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FUTURE LIGHTING SYSTEMS AT HOME: INTERACTION CONCEPT FOR FREQUENT AND SPORADIC BATHROOM LIGHTING CONTROL

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ABSTRACT
Advancements in lighting technology, namely through achievements in solid-state lighting, e.g. LEDs (light emitting diodes), have expanded the horizon of possibilities artificial lighting has to offer. As these lighting systems become increasingly complex, it is crucial to find intuitive ways of interaction for domestic users, enabling them to control lighting in a flexible and simple way. This paper discusses the participatory design and usability evaluation of an interactive lighting controller for the bathroom. The interaction concept has been created based on the results of an ethnographic study conducted by means of Cultural Probes and Workshops with representative end-users. In the final evaluation the interaction concept was rated highly on its perceived usefulness and ease-of-use. The participants successfully interpreted the metaphors used in the design to present the functionality provided by the system.

KEY WORDS
User Interface Development, Usability Evaluation, Home

1. Introduction

Through centuries the use of lighting has been twofold: a functional aspect has been to create optimal conditions for good visibility and an emotional aspect has been to create a pleasing ambience, like when using candles. Nowadays, developments in solid-state lighting have opened new possibilities for manipulating light parameters and creating rich lighting scenes with variations in intensity, color, spatial distribution and even dynamic scene changes. A good example of the new opportunities provided by advanced lighting technologies is the Vos Pad [1] [2]. In this London apartment, light ambiences have been created using LEDs in the main rooms of a household, including the separate toilet and bathroom.

From our literature study we could conclude that activities taking place in the bathroom are well defined and could be classified in distinct categories. According to Kira [3], bathroom activities can be divided into Hygiene, Quasi-medical and Grooming activities. Most activities in these three groups are short functional activities that occur frequently, and demand good visibility conditions. Other activities such as Relaxation activities (e.g. hot bath after work) only occur sporadically and demand the creation of a suitable ambiance, where visibility is not critical. The rich mix between different types of activities that require the support of both functional and atmospheric lighting, made the bathroom a unique room to focus our work on.

Based on trends in the use of the bathroom identified in user studies, Philips Lighting conducted a feasibility study by installing a demonstration of state-of-the-art lighting in the bathroom of HomeLab [4] [5] in Eindhoven, the Netherlands. The demo was created to experiment with this new lighting technology and to explore the scope of potential concepts for domestic use in our research lab. The demo consisted of different light modes (Night, Wake-up, Day, and Relax) that created functional as well as ambient atmospheres using variations in light intensity, colour, colour temperature of white light (ranging from cold to warm, this is, ranging from a bluish to a yellowish white light), and temporal transitions between the modes.

Both the Vos Pad and the demo in HomeLab were very different from what most people have nowadays at home. Our HomeLab bathroom light installation consisted of 50 light sources, and was controlled through a 12-button interface to activate preset modes. For more complex tasks such as installing and modifying the presets, proprietary software, MultiDim (Figure 1), was used. In this interface, users would manually drag sliders to define the intensity of light for each lamp, having to map each slider to a specific lamp or group of LEDs in a room. For example, they must remember that “Ballast 11” corresponds to “the halogen lamp located by the door”.

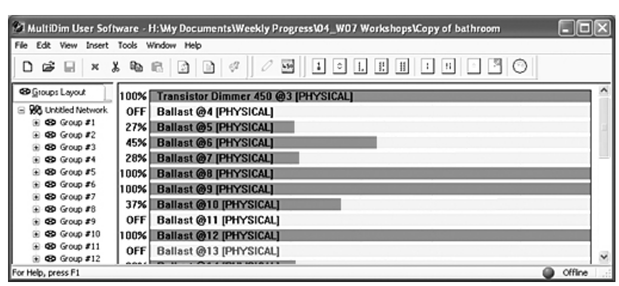

Figure 1: MultiDim interface to control 50 light sources.

We realized through our experience with MultiDim and its 12-button control unit that available user interfaces for these systems are difficult to use and would not be acceptable to the majority of consumers. Similar complex controls were used in the Vos Pad where 135 groups of LEDs had to be manually adjusted. As such, in our project we focused on creating an intuitive user interface control for an advanced multi source lighting system.

