Affective Lighting Seminar: Interactive Cube

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ABSTRACT

This paper describes the prototype "Interactive Cube", a cube which uses LED light as an output source and its development during a two weeks long timeframe. The prototype is a result of the seminar "Affective Lighting" at the Saarland University in summer term 2015. The final cube consists of plexiglass and offers several functionalities such as displaying current time or temperature and can also act as an ambient light. In every mode, the appropriate information is represented by lighting patterns on the surface of the cube. The different functionalities are linked to a certain side of the cube and can be selected by rotating it. In addition to the detailed functionality of the cube, this paper documents the whole development process, including problems and corresponding solutions as well as hardware and software decisions. Moreover, it outlines perspectives of how to improve the developed prototype even further.

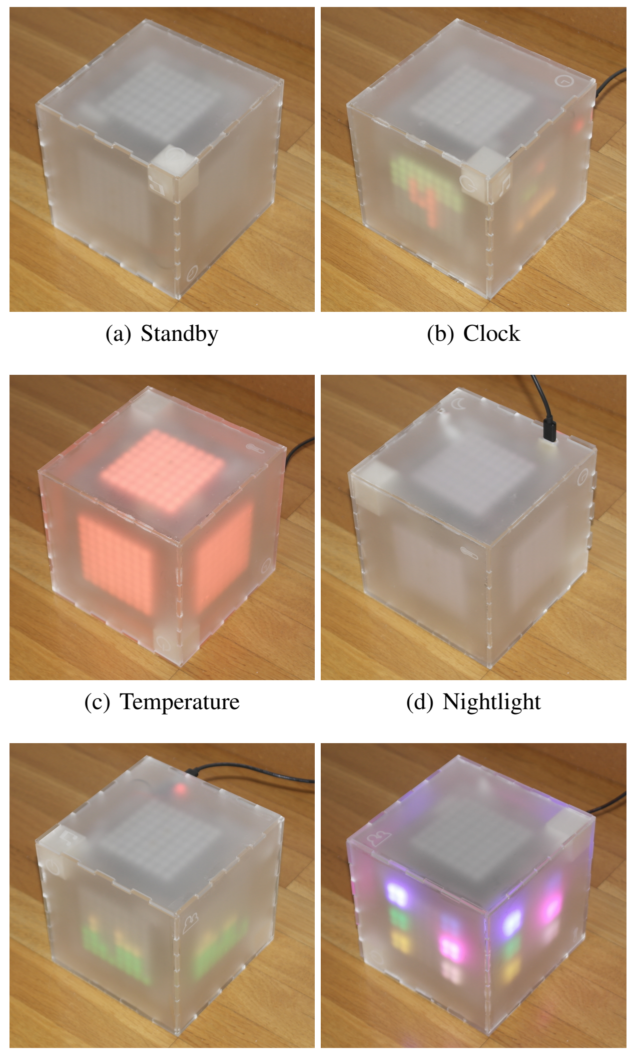
Author Keywords

Documentation; Design; Experimentation; HCI; Interaction Design; Human Computer Interaction; Tangible Interface; Ambient Lighting; Ambient Light Display; Rapid Prototyping; Arduino

INTRODUCTION

The development of light-emitting diodes (LEDs) and their improvement has changed the role of lighting systems in today's everyday life. Due to the variety of advantages LED lights offer, lighting systems don't act exclusively as illumination sources anymore. Several corresponding products emerged in the past. One important area where lighting can be applied is the field of human computer interaction. There exist several different methods to represent adequate output information to an user. Through the use of LEDs, lighting systems can be one of them.

When working with light as a source of information, a couple of different approaches for displaying the given information have to be distinguished. It is possible to alter either the light intensity or the color to illuminate special locations, which are linked to information (e.g. illuminating the button the user has to press next) or to generate a special light pattern to symbolize something (e.g. a state). Combining some of these approaches allows for even more possibilities to convert simple lighting into a meaningful output medium. In this approach the surface of a physical object – a standard cube – is used for displaying the desired information with the aid of different lighting patterns. The specific form of a cube allows to place different functions on each side of it. The implemented patterns are based on the previously mentioned methods and use either only one or a combination of them. Through the integration of informative lighting patterns on the physical object, it becomes an atmospheric



(a) Standby (b) Clock (c) Temperature (d) Nightlight (e) Disco (f) Presence

Figure 1. Interactive Cube

information source, which smoothly fits into the environment.

