews, we examine the cards' strengths and limitations, aiming to devise recommendations for future applications.

3. 1. Participants

A total of 16 participants (nine men and seven women; mean \pm standard deviation age of 24.44 ± 3.37) participated. All participants were students in industrial design programs and all had prior experience with design projects. The sample consisted of 12 graduate students and 4 undergraduate students.

Participants were grouped into four teams, on each of which were four members. All participants signed the consent form.



Figure 2 Participants using the LUX Cards during the workshop

3. 2. Procedure

The goal of the workshop was to design smart lighting solutions in three major design spaces: smart homes, smart cars, and smart buses. Before beginning work on their projects, participants were exposed to a 5-minute presentation about the design spaces. Scale models and video clips were provided to help participants explore the design spaces. The participants were then asked to familiarize themselves with the LUX Cards for 5 minutes. We did not impose any constraints on using the cards. Each team worked on the first design space for 40 minutes. In the first 15 minutes, each member was asked to generate design concepts individually. This first phase was followed by a 15-minute group ideation session and a 10-minute presentation. The teams repeated this procedure for the other two design spaces. Participants were asked to complete a questionnaire containing four questions on a five-point Likert scale. The questions focused on participants' willingness to use and experiences using the cards, focusing on whether the participants found them useful and whether they promoted collaboration and inspiration. The questions were formulated based on the findings from the previous literatures (Bekker & Antle, 2011; Deng et al., 2014; Mora et al., 2017). The workshop concluded with a semi-structured group interview. The workshop was recorded with video and audio, which were transcribed later on.

4. Results

We first introduce an idea generated in the context of the workshop to exemplify the type and complexity of ideas that can be achieved within the circumscribed 30-minute period of ideation using the cards (Figure 3). The idea envisions smart lighting that automatically changes in color and brightness to meet the users' circadian needs. Basically, in the evening, the lighting automatically turns into a warmer tone to promote healthy sleep. In the morning, the lighting grows bright and cool to energize users who are coming out of the drowsiness of sleep. Data derived from billions of IoT devices provide the basis for more sophisticated customization. For instance, when the user has an important appointment in the early morning, the lighting dims earlier than usual the previous night, to advance the timing of sleep.

The results of the survey reflected, in general, positive perceptions of the card uses. The willingness to reuse received the highest ratings ($M = 3.88$, $SD = 0.43$), followed by the usefulness of information ($M = 3.79$, $SD = 0.41$). However, participants expressed weaker enthusiasm for the cards in their roles of engendering creative inspiration and collaboration.

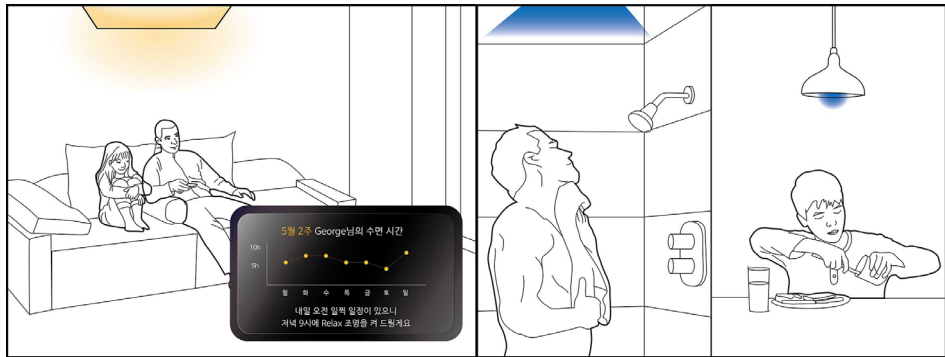


Figure 3 Example of the ideas generated: circadian lighting for smart homes

Table 1 Results of the survey on card uses, scored on a five-point Likert scale

Questionnaire	M (SD)
Are you willing to use the cards again in future project?	3.88 (0.43)
Are the information provided on the cards useful?	3.79 (0.41)
Does the cards help to promote collaboration?	3.48 (0.65)
Does the cards help you come up with creative inspiration?	3.29 (0.69)

We further analyzed the transcripts using a qualitative coding process. Five researchers individually conducted an initial round of open coding, which provided a general sense of the themes that were prevalent in the data. In the second round of coding, the authors reviewed the transcripts again to allow additional codes to emerge. Rearrangement and reclassification of coded data continued until the conclusive emergence of key themes, which are described in the following sections.

