Fiat Lux – Interactive Urban Lights for Combining Positive Emotion and Efficiency

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ABSTRACT

We fuse science and design thinking to create a novel, IoT interactive urban lights system focused on increasing positive affect among pedestrians. Our contributions are three-fold. First, the design, construction, and evaluation of an efficient interactive lighting system focused on well-being, as opposed to systems focused on utility or landscaping. Second, we used scientific methods to discover basic design parameters for affective outcomes. Third, we optimized user experiences for low energy profiles, positive affect, and interactivity. Tested interactions show positive and some unexpected negative responses. Optimal interactive designs cut energy consumption by 75% while maintaining positive affect. Furthermore, card sorting design exercises revealed an inverse relationship between perceived pleasant feelings and interactivity. We conclude by discussing the implications of our research for the design of coherent, attractive, and efficient urban lighting.

Author Keywords

Interactive urban lights; place-making; Internet of Things; pedestrian safety; affective; emotional well-being; energy conservation.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

INTRODUCTION

Urban lighting systems fall into either a functional, ambient, or ornamental category [12]. The first category focuses on illuminating streets for locomotion. The second focuses on improving pedestrian safety. The third appeals to aesthetics.

Figure 1. Our interactive pedestrian lights were deployed in downtown San Leandro, CA.

High-power programmable LED technology could blend function, safety, and aesthetics needs concurrently. We hypothesize that these systems could also have predictable positive emotional outcomes which, in turn, improve emotional well-being [6]. In this paper, we introduce an interactive system constructed to deliver functionality as well as positive emotions. We use a network of passive infrared sensors to provide “on-demand” illumination. We base our interactions on an on-line estimation of pedestrian's linear speed. We use a low-cost commercial high power flood LED lamps to provide a smooth path of ambient light for walking pedestrians. The system was designed to be mounted on any existing infrastructure for ambient lights, which usually range between 3 and 5 meters of height. Our first deployment was installed at 2m of height to illuminate a 30m x 3m segment of a low-traffic sidewalk in downtown San Leandro (Figure 1) [12]. As mentioned, baseline lighting (~2 lux) is required for obstacle detection and locomotion for humans [4], while well-lit sidewalks (~10 lux) can increase perceptions of pedestrian safety [5,25] and security[4].

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Figure 2. Experimental setup a) metrics: light radius = 1.12m, distance between lights = 2.7m, hallway width = 4m, hallway length = 30ft, base luminance with lights off = 2 lux. Note: low illumination not displayed in this image; b) User walking with all lights on. Max luminance per light = 40 lux. Note: Image captured with high sensitivity camera, appears to be brighter than reality.

Lights at night allow pedestrians to judge other people's intentions [8] and help them locate escape or refuge [7]. However, such lights often waste energy and generate light pollution during late hours or in places with low pedestrian traffic. We show how interactive lighting optimizes efficiency without sacrificing pedestrian needs. We conducted three experiments in a "lab" setting - a dark, indoor, underground hallway (Figure 2). Spatial factors (lighting angles and sizes of illuminated areas) and color were kept stable. Temporal factors addressed if lights turned on *Before*, *During*, or *After* the pedestrian has passed by, and if the lights appeared *Soft* (slowly/gradually) or *Hard* (immediately/instantly). The lighting effects ranged from what one user described as a *"luminous path unfolding before* [the user] *with every step"* to designs that *"followed* [the user] *in a creepy way."* We found no emotional preference for always-on systems while interactive systems consumed 75% less energy. Finally, queries about deployment preferences describe an inverse relationship between emotions and interactivity. Pleasing locations could benefit from interactive lights while unpleasing locations should remain lit. Finally, we present a set of design ideas and group the implications for interactive light design into three broad categories: a) coherence, b) attractiveness, and c) efficiency.

PREVIOUS WORK

Illumination and Perceived Safety

Haans and de Kort [7] describe the association between illumination and perceived safety (outlook, escape, and refuge). Increased outlook occurs when there is more light close to the pedestrian, rather than farther down the walking path. Fotios, et. al. describe a gap between the optimal perceived safety luminance level (10 lux) and current luminance levels in areas with pedestrian traffic [5]. The optimal luminance level is the result of a series of studies on the ratio of perceived safety at day versus night. Currently, most lighting systems only support obstacle detection (2 lux). The challenge is to deliver the appropriate luminance level without a huge toll on energy consumption.

Urban Interactive Lighting Design

A series of workshops presented at DIS 2012 [3], CHI 2013 [1], and NORDICHI 2014 [2] have introduced novel urban interaction design concepts for streets, city parks, and playgrounds. We focused on the designs that promoted responsive systems for experiences with positive emotional outcomes. Seitzinger and Warwick discuss the importance of response timing as a key factor for interactive lights [22]. Poulsen et. al.'s call for developing mood-sensitive lighting validated our intuition to focus on affect [20]. Pihlajaniemi et. al.'s algorithmic movement-light-response patterns to attract pedestrians support our notion of responding to pedestrian's speed [19]. Our work adds to the state-of-the-art with empirical data validating the proposed concepts.

Light Interaction and Expressivity

New advances in LED technology control offers the possibility to deliver highly responsive interactions with low energetic costs [16]. Offermans et al. describe everyday, indoor, interactive lighting in two planes: user interface and context [15]. Context should include: user motivations, lighting needs (utilitarian and emotional), and context and routines. Interfaces should be defined by: degrees of freedom (color, intensity, timing, angle), control location and availability, autonomous behavior, and interaction qualities (fun, challenging, tactile, aesthetic). Harrison, et al. explored how simple indicator lights with ON/OFF patterns communicated specific information to users [9]. The authors identified patterns such as "turn on," "notification," and "low energy." Our system blends interaction and information parameters to create a responsive, surface-covering, sidewalk experience. We hypothesize that expectations and needs should be equivalent to those of indoor lighting.