2. User Study

The goal of the user study was to gain insight into bathroom activities and other contextual aspects related to the use of light in the bathroom. To reach this goal, we conducted an explorative ethnographic study that included interviews, Cultural Probes [6] and Workshops in our lab.

2.1 Participants

Based on ethnographic design research, we chose to study a small number of users in depth rather than a large number superficially. In this way, a richer and deeper understanding of user needs could be obtained [7]. We recruited five couples, ten participants in total, for our study to ensure different viewpoints.

2.2 Cultural Probes

The first part of the study took place in the participants' homes and focused on bathroom activities, activity-related areas and objects used in this context. We were also interested in how lighting was currently being used, for what kind of activities, and whether participants were experiencing any problems with lighting in the bathroom. Cultural Probes were designed to address these questions.

The probes consisted of a Diary, which contained questions, a timeline for tracking their activities, and assignments such as drawing and describing what their ideal bathroom would be like. The probes also included a disposable camera to allow participants to take pictures to visually support and highlight some of the experiences they had while filling-in the diaries (Figure 2). The probes were introduced during an interview in the participants' homes, where a brief explanation of what they were expected to do with the probes was given.

The main advantages of this way to elicit requirements include collecting data from participants over an extended period of time (one week), something formal interviews do not allow because they do not go beyond a couple of hours. A one-week period allows participants to reflect on different aspects of their use of the bathroom and to become more aware of the problems they might experience, but also of their wishes and needs. Another advantage of the probes is that they provide better conditions for participants to answer questions related to a very private space, the bathroom, which may make them feel uncomfortable in a formal interview.

Figure 2: Pictures made by participants.

Most of our literature findings concerning different activities performed in the bathroom were confirmed. However, some interesting new aspects were mentioned in the diaries. The most important one was the strong need expressed by the participants for good lighting conditions to support activities in the bathroom. At the same time, participants expressed a strong reluctance to have coloured lighting in their bathrooms.

2.3 Workshops

The main objective of the Workshops was to allow participants to witness and have a first-hand experience with the lighting demonstrator in the bathroom of HomeLab. In this way, we were able to gather requirements from the participants through their initial reactions on the demonstrator, and trigger their imagination for new ideas.

The bathroom lighting demonstrator was presented in a sequence of modes that include a Night Mode, a Wake-up Mode, a Day Mode, and a Relax Mode. Scenarios were used to help participants understand the context of the occasion when each mode would most probably be used (Figure 3). At the end of the workshop, the impressions of the participants were discussed in depth with respect to their concerns related to safety, location of the interface, interaction style, automatic triggering of modes and sharing.

2.4 Conclusions from User Study

Although all participants were reluctant about having coloured lighting in their bathrooms during the Cultural Probes, after all the Modes were presented in the demo in HomeLab, all participants were enthusiastic about what they saw. This sudden shift in opinion can be explained by the difference between asking participants to imagine what coloured lighting could do for them in the bathroom, and actually experiencing it [8].

Figure 3: Participants viewing Modes during Workshop.

Data from both studies supported our initial assumption, i.e. the need for lighting in the bathroom both to functionally support activities and to provide atmospheres. Functional use of lighting refers to providing good visibility conditions for example in the mirror-sink area for activities such as applying make up, shaving or brushing teeth. Atmospheric use of lighting refers to creating a suitable ambience in situations when visibility is not critical, for example, the Relax Mode in the HomeLab demonstrator.

Although participants were enthusiastic about the bathroom lighting demo, they were concerned about the potential complexity of the interaction with the system. They indicated that, preferably, controlling the system should be as simple as controlling lighting in their homes.

3. Design

Based on the feedback received from participants of the user study, we formulated general design guidelines that would help us make a simple lighting system control.

3.1 Design Guidelines

Grouping lights: We tried to decrease the complexity of controlling 50 light sources by grouping lights into logical combinations between activities and areas where they take place, as identified in the Cultural Probes. One example is the Relax Mode, strongly related to taking a bath in the bathtub. As such, lights around the bathtub that create the atmosphere for relaxation could be grouped together.