4. 1. Main use of the tool

The strongest repeating theme throughout the workshop arose from the lack of relevant information about lighting, relative to other design issues they dealt with before. Participants noted that the cards' greatest value resided in providing them with academic knowledge: *"I didn't have a clue about how to control the lighting before; now I feel I have better knowledge."*

We observed a distinctive pattern of use between the cards in the Light category and those belonging to the other categories. Participants often used the Light cards to turn abstract ideas into concrete solutions: *"Light cards were frequently used when making the initial ideas concrete."* In the initial phase of the workshop, participants browsed through all categories seeking inspiration. In the later phases, however, participants mostly perused the Light cards as they sought to get informed. While the other cards fostered divergent thinking, the Light cards facilitated the refinement and convergence of ideas: *"To put it simply, the first four categories acted as a trigger, whereas the Light category often acted as a helper."*

There were different opinions on the most-used category; however, participants agreed upon which category is most needed. *"I used the User and Activity cards most often, but if I could pick only one category for the project, I would pick the Light cards," "For the other four categories, I can figure them out by myself, but for the Light category, I definitely need help."* For this reason, participants commented that it would be helpful to make the Light cards stand out from the pile of cards. This issue will be discussed in further detail in Section 5.1.

4. 2. Other uses of the tool

We next reflect on the roles of the LUX Cards that conform to general card uses reported in existing literature.

4. 2. 1. Source of inspiration

Participants commented that the cards induced them to assume of multiple points of view, inviting them to look at a design space that they may otherwise have ignored: *“As a man, I’ve generally never thought about pregnant women in my design projects. By looking at this ‘Pregnant’ card, I was able to come up with an idea that I hadn’t thought of before.”* The cards were also used as a way to escape from a creative slump. Several participants indicated that the randomness presented by the LUX Cards unlocked new ideas, and they expressed ideas about how to leverage this randomness as a source of inspiration: *“I once closed my eyes and picked a card in random, and this turned out to be quite helpful.”* We observed a number of instances where participants combined cards from different categories to develop new ideas. They mentioned that the combination of cards turned individual components into a meaningful blend that facilitated their construction of a scenario: *“I have once tried to select one item randomly from each category, and this resulted in a creation of a well-designed story.”* However, participants noted that the cards’ value as a source of inspiration decreased over time. There was also a participant who indicated that he did not want to think outside of the given information. This prompts reflection on the future development of similar tools: if the primary use of the cards is meant to function as a source of inspiration, multiple ideation techniques should be provided, along with the cards.

4. 2. 2. Collaboration aid

Participants felt that the LUX Cards were more valuable when used in a group than by individual participants. The cards supported collaboration by providing a tangible reference and common vocabulary to help the group achieve a shared understanding: *“The cards helped us to reach shared understanding, so the communication was much easier.”* Moreover, the cards recalled playing board games, which made the atmosphere more pleasant and helped to break the ice. We observed many instances where the cards acted as a conversation starter: *“[pointing at a card someone was working on] I think your Activity card is well suited for this Light card I’m currently working on.”* Participants suggested the incorporation of gamification into the workshop to foster group collaboration, an issue which will be discussed further in the following section.

5. Redesign of the Tool

In this section, we identified the areas that need improvement, based on the suggestions from the participants. The findings have been adapted to reflect on the edited version of the LUX Cards (Figure 4).