The following section will initially introduce some related work, which shows the different lighting possibilities, which were investigated in the past. In the three subsequent sections there will be a description of the concept, the development process and the finally built prototype. The concluding section depicts the future work related to the presented final prototype, including the remaining functionalities that arent finished yet and possible extensions that could improve the lighting experience even further.

RELATED WORK

In recent years the rise of enabling technologies for interactive lighting has led to increased interest in research on dynamic and adaptive light situations. The introduction of connected lighting that can be integrated with sensors and other devices is opening up new possibilities in creating responsive and intelligent environments. The role of lighting in such systems goes beyond simply functional illumination. With the advent of the LED, new types of lighting output are now possible. LED based light sources can be used as actuators for signaling events or to transmit data and information [2].

Aliakseyeu et al. recognized that it is not enough to replace the light switch with a smartphone based app that offers extended control over lighting (e.g. Philips hue [5]). They believe that in many situations the UI will need to be intelligent and sensitive to the context and responsive to the people. To create such a system you can enrich lighting systems with sensors, thus enabling intelligent and autonomous lighting control based on contextual or implicit user information [2]. The Arduino micro-controller platform [1] significantly simplified physical prototyping and became a tremendously popular tool for students and developers worldwide. There is also a number of existing products that support lighting based atmosphere creation and that are adapting to people (e.g. [3], [6], [7]).

Because light is an intangible and very transient medium, which is influenced by a wide variety of factors, new design concepts need to be applied and tried on an experimental basis in order to arrive at an aesthetically appealing result. To address this problem, Wiethoff et al. [8] created LightBox, a tool for exploring interaction with colored light and for testing concepts for responsive environments.

A problem of enhanced lighting systems is the increased complexity in terms of control and understanding. New and richer ways of interacting with light will be required, ones that clearly communicate the status of the system and enable control on multiple levels from commissioning to daily use [4]. This may require multiple interaction technologies to work alongside one another such as tangible, multi-touch, or gesture-based user interfaces combined with implicit sensor and rule based interaction [2]. Westerhoff et al. [7] presented the design and implementation of M-Beam – a tangible interface that can be used to set the atmosphere based on the desired mood. The physical appearance of the M-Beam expresses the atmosphere the user is trying to create, while also reflecting the current state of the system. Another way of interaction with light, was presented by Hausen et al. [3]. They developed the StaTube, a tangible object offering peripheral interaction for setting ones own state and peripheral awareness of selected others state.

CONCEPT

The main concept that emerged from the initial idea consists of a tangible, light emitting LED-cube which provides six different functionalities. Each functionality is linked to one specific side of the cube object. The following six modes were elaborated for the use in the prototype:

- Standby-Mode: In this mode the cube is set asleep and is just listening for incoming state changes until the cube is rotated again.
- Thermometer-Mode: In this mode the room temperature is measured and the cube emits an ambient light with a light color representing the measured temperature value.
- Nightlight-Mode: In this mode the cube is representing a common night light. The cube is emitting light, with its intensity adapting to the overall illumination of the room. As the room gets darker the luminosity of the cube rises appropriately.
- Clock-Mode: The four orthogonal, surrounding sides of the cube display a representation of the current time.
- Disco-Mode: The cube reacts to measured sound information in real-time by displaying a visualized representation of the sound input, e.g. a frequency spectrum.
- Presence-Mode: In this mode the cube is used to act as a presence indicator for people of a predefined group, which is specified by the user. As people switch their presence state (e.g. go online) by turning their respective cube to the presence mode, other people of the group, which have the presence mode activated, can see the updated state change as well as the overall situation within the group (see [3]).

To activate one of these modes the appropriate cube side has to face upwards. Thus, the mode can be changed by rotating the cube to the appropriate side. For example, once the side attributed to the ”Standby-Mode” is rotated to the top, all LED lights are turned off and the cube is going to sleep, waiting for another rotation input. A further part of the initial concept is the ability to customize the different modes of the cube. As the cube itself is a closed physical object and it has no other input mechanisms than rotation, it was opted for an external application, which interfaces with the cube and enables further input methods. This application should provide the ability of changing the adjustment of the mode settings. Examples for possible adjustments are the night light color, different clock representations and the possibility to define concrete group members for the presence mode. This overall concept should contribute to an appealing and informative lighting object.