Implicit Interaction and Approachability

The theory of implicit interaction [10] describes the qualities of intuitive communication between users and devices. First, interactions should be dynamic, i.e. adapting appearance, behaviors, and responses to changing situations. Second, they are demonstrative - using actions and embodiment for expressivity. These qualities informed designs of approachable interactive devices [11]. We applied both concepts to our system. Lights adapt to pedestrian's speed while displaying welcoming and pleasant lighting patterns.

LIGHTING SYSTEM CONSTRUCTION

We designed a modular lighting platform that would allow the setup of linear arrays of interactive lights. Lights can be programmed individually to respond to pedestrian speed and direction of movement. After teaching a course in urban sensing, we learned that the key design parameters for outdoor systems are: anti-theft, weatherization, and low cost. We chose low-cost passive infrared (PIR) sensors covered with a tubular 3D printed wrapper, which reduced their sensitivity angle. We used low-cost weather resistant LED RGB lamps to make it easy to maintain and replace lost units.

Current commercial systems such as Tvlight.com[1] have prototyped functional interactions with a major focus on automobiles. In contrast, our system provides surface-covering sidewalk illumination for pedestrians. We advance the state-of-the-art in two aspects: we track pedestrian speed and direction instead of position, and we show the positive affective impact of responsive and anticipatory lighting.

METHODOLOGY

From our pilot designs and pilot outdoor testing, we were able to hypothesize that lights appearing ahead of a pedestrian would render positive emotions. We also speculated that a light shining directly on a user could have a different emotional outcome. We decided to explore the effects of light activation timing on human emotions. We chose the scientific method as a design tool. A need-finding method may not have fully explored some "apparently" useless conditions. Our formal approach revealed valuable information about timing parameters for the design of interactive lights. The first question we asked was about the impact of interactive light activation factors on user's affect. Later, we iterated our experiment to contrast interactive with always-on lighting schemes. Finally, we refined our search to explain design nuisances for optimal affective outcomes.

Location and Lab characteristics

Our outdoor location was the perimeter of Casa Peralta, a historical landmark in the city of San Leandro, CA. Our indoors lab emulated a portion of the outdoor installation, the width of the sidewalk and the height of the lamps. In this environment we were able to capture stable emotional data by controlling for external factors such as pedestrian and car traffic, day temperature variations, and natural and urban illumination levels. An indoor location also allowed us to test users during the day. We built our lab using a 10-meter long hallway inside our building. We controlled the illumination level to the basic functional level of 2 lux, similar to the outdoor conditions. We closed down the hallway to any other traffic with dark curtains. Figure 2a shows the lab's dimensions and base luminance. Figure 2b shows the four light projections.

Method

We recruited 94 participants from our institution and the surrounding community. Ages varied from 18 to 70 years old. We screened participants for adverse reactions to light exposure and offered a $20 gift card as compensation. Each experiment had four stages: (a) a pre-test questionnaire, (b) experience of the light conditions, (c) a post-test survey, and (d) a card sorting exercise (Figure 3). The procedure received approval from our Internal Review Board.

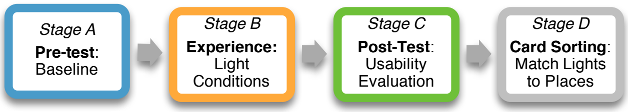

Figure 3. Stages for each of the three experiments

First participants rated their emotions once when they arrived and again after watching a 2-minute relaxation video. Subsequently, participants were introduced to the different light conditions. Light conditions were created from the combination of two factors: *Timing* and *Transition*. *Timing* is defined as the moment when the light appears (turns on) in response to the user's speed. The *Timing* types are: *Before*, *During* or *After*, depending on whether the light appears in front, upon, or behind the user. A control condition for the value of interaction has the lights appearing at Random intervals. *Transition* is defined as the manner in which each light turns on. It is either the *Soft* (gradual) or *Hard* (instant) transition. Table 1 describes the different factors.

Factor	Types	Description
Timing	*Before*	Light appears ahead of the user.
	During	Light appears on top of the user (as a spotlight).
	After	Light appears behind the user.
Transition	*Soft*	Light appears gradually (slowly).
	Hard	Light appears abruptly (rapidly).
Controls	*Random*	Light appears at random times.
	Always-On	Lights are always on.
	None	Lights are always off.

Table 1. Factors and their different Types

These factors were combined to create the different conditions; e.g. when the lights appeared slowly before the users, they were experiencing the *Before-Soft* condition. If the lights appeared instantly and behind the users, this would be the *After-Hard* condition. Figure 4 shows a representation of the *Before-Hard*, *During-Hard,* and *After-Hard* conditions. The light circles appeared projected on the floor as the participant walked through the corridor. The baseline affect control condition was *None* (no lights). In Experiment 2 we further added an *Always On* condition. We presented each condition twice to reduce novelty effects [26].