Figure 4 Edited version of the LUX Cards

5. 1. Card design

Overall, the participants responded with positive feedback concerning the card design. They responded that the colors made it easy for them to distinguish between categories. They also felt that a given card was just the right size for them to hold with one hand. Still, participants did offer up some critiques and suggestions for improvement. First, many participants reported that the color tinting on images led to confusion in understanding the content. Next, although we numbered the cards to simplify data logging, doing this actually caused confusion among the participants. Last, there was a comment on the need to increase the font size.

When asked about the number of cards, participants commented that, in their opinion, the more cards, the better. Still, they acknowledged finding it difficult to arrange the cards on the table. We observed several cases where participants failed to locate a card that they had in mind from among a bunch of cards. Such observations indicate the need for an organizational tool to manage the cards. This may be in the form of a card tray or a board game playmat. Accessories like sticky flags may also be advantageously used to mark important information.

Participants also proposed the idea of distinguishing the Light cards from the rest of the categories through some form of design differentiation. From this we can infer that the category that requires special knowledge or expertise should be designed differently from the rest of the cards. The relevant category to highlight may any one of the five categories, depending on the audience's prior knowledge or interest in the domain.

5. 2. Information provided

Incorporating a vast amount of theoretical knowledge into a set of cards naturally required a process of extraction and simplification. However, some participants mentioned their desire for more information, especially from cards in the Light category. One participant suggested that he would benefit from in-depth explanations of the mechanisms underlying the impact of light. However, given that the provision of too much information may impose a communication barrier, one way of addressing this request may be to provide external links to detailed information. We leave this as a possibility to consider in our future work. The participants also pointed out that the content must be kept up-to-date. We will be responsible for updating the content periodically.

5. 3. Instruction and guidance

Although we intentionally avoided imposing any constraints on using the LUX Cards, participants were actually seeking more detailed guidance. Participants suggested that we include an overview of the complete card set within an instruction leaflet. The participants also wanted to be provided with different ways to make use of the cards. We therefore delve into various uses of the cards identified by the participants.

5. 3. 1. Usage scenarios for ideation

First, harnessing simple game rules may foster creativity and support idea generation (Hornecker, 2010; Lucero & Arrasvuori, 2010). Gamification may also create excitement and promote group collaboration. In this regard, we herein suggest a turn-taking game where each player must choose one of the five categories in the set. In the game, the players take turns drawing a card from their own deck, until the group selects a meaningful combination of cards from the categories to generate new ideas.

During the workshop, we also received feedback on the use of the cards in the context of interacting with physical design space. The ability to place the cards virtually anywhere fosters their use as a rapid idea expression tool. The cards can be attached physically to a working space to externalize ideas. For instance, the Light cards "Warm" and "Cool" can be attached to an air vent of a car to express an idea about lighting that changes color to make users feel warm or cool. In this case, the cards function as a sketch pen, while

the car serves as a sketch pad. The output platform may be a board, a scale model, or a real-world space. Participants also suggested making stickers connected to each card, to facilitate this use.

5.3.2. Broader adoption of the tool

We further observed the potential of the LUX Cards for use across a wider range of design contexts, and not just in support of the ideation of designers.

By observing the use of the cards during the early design stage, we confirmed the beneficial role of the LUX Cards in expanding the design space. However, the cards may also be valuable for evaluative uses in later phases. Designers can make a very quick review of each category to evaluate if something's missing. The cards would be useful for pinpointing the issues designers may have missed and confirming whether the solution meets user needs.

Next, the uses can be extended to a communication tool between stakeholders and designers. The cards could be used at the start of a project to find out what clients want. Having a quick look through the cards together may help to set design directions when the client has no idea what they want. The cards may also serve as strong empirical evidence that persuades stakeholders later in the design stage.

