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A Transformational Approach to Interactive Lighting System Design

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ABSTRACT

Light affects our behaviors and experiences. Research into this field mainly focuses on the effects of lighting conditions on people. The current paper focuses on human interaction with lighting systems, and the way this interaction transforms people's behaviors and experiences. Technological developments, such as Solid State Lighting and increasingly powerful and economic sensing and control electronics, open up a myriad of possibilities for incorporating interactivity and intelligence in lighting systems design. How can we design an interactive lighting system that influences people's behaviors and experiences in a positive way? This paper explores this area from an industrial design research point of view. It introduces a transformational approach to interactive lighting design, combining frameworks of Technological Mediation, Human Values and Kansei design. In a research-throughdesign process, a set of interactive lighting systems are designed based on this transformational approach and empirically evaluated. Results indicate that it is indeed possible to invite specific behaviors and experiences through interactive lighting system design.

Keywords

Interactive lighting systems, transformational design, human values.

INTRODUCTION

A growing body of research studies how light influences human behaviors and experiences. Such research mainly focuses on the effect of specific artificial lighting conditions on people, e.g., [8], [12] and [14]. But artificial lighting becomes ever more dynamic. Technological developments, such as Solid State Lighting, and increasingly small, cheap and powerful sensing and control electronics, open up new possibilities for incorporating interactivity and intelligence in lighting systems design [4]. Increasingly intelligent lighting systems are envisioned to integrate into the everyday environment, playing a role in everyday life that goes well beyond task lighting [1][9]. In view of these developments, the current paper focuses on human *interaction* with lighting systems and the way this interaction affects behaviors and experiences, rather than on the influence of given lighting conditions on people. Our focus on interaction entails that we treat situations in which lighting systems and humans respond to each other's actions in a meaningful way. These lighting systems are typically equipped with electronics that enable them to sense human actions, process the data, and respond accordingly with lighting actuators. How can we design interactive lighting systems that influence people's behaviors and experiences in a positive way? The current paper explores this question from an industrial design research point of view.

Technological mediation, ethics and light

The theory of Technological Mediation [13] is used in the current research to conceptualize the influence of interactive light on our behaviors and experiences. The theory states that every technology in use transforms our experiences and behaviors. This transformation has a dual structure. Each technology on the one hand amplifies specific experiences, and on the other hand reduces others. Compare for example how an mp3 player amplifies the experience of music and reduces the experience of the environment, by immersing the listener in music and blocking other sounds. The theory also states that technology in use always invites specific behaviors while inhibiting others. The mp3 player, when used in a busy train, invites a person to concentrate on his work, while at the same time it inhibits social interaction with people in the vicinity. These mechanisms can also be applied to interaction with lighting systems. When we do this, the question arises for designers of interactive lighting systems what experiences their system should amplify or reduce, and what behaviors they should invite or inhibit. This question has an ethical dimension: People with different ethical beliefs might prefer to engage in different behaviors and might prefer to have different experiences in a given context.

A research-through-design process

This paper presents design research that explores how to design interactive lighting systems that aim to invite specific behaviors in interaction. We call this approach to lighting system design *transformational*. In a research-through-design process [3][5], actual lighting systems are

designed using a combination of design techniques and auxiliary theoretical frameworks. The aim of these lighting systems is to invite specific behaviors in human-system interaction. These designs are evaluated in an empirical study. Central in the current process is design work from a 40-hour bachelor course called Personality in Interaction [10], conducted at the department of Industrial Design at Eindhoven University of Technology [6]. In this course, students designed interactive lighting systems with the aim to invite behaviors that fitted the personality of a specific fellow student.

A framework for ethical beliefs

Before elaborating on the course, we treat an auxiliary theory that was used to operationalize people's ethical beliefs, namely the theory of Human Values [11]. This theory offers a way to understand what kind of behaviors and experiences a specific person would desire to engage in. Human values are defined as follows: 'Values (1) are concepts or beliefs, (2) pertain to desirable end states or behaviors, (3) transcend specific situations, (4) guide selection or evaluation of behavior and events, and (5) are ordered by relative importance' [11]. Examples of values are Creativity, Helpfulness and Social Power. Empirical research in 20 countries identified a set of 57 values considered near-universal. This research allowed Schwartz to meaningfully locate the 57 values on a plane with four quadrants, labeled Self-Enhancement, Conservation, Self-Transcendence and Openness-to-Change. Figure 1 shows a selection of 13 of the 57 values plotted on this plane. In this value scheme, the distance between values represents their mutual compatibility. Figure 1 shows, for example, that the closely located values Helpful and Loyal are more compatible than Helpful and Social Power. The behaviors these values motivate are compatible (or not) in a similar manner. Schwartz developed a survey to measure individual people's value priorities. The instrument is called the Schwartz Value Survey [11] and consists of the 57 value items that can be scored on a 9-point scale.