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[1] http://tvlinght.com

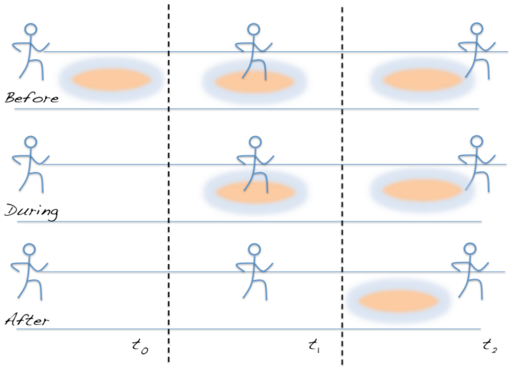

Figure 4. *Hard* Transition Interactions

After each condition, users answered two questions based on the Circumplex Model of Affect (CMA) [21], as well as a subjective stress rating (SSR) question (Table 2).

Metric	Question	Levels
Arousal (Personal Energy)	*What is your current energy level?*	Least Excited (0) to Most Excited (10)
Valence (Pleasantness)	*How pleasant are your feelings right now?*	Least Pleasant (0) to Most Pleasant (10)
Subjective Stress Rating (SSR)	*What is your current level of stress?*	Least Stressed (0) to Most Stressed (10)

Table 2. Questionnaire presented after each light condition

After the experiential stage, participants completed a post-test survey (17 questions) composed of two parts as follows: 1) Right after the experience stage, users were asked for the conceptual model – users were requested to describe in their own words the experience they just had with lights. 1) After revealing the light conditions, in the order they were experienced, the user was asked to describe: their emotions, preferences, and the use they would give to these lights.

Finally, we used printed cards to determine where users would like to see the interactive lights they had experienced (Figure 5).

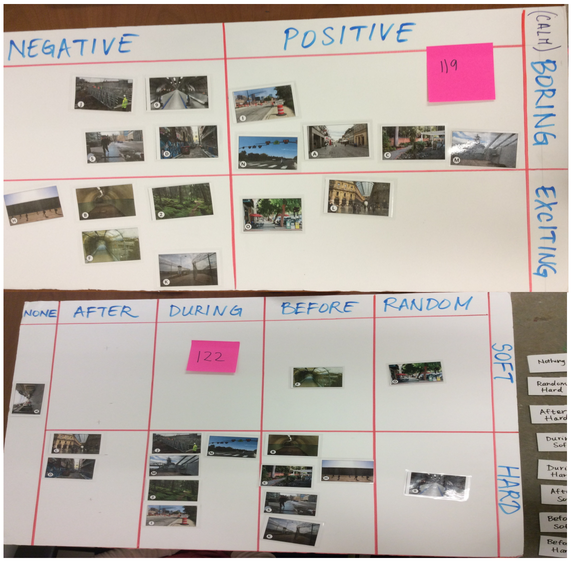

Figure 5. a) Affect: Negative vs. Positive feelings and Exciting vs. Boring/Calm energy (top), b) Light Conditions (bottom)

We gave the users 16 different cards depicting different scenarios for pedestrians: *crosswalk, tunnel, overpass, construction site, metro, airport conveyors, museum, snowy street, pleasant street, nature, backyard, battleship, a war zone, industrial bridge, alley, prison*. Figure 5a shows the Affect board used to rate their feelings towards a location at night. They placed the cards in the category that best matched their feelings (Negative or Positive) and their level of excitement (Boring/Calm or Exciting). Figure 5b shows a second board with the selection of the light conditions preferred for each place. For example, if a user preferred the *Before-Hard* condition, we would see more cards in that category. Finally, they were told to explain their selections in open text form.

EXPERIMENT 1: INTERACTIVE LIGHT FACTORS

In this study, we compared interactive modes responsive to the speed and position of the user. Our hypothesis was:

> *H1 – Timing and Transition factors have an effect in Affective Response, Valence, and Arousal metrics.*

We chose a factorial (2x4) within-subjects design with N=36 participants, 19 females and 17 males (M = 29.7 years). 38.9% of them were students and most of the rest were employed in a variety of trades. We measured Valence, Affect, and Stress. We manipulated *Transition* (*Soft, Hard*) and *Timing* (*Before*, *During*, *After*). We had two controls: *Random* and *None*. Figure 6 shows the means for Arousal and Valence for each of the light conditions.

Figure 6. Circumplex Model of Affect mapping of the baseline corrected metrics for each light condition

Quantitative Analysis

We performed a two-way within-subjects ANOVA to compare the effect of *Timing* and *Transition* on Valence and Arousal. Neither factor had main effects on Arousal. *Timing* had a main effect on Valence, $F(3,36) = 3.74$, $p<0.05$. Multiple comparisons (Bonferroni, $\alpha=0.05$) showed differences between *After* ($M=-1.5417$, $SD=1.9205$), *Random* ($M=-0.6111$, $SD=2.1$), $p<0.05$ and *Before* ($M=-0.5972$, $SD=1.9763$), $p<0.05$. This implies that *Timing* has an effect on pleasantness (Valence).

The energy consumed depends on the power dissipated by the lamps while the users walked down the hallway. On average, people traversed the hallway in 10.8 sec. Energy consumption and Valence show a moderate correlation (r=0.3786) (Figure 7). The amount of energy depends mainly on *Transition* (Hard or Soft). *Timing* does not affect the energy outcome.