Simple interaction for both frequent-use and sporadic-use functions: In our problem analysis we identified two types of tasks, those performed frequently and those performed only sporadically. Frequent-use functions include switching the lights on and off, and changing the intensity of light. Interacting with the frequent-use control should be as simple as interacting with the ordinary light switches that people have at home. Due to the simple nature of the tasks involved at this level, simplicity should easily be reached. Sporadic-use functions are more complex, like creating presets for a relaxing atmosphere or modifying existing presets. Users must select light sources and colours, change the intensity of light, and map lamps to positions in the bathroom in order to create atmospheres. Because it is questionable whether people will spend much (if any) cognitive effort on the adjustment of lighting conditions for complex functions that are only used occasionally, the user interface for sporadic-use functions needs to be simple.

Single control for both frequent-use and sporadic-use functions: To prevent using several function-specific controls, a single control having both frequent and sporadic-use functions should be encouraged. Although there may be more than one control in the bathroom, all controls should provide a consistent interaction style.

3.2 Usability Goals

We defined usability goals to serve as selection criteria for our design ideas and as acceptance criteria for the evaluation. Qualitative usability goals and measurable objectives were defined for each of the following items:
Simple controller for frequent-use: Users should be able to switch the lights on and off, change the intensity of light and activate Modes in a simple way.
Direct manipulation through familiar control objects: For frequent-use functions users should be able to control them via ordinary light switches and dimmers.
Direct access from place of activity: Users should be able to control functions where the activity is taking place (i.e. control Relax Mode from the bathtub).
Users being in control: Users should be able to override the system at any time, especially in case of emergency.
System easy to set up: Users do not want to spend significant time setting up or modifying functions.

3.3 Metaphors for the Master Control

In the following sections we discuss the graphical user interface and interaction design for the lighting controller.
Natural light metaphor: We found that the change between cold and warm colour temperature of white light, this is, the change from a bluish to a more yellowish white light, was the most difficult function to explain to users. A very simple process in nature gave us an idea on how colour temperature could be represented with the help of a metaphor that builds upon common knowledge of nature. The transition between cold and warm colour temperature of white light occurs in nature when, on a sunny day, white fluffy clouds cover the sun, making the light colder. As clouds go away, the light becomes warmer. Therefore, in our interface, a sunny sky corresponds to maximum warm white light (Figure 4a), while clouds covering the sunny sky correspond to maximum cold white light (Figure 4b). The user can control the ratio of warm and cold by dragging clouds onto the sunny sky.

We decided to use a clear blue sky as a metaphor for the source of light. In nature light starts fading away as the sun sets; therefore, total darkness is represented as night.

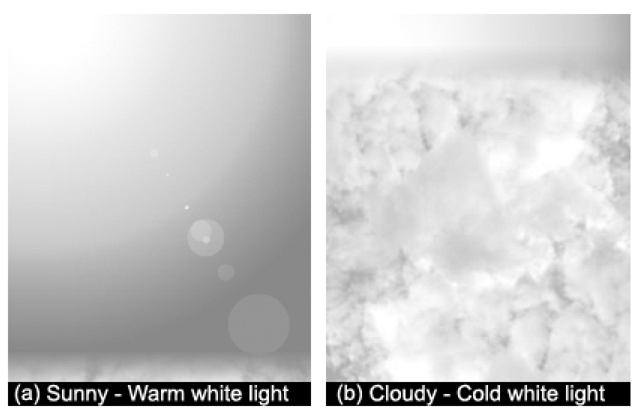

Figure 4: “Natural Light” Metaphor.

Figure 5: Master Control: "Light Switch" Interface.

Light switch metaphor: A "Light Switch", implemented on a similar-sized platform provides an equivalent interaction style, press plus press-and-drag, to control lighting via an object that is familiar to users, and that could be accessible from the activity areas, namely, by the bathroom entrance, by the mirror and near the bathtub.