A large body of research exists that relates people's value priorities to certain behaviors, attitudes and personalities. Several research projects demonstrate the relevance of Human Value theory to design research. For example, Allen and Ng [2] show how values could be related to choice for products as varied as different sunglasses and different cars. The fact that values guide selection and evaluation of behaviors connects ethical beliefs of people and specific kinds of behaviors. The definitions of values can serve as a characterization of desired behaviors a lighting system should invite. For example, for people that value creativity, we could aim to design an interactive lighting system that invites creative behaviors.



Figure 1: 13 out of 57 value items arranged according to the research of Schwartz and placed in the four quadrants (adapted from [11]). The distance between values indicates motivational compatibility.

DESIGNING INTERACTIVE LAMPS: THE PERSONALITY IN INTERACTION COURSE

Research into the influence of interactive lighting systems on human behavior and experience requires evaluation of actual lighting systems. These lighting systems were designed and built in the Personality in Interaction course. The students' design assignment was to create an interactive lamp or lighting system that invited behaviors and experiences that corresponded to the most important values of a fellow student. So if a fellow student prioritized Creativity highly, the assignment was to create an interactive lighting system that invited creative behaviors from the person interacting with it. Note that the assignment was *not* to create a lamp that acted creatively itself: It was about inviting creative behaviors from the person interacting with the lamp. The lamps did not need to be functional in the sense of providing task lighting.

Course set-up

The course's design process followed a Kansei design approach [7] that was adapted for this specific course. It included the following steps:

- 1. Students (voluntarily) completed the Schwartz Value Survey [11] to learn about their own personality. Pairs of students with contrasting personalities were created with the test results.
- 2. Relevant theories (Human Value theory, Kansei) were introduced in a lecture and students read accompanying papers.
- 3. The students created a one-minute 'dynamic personality collage' on video of their assigned fellow student. This collage had to display behaviors of the fellow student that expressed his or her values.
- 4. The personality collages were analyzed to find interaction qualities for design.

- 5. The next step was to design and prototype an interactive living room lamp or lighting system that invited behaviors that related to the fellow student's top priority values.
- 6. The course ended with a final presentation, in which the students interacted with the prototypes designed for them, and the design and design process were evaluated.

Resulting lighting designs

This section treats three designs resulting from the course, to illustrate the nature of the design work. See Figure 2 to 4 for images of the lighting system interactions and accompanying explanations. Film clips of these lamps and the other nine lamps used in the current research are available at http://www.philipross.nl/thesis.



Figure 2: This staircase lighting system targets Creativity related behaviors. It consists of several light balls hanging from the ceiling above the staircase. When the balls are moved, they light up and create a dynamic light and shadow play in the staircase. The balls stick to each other with magnets when they touch, allowing a person to rearrange the layout of light balls as desired. The system's easy interaction, combined with the beautiful, dynamic light and shadow effects that each action creates, invites a person to be creative while walking the stairs.





Figure 3: This decorative lamp is designed to invite curious behavior. The lamp's main interaction elements are three semi-transparent light cubes, placed in a cubic space delimited by three mirrors. The cubes are equipped with colored LED's but do not give away their lighting effects until they are combined with each other. Different ways of stacking or aligning the cubes result in different dynamic colored lighting effects. The lamp triggers curiosity in interaction through its intentional absence of feedforward for actions, combined with the reward of beautiful effects after each interaction.



Figure 4: The Throw Ball light object targets the value Pleasure. This design is conceived for a person that likes to have fun in social setting. The final design is a ball the size of a soccer ball with holes in it that transmit light. The ball tries to stimulate people to throw it by blinking when it is held longer than 0.5 seconds. When it is thrown, it lights up fully. When held longer than 2 seconds, the light dies out which could mean the game is over.