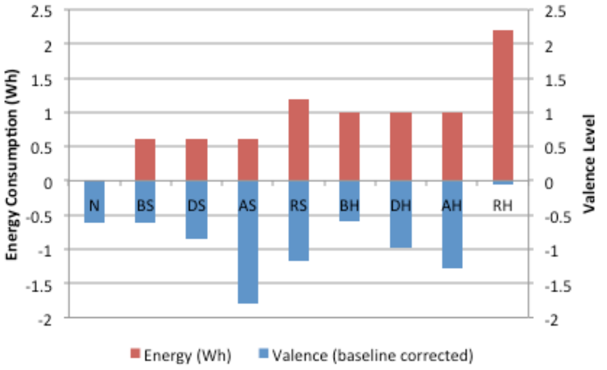

Figure 7. Energy consumption (Wh) in red, contrasted with Valence (baseline corrected) in blue for each light condition

A Kruskal-Wallis test revealed that *Timing,* H(4)=86.79, $p<0.0001$, had a significant impact in preference (1 = most → 5 = least). Multiple comparisons (Bonferroni, $\alpha=0.05$) revealed that *Before* (Median=1, SD=0.5248) was preferred above all other conditions. *During* (Median=2, SD=1.079) ranked higher than *After* (Median=4, SD=0.8669), *None* (Median=5, SD=1.331), and *Random* (Median=3, SD=1.1557). No effect of the *Transition* mode was found.

Qualitative Analysis

20% of participants identified all the interaction factors. Virtually all users (98%) recognized the *Before* condition and one more condition (other than *None*). 15% of the participants associated the light patterns with their position.

> *"The first pattern was that the light turned on in front of me while I walked in the dark. / The 2nd was that the light turned on after me when I walked in the dark. / The 3rd was the colorful light turned on to light my way when I walked in the dark. / The 4th was that the colorful light followed my steps when I walked in the dark. / The 5th was there was no light at all."*

42% of the participants selected *Before-Soft* as the best interaction. 25% of the participants considered *Soft* relaxing while 20% considered *Hard* useful (visible and predictable).

> *Before Soft gave me leisure time to adapt to whatever was coming into view as I progressed. The softness of the increasing illumination as I approached was relaxing, appealing, pleasant.*

None, *After-Hard*, *During-Hard* and *Random-Hard* were considered the worst conditions. People found *Hard* transitions "harsh." Notably, 30% of the people considered the *After* condition to be creepy and threatening.

> *It [After - Soft] was very creepy and felt very threatening. It reminded me of someone coming up behind me at night and it just kept on happening as each light creeped on.*

Most participants (67%) agreed that interactive lights would prompt them to walk more. They believed the lights would make it safer and more comfortable with the added benefit of lower energy consumption and less light pollution.

> *While I like lights on all the time, it would be neat to have lights that only came on when needed, that way you could also see if someone was walking from a long distance away as lights would come on further down the street. Also, this would mean less light pollution.*

Those who would not choose to walk more at night (33%) believed that walking at night is inherently unsafe and that lights do not play a major role towards improving safety.

> *Lighting does not change the variables that make walking alone at night dangerous. Predators will continue to lurk around regardless of the lights.*

Users voted on the places where they would use interactive lights. As seen in Table 3, Urban (non-residential) and Leisure places were foreseen as good use cases for interactive lights.

Place	% of votes
Urban (non-residential)	31.6
Leisure	22.4
Residential	14.5
Traffic/Commute	14.5
Other (Business, Events, Construction, etc.)	17%

Table 3. Expected Places with respect to the feelings

Card Sorting Analysis

A quasi uniform distribution was observed across the different affective states (Table 4).

Places	Negative Feelings	Positive Feelings	Total
Calm / Boring	137 (23.8%)	143 (24.8%)	**280 (48.6%)**
Exciting	170 (29.5%)	126 (21.9%)	**296 (51.4%)**
Total	**307 (53.3%)**	**269 (46.7%)**	**576**

Table 4. Counts of Places with respect to the feelings associated with them and the level of excitement

A four-way within-subjects ANOVA revealed an interaction effect between the feelings towards a place with *Timing,* F(3,36)=8.107, p=0.0129 (Figure 8a) and *Transition,* F(1,36)=4.4177, p=0.022. (Figure 8b).

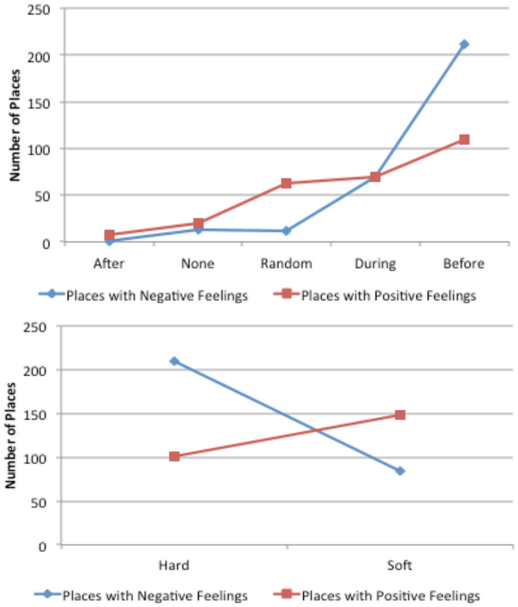

Figure 8. Interaction between feelings (Valence) about a place and (a) *Timing* and (b) *Transition* functions.

Twice as many people preferred *Before* interactions for negative places than for positive places.