Last, the intended users of the LUX Cards were designers, given that smart lighting technology is still in its infancy. However, in the long term, the target audiences may be expanded to include non-designers. The playful nature of the card tool permits engagement of people unused to design workshops. Moreover, the cards may act as an idea expression tool for people unskilled at or unfamiliar with drawing. However, there is a need for modification if the cards will be target for non-designers. As non-designers may struggle to understand how the cards are meant to be used, a quick-start guide should be provided to supplement the set of cards.

6. Discussion and Conclusions

As smart lighting continues to gain popularity, designers must fully understand and consider the diverse effects that light exerts on users. The design and evaluation of the LUX Cards provided insights into how the cards can be used during the design of smart lighting solutions (Figure 5). We first observed the roles of the cards that conform to general card uses reported in existing studies. Designers used the cards to gain inspiration and foster group collaboration. However, dependence on the cards for such uses has decreased over time, which means that the cards must be complemented by instructions, furnishing different techniques for making use of the cards. In the later phase, designers mostly sought out the Light cards to get informed. They often used the Light cards to transform abstract ideas into concrete solutions. By observing such a distinctive pattern of use between the Light category and all four of the others, we can infer that the cards requiring special knowledge or expertise should be designed differently from the rest of the cards. Next, we identified the areas that required improvement, including the card design, content, and lack of guidance. Our responses to these observations are reflected in the edited version of the cards, and we have suggested techniques to maximize the use of the cards.

The strongest repeating theme throughout the workshop arose from the designers' lack of knowledge about smart lighting compared to other design issues they have dealt with before. Smart lighting has become a rapidly emerging topic; however, this is only one of many technologies that will emerge in the coming decades. Design plays critical roles in integrating new technologies into our lives, and thus, there promises to be a constantly increasing demand for the design tools acquaint designers with emerging issues, challenges, and opportunities.

	Existing Card Uses	LUX Cards
Roles of the Card Tools	<ul style="list-style-type: none"> Transfer knowledge Give inspiration Foster collaboration 	<ul style="list-style-type: none"> Light cards were used to turn abstract ideas into concrete solutions. The cards' value as an inspirational source decreased over time. The cards were frequently used as a tangible reference to support idea.
Rooms for Improvement		<ul style="list-style-type: none"> The category that requires special knowledge should be designed differently from the rest. The content provided in the cards must be kept up-to-date. Game rules and physical interaction may further promote idea generation, and the uses of the cards can be extended to evaluation, communication with stakeholders, and engagement of non-designers.

Figure 5 Reflections from the workshop

Unlike card tools that were designed to function as a source of inspiration (Halskov & Dalsgård, 2006; Lucero & Arrasvuori, 2010), divergent and convergent thinking were both presented during the card uses. Moreover, while most card tools were aimed at the early design stages, we observed the potential for extended uses in the later stages of the design process. When developing the card tool to inform designers, design consideration should, therefore, be given within the broader design process.

Moreover, we intentionally did not set up any specific rules for card uses to avoid constraining the creative nature of the design process. Surprisingly, allowing designers a great deal of freedom to navigate the cards did not provide sufficient stimulus to drive design. This might have been due to the novelty of the problems compared to other design issues. Adequate guidelines seemed to have been critical for supporting designers dealing with unfamiliar technologies. Therefore, we suggest considering this when developing design tools for emerging issues, challenges, and opportunities.

There are several features of the research design that may have affected the quality of the findings. With the current study design, it is difficult to see the difference in the design process and the results between a group that uses the cards and one that does not. Further research should be performed to fully elucidate the overall impact that LUX Cards can have on the design process. Furthermore, the use of the cards has to be evaluated with different workshop techniques and other groups of users. Another avenue for further study would be to examine the cards' uses under real-life constraints by professional designers.

Nonetheless, this study builds upon and extends earlier studies and demonstrates card-based design tools' value across a range of uses. Although further research is necessary, the insights gleaned from this study are expected to provide useful guidelines for the future development of card tools to inform designers dealing with emerging technologies.

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