3.4 Master Control: Light Switch Interface

The "Light Switch" interface controls the frequent-use functions, thus it became the master control of the system.
Interaction Style for Master Control: We defined the following interaction style for the "Light Switch" user interface implemented on a PocketPC (the rationale for choosing this platform can be found in section 3.7).

- With a press of a finger on any part of the touch screen of the PocketPC, the current state of the system is changed (on-off).
- Press-and-drag up or down with a finger increases or decreases the intensity of light depending on the direction of the movement. Similarly, the colour temperature of white light can be changed from warm to cold after activating the "Sunny/Cloudy"mode.
- When the "Light Switch" is turned off, the system stores the last values of the intensity and colour temperature of light for future use.
- It is possible to access all atmosphere presets by means of buttons located in the corners of the switch, to prevent an accidental press during normal operation.

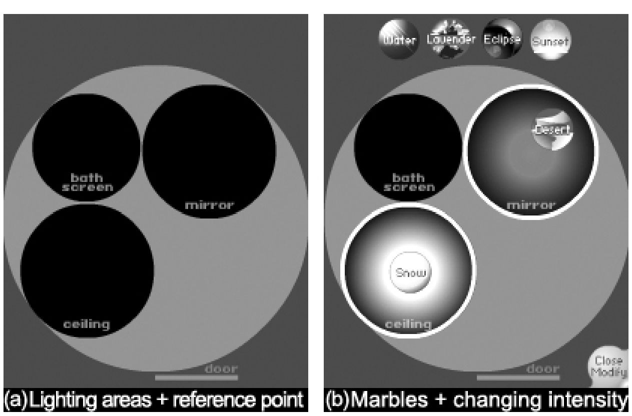

Figure 6: Secondary Control: Modify Presets Interface.

Feedback on the Master Control: A single line of text in the centre of the "Light Switch" provides feedback on what action users need to perform (i.e. press or press-and-drag) followed by the result they would achieve with their action (i.e. switch on, change intensity) (Figure 5). Feedback on the selected Preset is presented at the top of the interface. The intensity of light is presented as a numeric value in percentage and as a visual representation of the transition from bright day to a dark night. Feedback on the colour temperature of white light is presented by a visual representation of clouds covering the sunny sky.

3.5 Metaphors for Secondary Control

Fish-eye view of the bathroom floor Metaphor: Due to the variety of bathrooms and their configurations, namely differences in sizes, shapes and furniture, we decided to aim for a generic way of representing any bathroom. We proposed a fish-eye view representation of the bathroom (Figure 6a). With a physical fish-eye optical lens, any rectangular or square bathroom would be seen as a circle. In our generic bathroom representation a fixed reference point (the door) is defined for users to find their way around the bathroom, under the assumption that every bathroom has a door. Building upon this metaphor, smaller circles represent possibilities that a given bathroom has to offer in terms of lighting. Lighting areas could match activity-related areas such as bathtub, mirror, etc., but in other bathrooms this could not be the case.

Coloured Light Metaphor: Building up on the "Natural Light" metaphor, we wanted to find natural phenomena that influences our perception of light; phenomena that people would almost universally agree on the colour. During a sunset, for example, a warm orange light affects everything that is visible. We wanted to know to what extent these associations made sense to users. The associations we thought would be generically recognizable are, Sunset – Orange, Forest – Green, Water – Blue, Desert – Yellow, Snow – White, Eclipse – Red and Lavender – Purple. They were presented as Marbles that contained the name of the natural phenomenon associated, an icon symbolizing the phenomenon that would better help illustrate the concept behind the marble, and the colour itself (Figure 6b).

3.6 Secondary Control: Modify Presets Interface

The secondary interface for Modifying Presets can be accessed from the Master Control.
Interaction Style for the Modify presets Interface. Creating presets from scratch can be quite frustrating especially if users are not yet aware of the possibilities the system has to offer. Beusmans [9] [10] reported an experiment where two groups were controlling atmospheres through lighting, one had presets and the other started from scratch. In the second condition, users were unable to discover all the options themselves, and lost interest. The way to get them going with designing

atmospheres was to show them first what the possibilities were. To address this issue in our user interface, the initial state of presets is shown to serve as guidance for users (Figure 6b). Marbles which are in use in a particular preset are already located in the bathroom, while unused ones remain on the top part of the interface.