> *The purpose of light is well, to light the way and so having light after you have walked does not light the way, Having light in nature disturbs nature. Having soft light in public places might be a nice touch. Having light at intersections might prevent pedestrian accidents if they and drivers can easily see. There should be light during a tunnel trip.*

People preferred *Hard* for negative places (67.5%) versus positive ones (32.5%), while people preferred *Soft* for positive places (63.8%) versus negative ones (36.2%)

> *Large, unconfined outdoor spaces would be good to not have lights. Pleasant, safe places would be nice to have lights come on softly while you are walking past. A backyard might be a good place to have lights come on softly after you pass. Tunnels, crosswalks and construction zones would be well suited to have lights come on hard and before you pass. Neutral urban places would be nice to have lights come on before and softly.*

EXPERIMENT 2: INTERACTION VERSUS ALWAYS ON

In this experiment, we compare the best interactive light mode with a static *Always On* mode. Our main hypothesis is:

> *H2 - Before - Soft has equal Valence than Always On*

We chose a factorial (2x4) within-subjects design with N=30 participants, 15 females and 15 males (M = 29.9 years). 43.3% of them were students and most of the rest were employed in a variety of trades. We measured Affect (Valence and Arousal) and used the same interactive variables, *Timing* and *Transition*.

Quantitative Analysis

1-sample t-tests comparing *Always On* (M=-0.9667, SD=2.4842) and *Before* (M=-0.7, SD=1.779) were not significant for Valence, t=-0.9322, p=0.352 nor for Arousal, t=-0.2356, p=0.8154. *Always On* falls in the same group as the *Before* and the *During* timing options, so we accept H2. This implies that there is no difference on affect between traditional illumination and interactive modes. As shown in Figure 9, despite a non-significant difference in Valence or Arousal, the energy expenditure for *Always On* is 3.5 to 7 times higher than any of the interactive modes. Correlation between Energy and Valence (r=-0.2553) and between Energy and Arousal were weak (r=0.2393). Therefore, more energy does not guarantee more positive emotions.

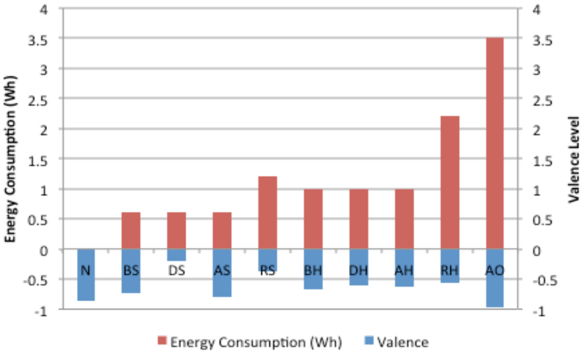

Figure 9. Energy consumption (Wh) in red contrasted with Valence (baseline corrected) in blue for each light condition

To complement, we compared the power consumed by an interactive system versus a non-interactive system. Energy drawn by the control electronics does not surpass 7% the amount of energy spent by the *Always On* option. Interactions not only to engage and make people happier, but also can save energy.

Finally, a left-side Wilcoxon non-parametric test indicated that the preference for *Before* (Median=1.5) was statistically significantly smaller (more preferred) than *Always On* (Median=2), Z=-2.1053, p<0.05.

Qualitative Analysis

Many of the findings are similar to the ones found in Experiment 1. The main contrast was the preference for *Always ON* instead of *Before Hard*. When asked if people would walk more at night, 83% of people said that interactive lights would entice them to walk more, while 77% people said that static (*Always On*) would entice them to walk more. Those who responded yes to both modes revealed that any light condition was okay to walk, while some believed that interactive modes were more vivid and felt like being accompanied, while the static mode was more familiar.

> *As long as there's lights in general, yes [I would walk more often at night]. That's always a plus. The interactive lights make it feel like there's another presence WITH you (in a comforting, secure way).*

When asked what percentage of time the interactive or *Always On* modes should be used, the decision is split. *Always On* was slightly less popular at 48% with interactive modes at 52%. Regardless of their main preference, most people found *Always On* as more secure and familiar, while interactive modes have the added benefit of saving energy.

> *I think interactive lighting is preferable for comfort, for saving energy, and for enjoyment, but static light is necessary for safety reasons sometimes.*

Card Sorting Analysis

Again, we observed that the places were distributed evenly across the different conditions (see Table 5).

Places	Negative Feelings	Positive Feelings	**Total**
Calm / Boring	134 (28%.4%)	102 (21.62%)	**236 (50%)**
Exciting	126 (26.7%)	110 (23.3%	**236 (50%)**
Total	**260 (55.1%)**	**212 (44.9%)**	**472**

Table 5. Counts of Places with respect to the feelings associated with them and the level of excitement

A four-way within-subjects ANOVA revealed again that there is an interaction effect between the feelings towards a place with *Timing* [F(4,36)=235.844, p=0.0012] (Figure 10.a), and the *Transition* function [F(1,36), p=0.0013] (Figure 10b). It is interesting to observe that the *Always On* condition was mainly chosen for negative places. People explained that *Always On* was useful for dangerous places, while they preferred the *Before Soft* option for safe places.

> *I put the places where I thought would be the least safe under the always on category. Places where I would look forward to seeing something ahead I put in the before (soft) category. Places where I think I would be around people just walking around, I put in the during (soft) category.*

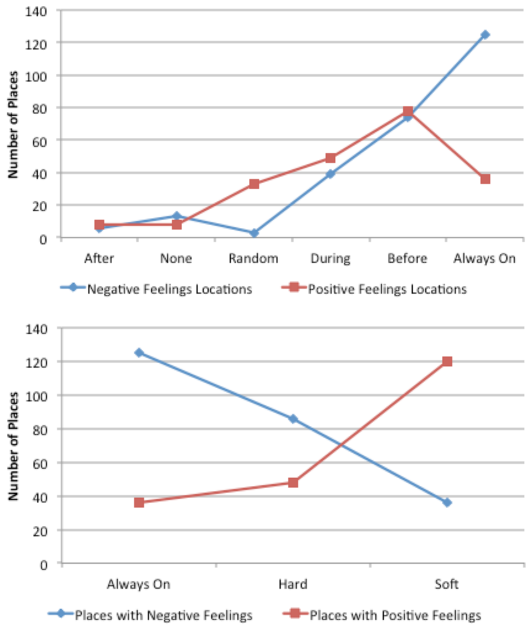

Figure 10. Interaction between feelings (Valence) about a place and (a) Timing and (b) Transition function.