PROCESS

The first phase of the development process consisted of selecting an appropriate hardware set which matches the developed conceptual design. The selected hardware set, which represents the fundament of the development process, is as follows:

- Arduino Uno/Mega
- Bluetooth module HC-05
- Photoresistor
- LM35 Temperature sensor
- LM393 Sound detector
- MPU-6050 Gyroscope
- 6x Adafruit Neopixel Matrix 8x8
- Power bank
- Mini USB Charging adapter
- Breadboard

In a second phase, the previously selected sensor modules as well as the LED matrices were tested to get familiar with their functionality and to figure out if they could meet the expectations (see figure 2). While most of the sensors were suitable for the intended use and almost worked out of the box, the sound sensor caused some problems. The sensor readings from the microphone were just too imprecise and delivered too little information to allow usage as planned at the beginning. Therefore, the sound sensor turned out to be unusable for the desired task. Besides the sensor testing, the testing of the LED matrices exposed an unexpected problem concerning their size. Since the matrices have eight LEDs at the height and the width, there is no middle LED row or column. This fact leads to several design problems when developing appropriate lighting patterns, since it was difficult to meet basic symmetry. The development of the clock mode was especially affected by this restriction and the overall size of the matrices. Therefore, it was necessary to develop novel possibilities to represent the actual time, which are adapted to the special situation. This was explored in detail in the concluding phase of the development process.

The concluding phase was the implementation phase, which is composed of the software development and the realisation of the physical cube object. The first step was to build a physical model of the cube and to explore how the cube could be constructed. Quickly, it turned out to be the best way to build two cubes: one inner cube and one outer cube (see figure 7). The inner cube contains all the required hardware modules in its center. Additionally, the LED matrices are installed on the surface of this inner cube. The outer cube surrounds the inner one, so that the light of the LED matrices illuminates it from inside. For a start, the inner cube was formed out of cardboard and all the components were installed on it in order to get a feeling for the correct measurements and the optimal positioning of the components, see figure 3. By the use of this first test with cardboard, the final dimensions could be established.

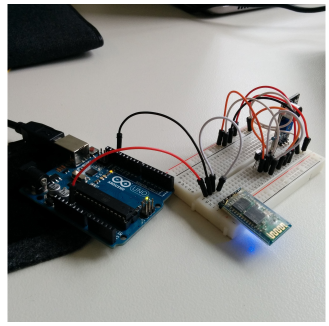


Figure 2. First sensor tests

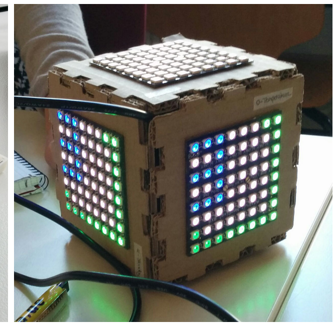


Figure 3. Cardboard prototype

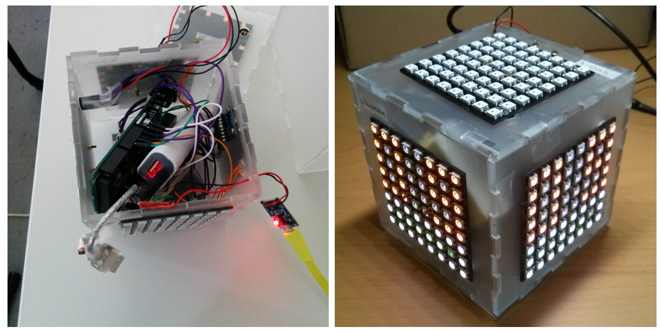


Figure 4. Inner cube.

Afterwards, the different parts of the inner and outer cube were cut out of acrylic glass. The cutting process was realised with the aid of a laser cutter. Little screws and nuts were used to lock the LED matrices in place on the six plexiglass plates of the inner cube. The breadboard as well as some other hardware components in the center of the cube were fixed with double-faced adhesive tape. Figure 4 shows the final inner cube containing all the hardware components. The only sensor that was not integrated in the inner cube was the photoresistor, since it is necessary that this sensor can react to the light from the outside of the cube. It was therefore positioned in a little hole in the outer cube so that the environmental light can impact on the photoresistor. In order to secure the inner cube in the center of the outer cube, there was a need for a kind of attachment. To resolve this problem, 3D pieces were printed in order to fill in the space between both cubes and to hold the inner cube in position. The last step of the construction process was to link each cube side with the appropriate function it represents, so that the user can recognise it. This was realised by small icons, which were engraved into the surface of the plexiglass plate with a laser cutter (see figure 6). This physical setup formed the basis for the subsequent software implementation.