By pressing and dragging a given marble into the different circles that represent areas within the bathroom, three things occur. Firstly, by pressing a marble, a given colour is selected. Secondly, by dragging a marble across the bathroom, a physical location is selected. Thirdly, dragging the marble inside one of the black circles and moving it towards the center of the black circle increases intensity of that light. Therefore, three different functions can now be addressed in one seamless action.

3.7 Implementation

We decided to integrate both the Master and the Secondary Control into one interface and implement our prototype on a Pocket PC for the following reasons:

- It resembles a real light switch both in size and in its ability to interact by touch, reinforcing our metaphor for the Master Control.
- Through its wireless connection, it is possible to transform a Master Control attached to the wall, into a mobile Secondary Control. While creating or modifying presets, a mobile Secondary Control has the advantage that the user can easily walk around in the bathroom, adjust the light presets and have immediate feedback by looking at the light changes in the bathroom itself.
- While creating presets, the high resolution bright screen is suitable for detailed interaction and feedback.

3.8 Alternative Approaches

Early on in the design process, we considered using TUIs (tangible user interfaces) [11] for controlling lighting in the bathroom, especially for creating atmospheres for relaxation. Some TUIs we envisioned included using coloured marbles, coloured soaps or rubber ducks that would float on the water and thus take part in the bathing experience. However, participants quickly ruled out using TUIs as a controller in the workshop discussions because these objects could easily get lost or be left in unexpected places. TUIs did not comply with two of our usability goals: allowing direct access to the controller from the place of activity and allowing users to be in control of the system at all times.

4. Evaluation

We evaluated our design by means of qualitative tests.

4.1 Participants

In the User Study, the lighting demonstrator in the bathroom of HomeLab elicited a strong positive reaction from the study participants. Back then during the workshop, only the lighting demo was shown to them. During the evaluation, both the demo and the new controller were shown. In order to evaluate the new controller without being positively biased by the initial impressiveness of the lighting demonstrator, we invited either the same participants from the first study. Since not all participants could make it we invited instead visitors who had previously seen the demo. In total we had 10 participants for the evaluation.

4.2 Experiment 1: Light Switch

An interactive explanation was given by the facilitator as a way of introducing the interface to the participants. Participants then had 5 minutes to play around with the basic functions of the "Light Switch" control (switch on-off, change intensity, change colour temperature). Finally, participants individually performed 13 tasks for 10 minutes and filled out a questionnaire.

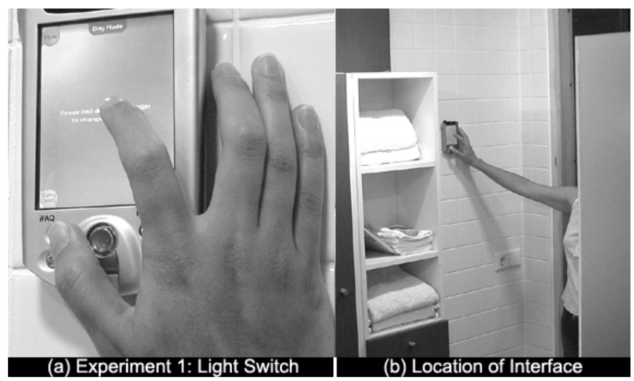

Figure 7: Interaction and location of the interface in the evaluation.

4.3 Experiment 2: Modifying Presets

The experiment leader explained how atmospheres could be created from a given preset. Participants had 5 minutes to explore the functions related to "Modifying Presets" (select, drag colours, change intensity). Participants individually performed tasks and filled out a questionnaire.

4.4 Debriefing

Participants were asked to verbally describe their understanding of the system. We tried to assess whether the metaphors helped participants carry out their tasks by checking whether the meaning of each metaphor matched the explanations given by the participants.

4.5 Results

The evaluation was focused on three main aspects, namely, success or failure to complete a task, Analysis of the TAM [12] (technology acceptance model) Questionnaire and Understanding of the Metaphors.