EXPERIMENT 3: BEFORE SOFT PRIMITIVES

We designed a final experiment to expand the understanding of the *Before Soft* mode. We chose three sub-factors. First we wanted to know if people would prefer a less smooth, more noticeable transition. We used a ripple to provide a clear distortion. Second, we wanted to know if people would prefer to see more lights in front of them to make sure people saw the lights coming on ahead of them. Finally, we tested a proxy between interaction and *Always On*. We added an always on base light which was very differentiable of the full blown interaction. Our main hypotheses was:

> *H3 – Smoothness, Look-Ahead, and Base Light have main and pairwise interaction effects on Affect.*

We chose a full-factorial within-subjects design with N=28 participants, 14 females and 14 males (M = 27.9 years). 64.3% of them were students. We measured Valence and Arousal and manipulated *Smoothness* (*Soft* / *Ripple*), *Look-Ahead Horizon (1- / 2-Lights)*, and *Base Light* (*Yes / No*). Figure 11 shows the mean affective metrics mapped to the upper quadrant of the CMA.

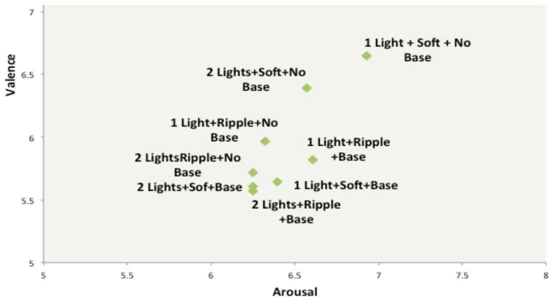

Figure 11. Interaction between feelings (Valence) about a place and (a) Timing and (b) Transition function.

Quantitative Analysis

We performed a three-way within-subjects ANOVA. We discovered no interaction effects. We found some main effects described below. We found *Ripple* to have an effect on Valence, F(1,27)=11.37, $p<0.01$. The number of lights has a near significant effect on Valence, F(1,27)=5.96, $p<0.05$. *Ripple* mainly triggered annoying feelings.

> *The flickering thing made me feel uneasy. As if something I was not expecting could suddenly happen.*

We found a near statistically significant main effect of the *Look-Ahead* function on Arousal, F(1,27)=4.67, $p<0.05$. People described the *1-Light* ahead horizon as more surprising than the *2-Lights* ahead horizon, which they found more relaxing and predictable.

I liked being able to see where I was going before I got there. The 2 lights w/ base lights w/o ripple did just that...

In terms of energy, the amount required to provide a *Base Light* and the *2-lights Look-Ahead* was about twice the *Before Soft* option. However, even though we light up twice as much, this option still represents only 55% of the energy consumed by the *Always On* option from Experiment 2.

A Wilcoxon test revealed that *Soft* (Median=1) is preferred to *Ripple* (Median=2), Z=-4.7581, $p<0.0001$. *2-Lights* (Median=1) are preferred to *1-Light* (Median=2), Z=-3.6986, $p<0.001$ and *Base Light* (Median=1) is preferred to *No Base Light* (Median=2), Z=-2.6392, $p<0.01$. This means that people prefer more light that appears slowly ahead of them.

Qualitative Analysis

Due to the subtlety of the conditions in this third experiment, some people focused on the colors, others on the intensity, and others on the timing. Some found the "flickering" (*Ripple*) disconcerting (but not scary), although they believed it could be fun under certain circumstances. People preferred 2-Lights Ahead with a *Base Light*, as they found this provided the best visibility.

> *The light patterns which flickered on made it difficult to keep a normal pace because I was not able to see what was in front of me. The lights that came on immediately (there were a couple of these) allowed me to keep a good pace throughout the whole hallway. There was one lighting pattern that started extremely dim and one by one would flicker on in front of me reminded me of lights that would be in a dark alley way. I quite enjoyed the lighting pattern that immediately and brightly turned on in front of my path allowing me to see everything before I got there.*

Card Sorting Analysis

We expected a similar inverse relationship between places and interaction variables. Card sorting showed a near-random distribution of cards in the CMA, i.e. no consensus about places and Valence or Arousal (Table 6).

Places	Negative Feelings	Positive Feelings	Total
Calm/Boring	104 (23.2%)	113 (25.2%)	217(48.4%)
Exciting	136 (30.4%)	95 (21.2%)	231(51.6%)
Total	**240 (53.6%)**	**208(46.4%)**	**448**

Table 6. Counts of Places with respect to the feelings associated with them and the level of excitement

However, participants preferred to liven up what they considered to be the least exciting places with the most interactive lighting modes such as *1-Light Ahead* or *Random*. Participants preferred the *2-Lights Ahead* mode and the *Always On* mode in places they considered to be dangerous, favoring outlook over entertainment. The *Ripple* mode was the preferred choice for sites where participants wished to be warned about obstacles, such as construction sites.

> *If it was an open space, then it didn't feel right to have a base light. Both because there is often already a base light, or because it would pollute the night. If it was a normal space, then no ripple effect. Only if it was a space with some kind of danger, then ripple effect seemed reasonable. If it was somewhere where people moved faster then 2 lights ahead, where they move slower, or rarely, one.*

An interaction effect was observed only for the number of lights ahead and the feelings towards a place (Figure 12).