THE EVALUATION EXPERIMENT

An evaluation experiment was conducted to see how people naïve to the design intentions would experience the interactive lighting systems. In this experiment, participants viewed film clips of interactions with twelve different lamps (including one trial) and rated them in terms of values. Twenty people participated, thirteen male and seven female. All participants were architecture students, coming from both the bachelor and the master program. Architecture students were chosen since they have no education in interaction design, but are still sensitive to design in general.

Procedure

The experiment procedure was as follows:

- 1. The participant received an introduction in which the experiment was explained.
- 2. A participant watched a film clip showing interaction with a given lamp.
- 3. The participant filled out a value rating form. Details about this form are treated further on in this paper.
- 4. Step two and three were repeated for all eleven film clips, preceded by a trial clip.

There were 8 separate sessions with 1 to 5 participants simultaneously. The clips were show in three different orders. Order 1 and 3 were randomized, order 2 was counterbalanced with order 1. The participants received $\notin 5,-$.

Stimuli

The designs from the Personality in Interaction course were only partly functional prototypes. It was impossible to test them live with participants in an experiment, so film clips of these interactions were shown to the participants. In these film clips, the prototypes seemed to be truly interactive.

A set of eleven lamps (plus one for the trial clip) served as the stimuli. Two of these lamps were not explicitly designed for a value. The students that designed these lamps deviated from the course assignment, and used other personality traits as input. These lamps were still included in the study to explore how they would be rated in terms of values. Ideally, each of the four quadrants of the Schwartz Value Structure was targeted by at least one lamp. This could however not be realized. There were only a few course students with highest priority values in the 'Conservation' quadrant or the 'Self-Transcendence' quadrant. So these values were rarely targeted in the course. The result was that there were no usable designs targeting the Conservation and Self-Transcendence quadrants. Explanations and pictures of all eleven lamp interactions and the trial lamp interaction are available in [9].

One of the clips was selected as the trial clip. The clip duration ranged from 15 seconds to 39 seconds. Screenshots of these clips are shown in Figure 2 to 4. The clips were numbered and shown on a 37" Flat Screen TV.

Rating form

To measure the way people characterized the interactions in terms of values, a rating form was devised including a list of Human Value rating scales. The form was originally created in Dutch, but treated here in English translation. The participant was asked to imagine they would interact with the lamp themselves. Then they placed a tick mark on the value scale to indicate to what extent a particular value description matched the interaction in the film clip. The value scales looked like this:

Imagine you are interacting with the lamp yourself. Use a tick mark to indicate to what degree the interaction evokes the following terms in you:

Does not	0	0	0	0	0	0	0	Describes
describe it								it perfectly
at all								- •

The value descriptions used in the scales were copied from the value descriptions in the Schwartz Value Survey [11]. A selection of 13 of the 57 values was made to include on the form, to keep the rating task feasible for the participants. These selected values were spread out over all four quadrants of the value plane. Furthermore, the list contained all the values that were targeted by the selection of lamps. The value rating list contained the following items:

- Inner harmony (at peace with myself)
- Curious (interested in everything, exploring)
- Humble (modest, self effacing)
- Freedom (freedom of action and thought)
- Social power (control over others, dominance)
- Capable (competent, effective, efficient)
- Pleasure (gratification of desires)
- Loyal (faithful to my friends, group)
- Politeness (courtesy, good manners)
- An exciting life (stimulating experiences)
- Sense of belonging (feeling that others care about me)
- Creativity (uniqueness, imagination)
- Helpful (working for the welfare of others)

The distribution of the corresponding values over the 2D structure is depicted in Figure 1. The forms were filled in on a laptop running SPSS Data Entry Station.

Hypotheses

If the design of the lamps has any effect measurable with the value scales, the ratings on the value scales should differ between lamps targeting different values. Formally put:

Hypothesis 1

H0: The mean ratings on the value scales are equal between lamps

H1: The mean ratings on the value scales are not equal between lamps

This effect should have a certain pattern for the lamps that targeted a specific value. One would expect that a target value would always have a significantly higher score on the scales than all other values. This leads to the second hypothesis.