A. Task Completion
All participants but one were able to complete all tasks in experiment 1 on the first try. The remaining participant was able to complete one task only on the second try. For the tasks in experiment 2, all participants were able to complete them in the first try with only minor difficulties.

B. Analysis of the TAM Questionnaire
A validated measurement scale was used for predicting user acceptance of this system. The TAM models the acceptance of technology using two dimensions: Perceived usefulness and Perceived ease-of-use. The questionnaire consists of 10 questions (Table 1), with the first 6 questions belonging to the Perceived ease-of-use dimension and the rest to the Perceived usefulness. Based on our usability goals, we set success criteria for each of the TAM questions. A usability goal was reached when the mean rating of participants was ≤ 2.5, with a standard deviation <1.4 , on a 7-point Likert scale where 1 is strongly agree, 7 is strongly disagree, and 4 is neutral. A maximum standard deviation of 1.39 was defined to prevent the ratings from reaching the neutral point (4.0) in case of a mean equal to 2.5.

For the first set of tasks, we reached our success criteria for 8 out of 10 goals. Table 2 shows the mean ratings on the Likert Scale per item on the TAM Questionnaire. The dotted line shows the threshold for the mean ratings (2.5) corresponding to our success criteria. The white bars show the items where the success criteria were met. Dark grey columns show items that did not meet the criteria. Items 4 and 7 were rejected both for high mean ratings (2.8 and 3.2 respectively) and for reaching the neutral point (4.0) due to their high standard deviations (1.32 and 1.48 respectively).

The most important items that were highly rated include participants agreeing on the system being "easy to use", "easy to learn to use", and "useful to have at home". Participants did not think the system was flexible enough, probably because, the prototype on the PocketPC demanded them pressing either really hard or with their nails, otherwise, the system would not respond according to their actions. Participants also disagreed that the system allowed them to control lighting rapidly. The slow response rate of the system to process users' requests is a critical issue, especially for tasks that control several lamps at a time.

N	Question or Item of the TAM Questionnaire
Q1	I find learning to use the system easy
Q2	I find it easy to get the system to do what I want it to do
Q3	My interaction with the system is clear and understandable
Q4	This system is flexible to interact with
Q5	I find it easy to become skilful at using the system
Q6	I find it easy to use
Q7	I find that by using the system I am able to control lighting rapidly
Q8	I find that by using the system I can enjoy controlling the lights
Q9	I find that by using the system it is easy to control the lights
Q10	I find this system useful at home

Table 1: Ten questions (items) of the TAM questionnaire.

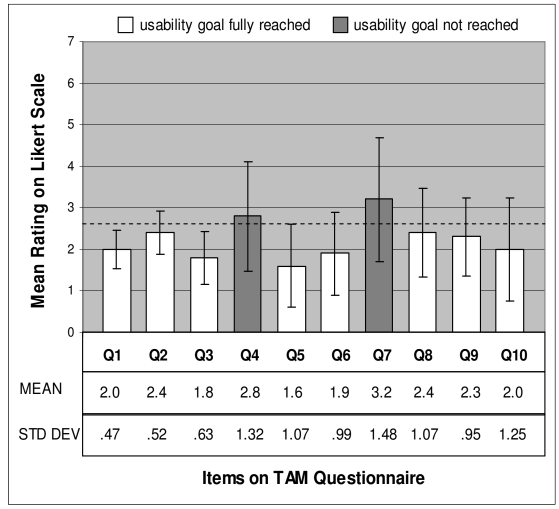

Table 2. Mean Ratings ≤ 2.5 with a standard deviation <1.4 on 7-point Likert scale for the First set of tasks.