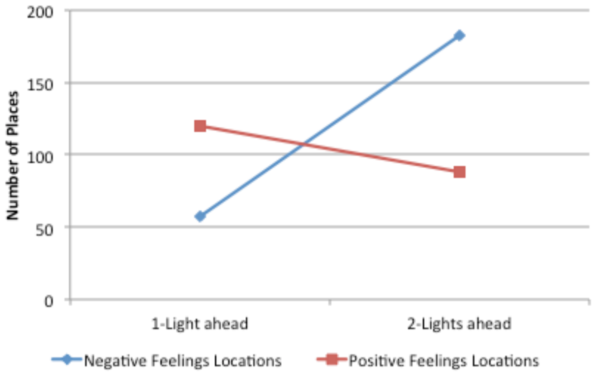

Figure 12. Interaction between feelings (Valence) about a place and number of Look-Ahead Lights

IMPLICATIONS FOR DESIGN

We have shown that interactive lights modify people's feelings and that the following parameters inform lighting designs that use less energy to "buy" more happiness.

Using Timing to drive Emotion

As expressed by previous researchers, timing [22] has a direct impact in the experience of interactive urban lights. Our study links positive emotional affect to the way lights appear while pedestrians walk. Lights that appear ahead of the pedestrian should generally be chosen to elicit positive emotional outcomes. However, lights that are always on or illuminate the user (like a spotlight) could be most useful in situations when safety and attention to obstacles are expected. Lights that appear instantly give users a higher perception of brightness while lights appearing gradually are more relaxing. Furthermore, smooth transitions are more welcomed as opposed to *Ripple* interactions. This again implies that calming designs can benefit from smooth transitions, while utilitarian designs could benefit from salient, sharp light transitions. It is relevant to highlight that a malfunctioning sensor could produce unintended emotional reactions. Intended or not, lights that appear "after" the user has passed produce negative emotions. Designers therefore should prevent these modes and beware of potential changes in the sensing that could trigger these undesirable effects.

Design for Coherence

We define design coherence as the design choices that help match a place or situation to a lighting scheme. For example, people who are in unusual places expect plenty of light to reduce anxiety. On the other hand, people in less stressful locations would be more open to pleasant illumination surprises. Overall, design choices for interactivity should match the level of perceived safety. External factors such as time of the day, neighborhood walkability, as well as internal factors, such as personality, past trauma, perceived femininity or masculinity [7], and stress levels modify the perceived safety and therefore the perceived emotion towards a place. Coherent designs take into consideration context and personal characteristics to choose the best lighting modes. Figure 13 shows an example of an interaction curve that adapts to the level of illumination. As day light becomes scarce, interaction also becomes less ideal.

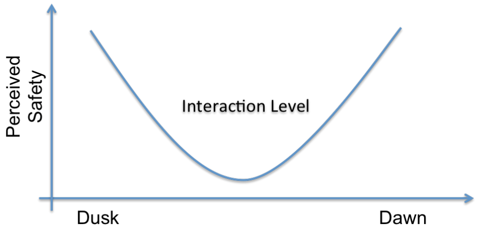

Figure 13. Inverse U curve (Valence) about a place and (a) Timing and (b) Transition function.

Design for Efficiency

Designers focused on decreasing energy consumption can take advantage of the energy efficiency of interactivity. First, energy savings can be explicitly shown to users. As expressed by several of our participants, they valued interactivity to reduce light pollution and energy consumption. Another way is to roll-out interactive illumination projects incrementally. As an example, in the context of neighborhood development, interactive lighting systems can be reprogrammed from an *Always On* mode towards *Before-Soft* modes. However, the design should be carefully crafted so perceived safety is not affected with the introduction of interactive lights. Finally, LED technology should be used to adapt the interaction design to the type of energy system. Table 7 shows potential design choices for different combinations between the type of energy available and the type of urban space. As it can be observed, depending on the type of Energy (Low or High Cost), and the type of urban space (Positive/safe or Negative/unsafe) there should be four types of design choices: Design for Comfort, Design for Adoption, Design for Efficiency, and Design for Safety. Comfort and Efficiency modes focuses on the best affective outcome leveraging interactive lights. The main difference is the permanent use of base light for comfort. Adoption and Security both manage the transition between an *Always On* and an interactive mode. The former prefers *Soft* transitions as opposed to *Hard* ones for the latter.

	Positive urban space (High safety perception)	**Negative urban space (Low safety perception)**
Lower Cost of Energy (Fossil Fuel)	**Design for Comfort:** - Use soft (slow) transitions. Reduce the number of lights ahead gradually. - Bring light intensity to a *Base Light* during low traffic hours; there is no need to use full intensity *Always On* mode.	**Design for Adoption:** - Meet perceived safety levels with a dimmed always-on effect. - As perceived safety improves, increase interactivity. Start with abrupt transitions and move later to smooth transitions.
Higher Cost of Energy (Renewable)	**Design for Efficiency:** - Use interaction patterns as a default, especially light patterns with 2 lights ahead. - Reduce the base lighting level during low traffic hours and turn off the base lights during peak demand hours.	**Design for Safety:** - Use 2 or more lights coming on rapidly ahead of the pedestrian during dusk or dawn, and increase the number of lights as the night gets darker. - Introduce slow transitions as emotions and safety perception improve.

Table 7. Design implications for optimizing affect and/or energy consumption in urban interaction illumination systems.