At the beginning, the used controller was an Arduino Uno, since the space for hardware was limited due to the size of the inner cube. However, it quickly turned out that the

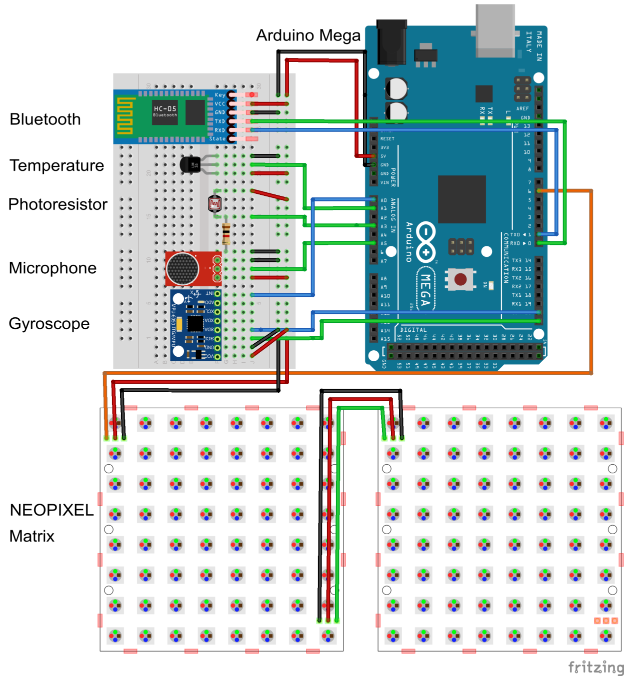


Figure 5. Sketch of the wiring diagram

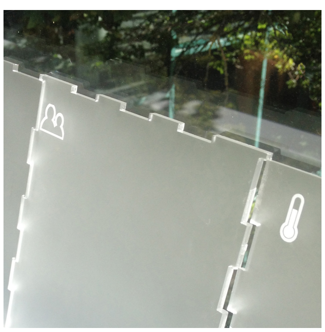


Figure 6. outer cube icons

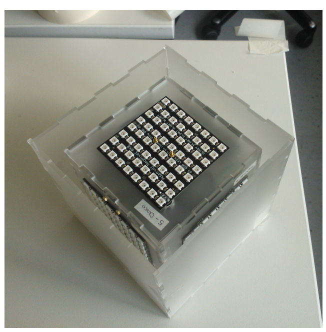


Figure 7. Inner cube in outer cube

memory capacity of the Arduino Uno was not sufficient. Since storing color patterns to trigger 384 LEDs needed a lot of memory space, it was necessary to replace the initial board by an Arduino Mega which offers a clearly higher memory capacity. The implemented code which was loaded onto this board was written in the programming language C++ in the environment Arduino. Since the microphone sensor was not able to deliver the desired information, it was necessary to find a solution on the software side. Therefore, the data was simulated by random values and used as input information.

In addition to the overall functionality of the cube, it was also necessary to implement the already mentioned application which serves as additional input source. This application was implemented for an Android device. At the end of the implementation phase, the cube should eventually run without cable supply. In order to realise a cable-free prototype, a rechargeable battery should serve as energy source. Unfortunately, the selected battery was not able to provide enough energy for a long-time experience. The life span of the prototype was therefore reduced to just a few minutes. Since this is obviously not enough time for an appealing usage of the cube, the rechargeable battery was removed and replaced by a permanent installed cable instead. In this way, the developed prototype of the cube can be used in the intended manner without interruption and can create a long-time atmospheric lighting situation.

PROTOTYPE

The final prototype is shown in figure 1. It includes all the hardware components previously mentioned in the Concept part. Overall, the capability of the cube could be realised as expected in advance. Merely, the realisation of the Disco-Mode does not exactly correspond to the initial objective. As already mentioned before, since the integrated microphone sensor does not deliver sufficiently accurate sound values, it was not possible to apply further sound processing such as the Fast Fourier Transformation. In order to realise this mode anyway, the sound values were simulated randomly instead. Some basic light animations in the form of moving bars could then be realised on the basis of these random values, as can be seen in figure 1(e). Since there were no further problems with the other sensor data, all other modes could be realised as expected.

The Standby-Mode therefore deactivates all previously lighted LEDs when it is activated. It is then listening for further user input, so that a mode change can be recognized and the behaviour can be adapted accordingly.