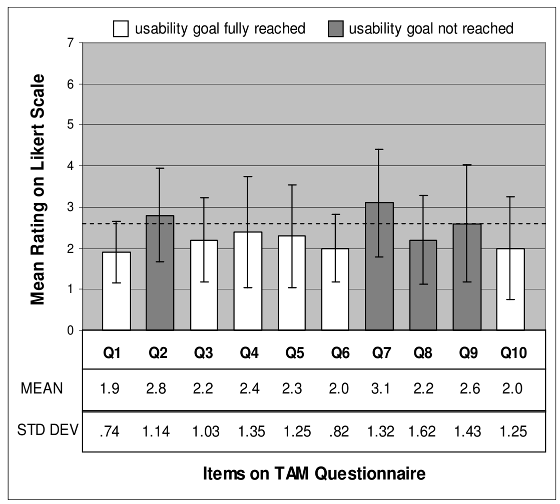

Table 3. Mean Ratings ≤ 2.5 with a standard deviation <1.4 on 7-point Likert scale for the Second set of tasks.

For the second set of tasks, we reached our success criteria for 6 out of 10 goals (Table 3). The dotted line shows the limit of the mean rating (2.5) to comply with our success criteria. White bars show the items that comply with our success criteria, while dark grey bars show items that did not. With a mean of 2.2, question 8 was rejected due to a high standard deviation of 1.62.

The second set of tasks confirms the ratings obtained previously, agreeing on the system being "easy to use", "easy to learn to use" and "useful to have at home". Participants again disagreed that the system allowed them to control lighting rapidly. Participants did not agree that by using the system it was easy enough to control the lights, because it was not clear to them which colours could be dragged to which areas. Item 8 was rejected due to one participant who rated the interface with a 6 (where 1 is strongly agree, 7 is strongly disagree), which caused the standard deviation to rise to 1.62, although the mean rating was 2.2 which did comply with our success criteria.

C. Understanding of Metaphors

For most functions, participants agreed the interface provides good feedback on the state of the system as well as on what the user can do at every stage.

- Most participants said it was clear to them that they needed to move the clouds away from the sun to have a warmer colour temperature of white light. The link between yellowish light and the sun was clear to them.
- Two participants misinterpreted the clouds as ice and snow. However, this difference in interpretation did not prevent them from understanding the core of the metaphor and how it was supposed to be used.
- All participants could map the marbles to the colours the system had to offer in terms of lighting. However, some colour associations made more sense than others. Red connected to an Eclipse seemed rather arbitrary.
- All participants could map the abstract representation of the bathroom to areas within the bathroom.
- All participants were able modify presets with the controller and said it was easy to understand and to use. One participant said only initially he had to remember the center corresponded to full intensity.

5. Conclusion

An interaction concept has been created for controlling lighting in the bathroom based on the results of extensive user research. The new design provides an interface involving small touch screens, and employs the metaphor of a "Light Switch" for controlling basic functions for groups of lights such as switching on and off and changing the intensity of light. The small touch screens are located in strategically chosen activity-related areas in the bathroom. Changing the colour temperature of white light, which had been found conceptually difficult with other lamps providing this function, can now be achieved through a "Natural Light" metaphor. Variations between warm and cold colour temperature are represented by a "sunny sky" or a "cloudy sky". The concept has been expanded to allow more advanced functions such as creating atmospheres for relaxation through coloured lighting. The new interaction concept allows selecting a colour, positioning the colour on an abstract map of the bathroom, and changing the intensity of light of that given colour in one seamless action instead of three separate actions. In the final evaluation, the interaction concept was highly rated by participants on its perceived usefulness and ease of use. The metaphors used to represent the complex lighting system and its included functionality, as well as for presenting the spatial configuration, were successfully interpreted.

As lighting systems offer more and more options through dynamic and coloured lighting, systems will undoubtedly get more and more complex. However, this complexity should not be introduced into the user interface since the user should be able to interact with these complex systems intuitively as they do today with ordinary light switches.

Future work includes integrating such a control for other areas in the house and expanding the idea of creating atmospheres for relaxation. Atmospheres could be created not only through lighting, but also by including music, odours, or projecting images.

Although the PocketPC was the best choice available for implementing our prototype at the time, it was not the ideal platform to implement the "Light Switch" concept. Future prototypes should allow flawless touch screen interaction between the user and the system. Users had to press the screen hard or use their nails, which is not the intended interaction style. Users should be able to control the system with their fingers no matter how hard or soft their touch is. Press-and-drag functions for changing the intensity or colour temperature of light were very sensitive to the amount of pressure participants were applying on the screen.

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