Hypothesis 2

H0: The mean rating of the target values are not higher than those of all other values

H1: The mean rating of the target values are higher than those of all other values

Human value theory predicts a structure in the relation of the score of the target value scale to the scores of the other value scales. As treated earlier in this paper, the mutual distance of value items on Schwartz' value structure is a measure of 'motivational compatibility'. If two values are located close to each other on the value structure, they are compatible. The larger the distance between them, the less compatible they are. For example, the values Helpful and Loyal (closely co-located) are more compatible than Helpful and Social Power (large distance in between). See the locations of these values in Figure 1. This degree of compatibility between values is expected to have a systematic effect on the scores on the value scales. For example, if a lamp in the current experiment succeeds in eliciting the value Helpful, the value scale Helpful would receive the highest mean scores. The value scale Loyal (the most compatible value in this experiment) would receive the second highest score, and the value scale Social Power (the least compatible value) would receive the lowest score. So it is possible to determine a theoretical rank order of the means of all value scale scores, based on the targeted value score. The occurrence of this rank order in the data would be an indication that the ratings are in line with value theory and that the interaction is really relevant in terms of values. The 'fit' of the measured rank order of value scale scores with the theoretical rank order of scores is determined here by a correlation analysis of both rank orders. Put in terms of a hypothesis:

Hypothesis 3

H0: The correlation between the measured and theoretical rank orders of the value scores is not significant

H1: The correlation between the measured and theoretical rank orders of the value scores is significant

Results

Figure 5 shows the ratings of the three lamps treated in the current paper. Most of the evaluated lamps targeted values in the Openness to Change quadrant. This shows in the ratings. The highest scores are generally located in the Openness to Change quadrant. This section continues with a treatment of the three hypotheses in light of the experiment results.



Figure 5: The mean ratings of the three lamp designs explained in this paper. The values are placed in order according to the value structure quadrants along the x-axis. The vertical lines indicate the borders of the quadrants. Each lamp's target values are highlighted with a large, filled dot.

Results for Hypothesis 1:

H1: The mean ratings on the value scales are not equal between lamps

Figure 5 show differences between the scores on the value scales. An 11 (Lamp) x 13 (Scale) repeated measures Analysis of Variance (ANOVA) was performed on scores for the value scales for all 11 lamps. The results are reported in Table 1. Significant main effects were obtained for Lamp, F(10, 2717) = 7.7, p < .001, and for Scale, F(12, p) = 7.7, p < .001, and for Scale, F(12, p) = 7.7, p < .001, p <(2717) = 47.7, p < .001. In addition, the interaction effect was significant, F(120, 2717) = 2.2, p < .001. Simple main effects analyses (Dunnett T3) were performed to examine the nature of the significant interaction. It was found that the means of 9 of 11 lamps were significantly different from one or more of the other lamps' means. The conclusion is that H(0) is rejected. (Note: Homogeneity of variance could not be assumed. Non-parametric test, the Friedman Two-way Analysis of Variance by Ranks and Kruskal-Wallis tests were performed on the value scale scores. The same significant effects were obtained from these tests.)

Table 1: Results of the ANOVA. Independent Variables are Lamp and Scale, the Dependent Variable is Score.

Source	Type I	II df	Mean	F	Sig.
	Sum c	of	Square		
	Squares				
Lamp	202.8	10	20.3	7.7	0.001
Scale	1515.9	12	126.3	47.7	0.001
Lamp * Scale	704.4	120	5.9	2.2	0.001
Error	7199.5	2717	2.7		
Total	52975.0	2860			

Total 52975.0 2860

R Squared = 0.252 (Adjusted R Squared = 0.213)

Table 2: Ranks of each lamp's target value scores compared to the other values.

Lamp name	Staircase lighting system	Mirror Blocks	Flower Lamp	Throw Ball	High Five	Segmen ted Ball	Stacker Lamp	Spring Lamp	Puzzle Lamp	Color Box	Tree of Light
Target value rank	2	2	2	1	n.a.	n.a.	1	2	1	3	5

Results for Hypothesis 2:

H0: The mean rating of the target values are not higher than those of all other values

Nine of eleven lamps tested in this experiment actually targeted a value. The other two designs targeted other aspects of personality, since the designers deviated from the course design brief. Three of the nine lamps targeting values actually received the highest ratings on their target value, i.e., Light Ball for Pleasure, Stacker lamp for Freedom and Puzzle Lamp for Curiosity (See [9] for a description all the experiment's lamps). In four lamps, the target value was rated second highest, one was rated third and one was rated fifth. See Table 2 for an overview. In almost all cases, H(0) cannot be rejected.