Content Novelty and Authoring

A key challenge to maintain engagement is to focus on content (the variety of interactive lighting experiences). Content design should follow the past recommendations, but should also incorporate novel elements. As an example, we created a novel interaction that presents two rows of lights with their lights interleaved slightly. It is similar to the *Before-Soft* condition, but the two rows make the interaction appear as a walking set of lights, which is novel and attractive. Figure 14 shows an image of this new interaction. Some users of our system found the different patterns very transformative.

"This makes the sidewalk look like a canvas"

"Now here looks like Europe!"

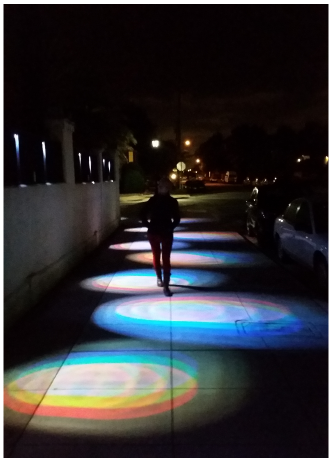

Figure 14. Walking lights interaction: lights alternate in front of the user giving the appearance that they are walking.

Authoring should accommodate three key stakeholders: multimedia and gaming designers, city officials, and citizens. Designers should create modular elements that can be reused by others to create novel content. Additionally, existing patterns could be used as templates. We aim at making the system available through a simple mobile interface, for the use of residents as well as through a programmable API for advanced users.

Multiple users challenge

In the presence of multiple pedestrians, the system has to adapt its interactions according to the amount of traffic. In *Low traffic* scenarios all pedestrians are sensed individually. These situations can be attended to with some of the same types of light patterns described in this paper. For *High traffic* scenarios, it may be necessary to think beyond our prior design principles. Although individual users could still be detected, individual light interactions may be more diluted due to larger numbers of pedestrians along the same path. In this case, designers should consider interactions that leverage all the lights. Figure 15 showcases an example of this design, in which all the lights are used to illuminate different colored paths to accommodate different people. We are currently experimenting with the use of thermopile sensors to help detect individual users.

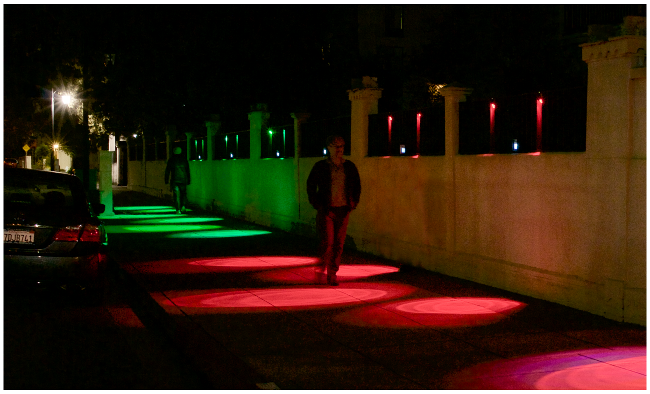

Figure 15. Multiple pedestrians challenge: different colors for each pedestrian pathway.

To further improve the meaning of interactions for different users, designers should investigate and incorporate third-party external data such as train schedules, traffic light status, ambient devices, social media, wearable computers, and personal data interfaces. Novel sensors and actuation devices could come into play for large groups of people.

Wearable and mobile devices

As already discussed in some of the work presented at the interactive lighting workshops at CHI, NordiCHI, DIS, wearable and personal mobile devices could be a great source of new streams of data that could be used to further improve our research. Affective design could greatly benefit from actual psychophysiological sensors that could generate immediate feedback to the lighting system. For example, a simple detection of emotion through EDA [23], HRV [14], limb movement [24], or body movement [13] could easily help close the loop in terms of emotion management. Furthermore additional synchronicity between the system and portable devices could allow for multimodal interactions with sound and haptics [18]. As an example, Figure 16 showcases an interaction where the user uses his hands to change the light colors.

Figure 16. Hand and body gestures detected by thermopile sensors, cameras, or wearable devices.

FUTURE WORK

Long term observation and more in-situ experimentation should lead to four important outcomes: establish the ecological validity of the tool, confirm the energy savings associated with the system, prove the long term engagement of users and leverage pedestrian circulation data for optimization of urban walking experiences. Paredes, et. al. [17] described how affective interventions suffer from novelty effects despite their efficacy. It is therefore important to engage an ecosystem of partners that could help maintain the level of engagement in the system. We are currently experimenting with specific interactions for larger groups (Figure 17), which are related to the number of people and which help the group be part of a common cohesive experience

Figure 17. Interactions for larger groups. Lights create patterns surrounding the group.

Another front is interactions with kids an families. Preliminary interactions show that kids find the lights very compelling. They want to chase them, activate them, jump in and out of them. Pretend they are aliens, or that they are lava. One kid even asked us to make the lights bright red and then he laid down on it pretending that he was bleeding. Parents found the lights very compelling and they often engaged in role playing games with their children (Figure 18).

Figure 18. Interactions for Kids and Families.

CONCLUSION

In this paper, we have shown significant relationships between emotions and interactions with urban lights. We identify design conditions that engender positive responses from users. We also highlight the energy consumption and light pollution reduction that could be achieved through interactive designs. Finally, beyond the well known relationship between illumination and safety, we describe the hierarchical relationship between emotions and interaction. We hope that interactive design parameters such as timing, transition, look-ahead horizon, and minimal lighting levels can serve as guidance to future designs for illumination systems that are not only efficient, but which improve the mood and affective state of urban residents.

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