For the Thermometer-Mode, the measured temperature is mapped to a specific color, following an already established standard that is used on weather maps (see figure 8). If the surrounding temperature is 14C or less, the cube is lighted in the color blue. If the temperature goes up, the color changes over turquoise, green, yellow and orange until it reaches 30C or more when it becomes red. Figure 1(c) shows a lighting example for the temperature mode.

The Nightlight-Mode also works as intended. The cube becomes brighter when the overall luminosity of its surrounding environment decreases, see figure 1(d). The developed android application also allows for customizing the color baseline of the night light, see figure 10(b).

As for the Clock mode, several different time representations, displayable on the 8x8 matrices, have been realized (See figure 1(b)). The first representation (a) is composed of two ciphers in the upper region and a loading bar metaphor below, used to depict the elapsed minutes. The second representation (b) similarly has a cipher in the upper left region and a loading bar on the right and lower border, again displaying the elapsed minutes. The third design shows the cipher in the middle and has a green background, that fills up, adding a brighter green dot for each passing minute until a full hour is reached. The last design (d) is a standard binary representation of the time, featuring hours (top), minutes (middle) as well as seconds (bottom). These designs differ

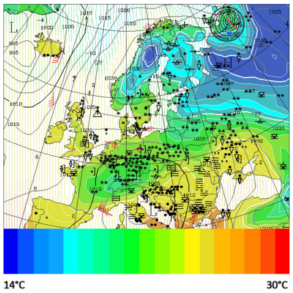


Figure 8. The color scale used for the temperature mode

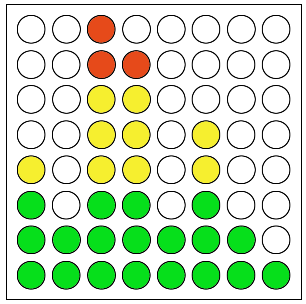
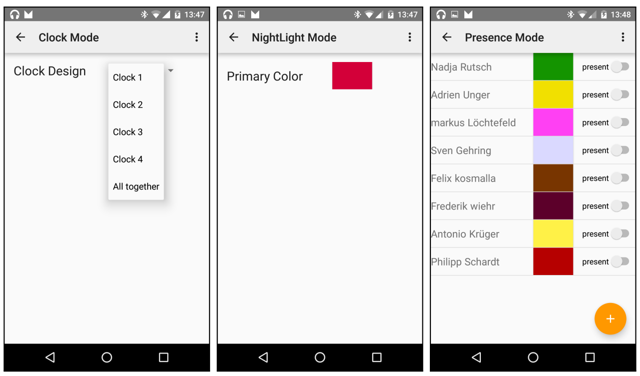


Figure 9. The displayed pattern of the disco mode



(a) (b) (c)

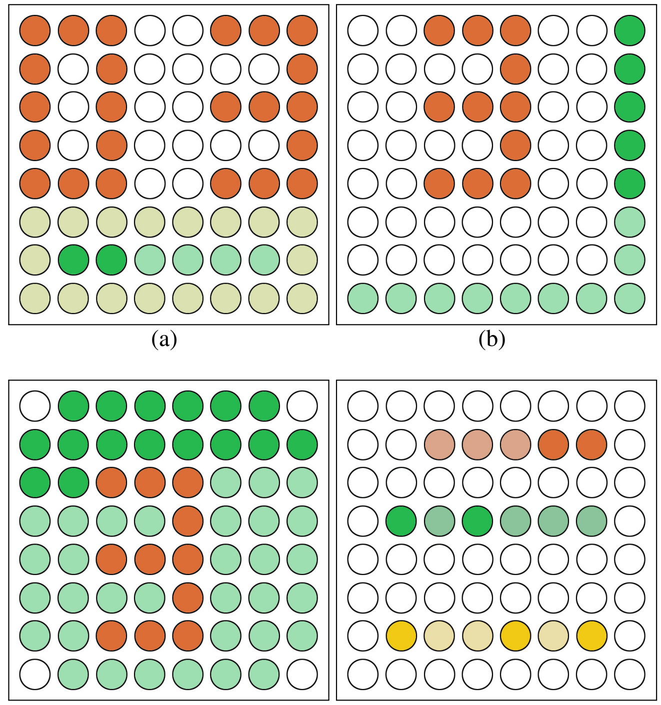
Figure 10. Android app settings for different modes

not only in their visual appearance, but also in the accuracy of the displayed time. As users might prefer different designs, it is possible to switch through designs via the android app, even with the possibility of displaying a different clock design on each of the four orthogonal sides (see figure 10(a)).