However, the target value is in most cases ranked second or third. Value theory says that the values are part of a motivational continuum. When values are located close to each other in the structure, they are similar in motivation. This means that behaviors motivated by a value very near a target value are still highly compatible with the behaviors motivated by the target value. An analysis considering the order of the ranks of all values gives a more nuanced view on how successful the lamps are, as explained for hypothesis 3.

Results for Hypothesis 3:

H1: The correlation between the measured and theoretical rank orders of the value scores is significant

To test whether the rank orders of the values as they are rated are equal to the theoretical rank orders, based on their mutual compatibility, a correlation analysis is conducted. In this analysis, the scored rank orders are compared with the theoretical rank orders. The theoretical rank orders are calculated by determining the distance between the target value and all other measured values on the structure. See Figure 6 for a graphical representation of this process. Table 3 shows the table of correlation coefficients.

The table shows that the value scores of 6 of 9 lamps that target a value correlate significantly with the theoretical rank orders. This indicates that the interactions they elicit show the same 'motivational structure' as the values they try to elicit. So although the target values are not in all cases rated highest, the values that motivate similar behaviors score higher than the values that conflict with the target value. And the structure of gradually increasing and decreasing compatibility is present as well. The approximate sinusoid lines in Figure 5 visually depict this. The results of this analysis indicate that these lamps elicit interactions that are actually relevant in terms of values.



Figure 6: Determining the first six rank orders for Creativity. The circles indicate the different distances from the values to Creativity. The circles have the Creativity value as their centre, and have a radius that corresponds to the distance to another value.

Table 3: Correlations of scored value rank orders with theoretical rank orders (all N=13). Continued on the next page.

Correlations – Kendall's tau					
Staircase lighting system	Correlation Coefficient	0.538			
(Creativity)	Sig. (2-tailed)	0.01			
Mirror Blocks (Curious)	Correlation Coefficient	0.564			
	Sig. (2-tailed)	0.007			
Flower lamp (Creativity)	Correlation Coefficient	0.641			
	Sig. (2-tailed)	0.002			
Throw Ball (Pleasure)	Correlation Coefficient	0.538			
	Sig. (2-tailed)	0.01			

Table 3: continued.

Stacker Lamp (Freedom)	Correlation Coefficient	0.641
	Sig. (2-tailed)	0.002
Spring Lamp (Pleasure)	Pearson Correlation	0.445
	Sig. (2-tailed)	0.128
Puzzle Lamp (Curious)	Correlation Coefficient	0.513
	Sig. (2-tailed)	0.015
Colour Box (Hedonism)	Correlation Coefficient	0.308
	Sig. (2-tailed)	0.143
Tree of Light (Self-Direction)	Correlation Coefficient	0.359
	Sig. (2-tailed)	0.088

Discussion of the experiment

The experiment results are encouraging. However, there are reservations that need to be made. The lamps were tested using video-clips of interaction. Experiencing an interaction captured on video may be different than experiencing interaction live. It is unknown how this difference manifests itself in the measurements. Because of the low number of participants and their specific background, caution is required in generalizing the results to a larger population. All lamps in this test focused on values in the Openness-to-Change quadrant and the Self-Enhancement quadrant. It is therefore still unknown if values in the other quadrants could be targeted. Although the rating form makes use of the exact formulations of the Schwartz Value Survey, it is not a validated measuring instrument.

GENERAL CONCLUSION AND DISCUSSION

The outcomes of this study indicate that it is possible to design interactive lighting systems that invite behaviors that relate to a specific range of values. 'Range of values' is mentioned since the lamps in the experiment invite a range of compatible values, rather than only one isolated value. Quantitative analysis of the value scale scores indicated that the behaviors and experiences invited by the lamps in 6 of 9 cases corresponded significantly to the values these lamps targeted. The authors interpret the outcomes of the study as a stimulus to continue this line of research. A follow up research question is to see if people evaluate lamps that invite behaviors that correspond to their own high priority values more positively than lamps that invite conflicting behaviors.

The theoretical frameworks of Technological Mediation and Human Values serve as useful input for design, helping designers define what they would like to achieve with their interactive lighting system. The creative and novel character of the resulting lamps indicate that taking a targeted value related behavior as an input for the design process is a fruitful approach to come to innovation in interactive lighting design.

On a general level, the results show the relevance and potential of design research specifically directed at *interaction* with lighting systems, taking the way they transform our behaviors and experiences into account. The current value-based transformational design approach can help designers create lighting systems that influence our behaviors and experiences in a positive way.

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