The Presence-Mode has been implemented as far as possible with the available means. The cube can display the presence of individual members of a predefined group, as depicted in figure 1(f). The layout of the squares, each representing the presence of a group member, changes in respect to the overall group size, similar to the dot pattern of dice. If a group member changes his state to present, the layout changes and an accordingly colored square blinks several times before it lights permanently. This makes sure that the user notices the incoming change. The group of people can be managed again via the android app. Group members can be added by determining a name and an associated color or they can be removed from the group (see figure 10(c)). For the prototype the presence change of other users was only simulated via the app. However, in a product scenario, the communication between devices could easily be managed over a standard web server.

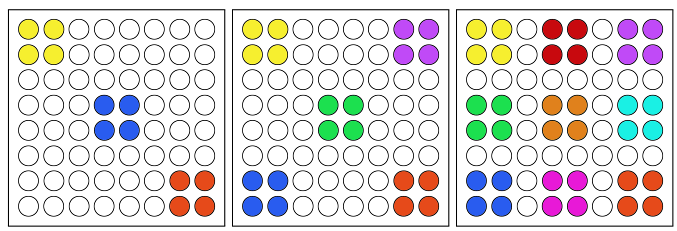
A video showing the cube in action and demonstrating all integrated functionalities can be found here [1].

[1] https://youtu.be/JcHGeRg2r_g



(a) (b) (c) (d)

Figure 11. Different time representations for the clock mode



(a) (b) (c)

Figure 12. Display patterns of the presence mode

FUTURE WORK

The future work concerning the presented prototype is composed of problem solutions, additional features and improvements, which together can form the current prototype to a finished lighting product.

One crucial problem encountered during the development process is the inaccuracy of the integrated microphone module. Since the values it delivers arent precise enough to control the light patterns used in the disco mode and the prototype is therefore based on randomly shown light patterns, it would be preferable to exchange the currently used sensor with a better one. In this way, the experience of the disco mode could be essentially increased, since lighting and sound patterns would act in a more harmonical manner.

An additional problem encountered during the development process were the constraints coming up due to the power consumption of the prototype. The experience of the current prototype is still restricted by a very short running time, since the integrated power bank is not capable to supply the prototype with enough energy over a sufficiently long time period. To realize a future version of the Interactive Cube it would be beneficial to find and integrate a more adequate powering solution. This could be realized either by replacing the tested battery through a more powerful one or, even better, by integrating a cable-free variant of charging. If the cube would be powered by inductive charging, the remaining cables and connections integrated in its surface could be removed. This would result in an even more polished design and a simple, beautiful surface, whichever function of the cube is activated.

Additionally, the overall appearance of the cube could be improved by reducing the size of the current outer cube and switching to slightly bigger LED matrices, so that the light of the integrated matrices would illuminate the whole surface of the cube. Maybe it would then be necessary to use another kind of plexiglass, which is less light-transmissive than the current one so that the lighting effect of the cube stays the same as before. On that occasion, it would be advisable to consider that the new LED matrices have an uneven size in order to eliminate the symmetry problem concerning the lighting patterns. By reducing the size of the outer cube, the currently integrated corner holders could also be removed and the cube could become much more appealing.

Besides these improvements at the hardware side, there are some software extensions that could complement the lighting product and enhance the user experience. First, a necessary step would be to completely finish the configuration and management processes concerning the presence mode, since this mode is still a proof of concept. A finished implementation of the presence mode should include a database which allows to define concrete groups of people and to administrate their login information to realise a registration process to a certain group. In this manner, the cubes of the group members could finally be connected and show the appropriate information.

At last, it would be possible to add more features to the current mode functionalities. For example, the clock mode could be extended by some additional clock designs, which could be selected via the implemented Android Application. This mode would also be improved, if the user were given the possibility to set an alarm clock in the Application. The alarm could then be realised by blinking and/or sound effects which would require to add a speaker to the internal hardware of the cube. Furthermore, the temperature and the disco mode could be extended by different lighting patterns reacting to the environmental information.

The given examples are only a few of the imaginable extensions which would be possible in the future. All this future work would transform the actual prototype into a fully well-engineered product which combines the functionality of being a source of information and an atmospheric light object.

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