The editor's version on the paper is available on the IEEE Explorer digital library
https://doi.org/10.1109/UIC-ATC.2017.8397404

Designing the engaging Energy-Box

Bridging the gap between energy control systems and users' energy awareness

Emmanuel Dubois
University of Toulouse – IRIT / Elipse
Toulouse, France
Emmanuel.Dubois@irit.fr

Fabio Pittarello
Università Ca' Foscari Venezia
Mestre Venezia, Italia
pitt@unive.it

***Abstract*—This work describes a design experience focused on the theme of eco-feedback, a technology complementary to traditional energy control systems and meant to obtain additional savings by increasing the awareness of the users about the factors that determine energy consumption. This experience, held during a multidisciplinary ideation workshop and involving students and researchers at the University of Toulouse, was focused on the conceptual design of an *Energy-Box*, conceived as an artefact (or a set of artefacts) for making people inhabiting the University campus aware of energy issues and leading them to more energy conscious lifestyles. Three different proposals stemmed from this experience, that were evaluated first by the participants to the workshop themselves and then, some months later, by 80 undergraduate students of the University of Venice working on the same themes. We extracted interesting lesson learned from this evaluation, that should be taken into account for the development of user's centred eco-feedback systems in public contexts.**

Keywords — control system; eco-feedback; prototyping; sketching

I. Introduction

Control systems are widely used to help technicians operate equipment involved in energy regulations. Such systems can be used remotely to control actuated devices such as shutters or windows, to sense data such as light and temperature, and to manage energy appliances involved in the energy consumption such as by modifying the heating temperature or switching on and off the light. Nowadays, robust solutions have been proposed and integrated in realistic software platforms to address the main challenges of control systems, i.e. in terms of communication with several appliances and data saving and retrieving [1]. However their appearance is mainly limited to the display of rough values through traditional graphical user interfaces, involving scrollable lists of data, more or less adaptable sets of curves showing history of consumption, and a multitude of menus and buttons to access the appropriate level of information required. Some attempts offer more readable representation based on graphical widgets, such as meters, bars, etc., but they still offer a very professional view on the data.

And yet, there is a need to overcome the simple monitoring and control of an energy system by technicians and experts, in order to effectively trigger a change of behaviour of end-users and real energy savings. The literature has already established that such so called eco-feedback systems may lead to consistent energy consumption decrease [2]. One of the recent programs of the European Union estimated the impact of systemic energy consumption and production and emissions reduction between 15% and 30% [3]. However, using technicians dedicated systems is obviously not well suited to eco-feedback. They are too unattractive to really foster the interest of end-users into these data and hence into any behaviour modification. Being centralised systems, their use would greatly affect the usual user's activity, requiring for example that the user explicitly comes to a predefine space to access energy related information. Furthermore, control systems are oriented toward a monitoring activity that is not engaging enough for unprofessional users: data should be associated to a more direct goal for the users and information should not be subject to interpretation but should instead be self-explanatory.

There is therefore a gap between the available and robust industrial products related to the field of energy monitoring and the requirements for a more user-oriented energy monitoring system. Recent research advances have started to investigate this eco-feedback concept. Some have explored different visualization and devices to provide access to such data [4]. Other lead to the extraction of a systematic set of requirements for eco-feedback systems in a home and family context [5].

To contribute to bridging this gap between industrial products and research advances related to energy monitoring and savings we involved multidisciplinary groups in the design of an Energy-Box for a university campus context. The Energy-Box is an artefact that provides eco-feedback in an innovative manner, likely to affect positively how much users of a university campus feel concerned about energy consumption.

We first propose a set of requirements that extend those identified in the context of home energy monitoring [5], derived from the analysis of relevant bibliographic sources. We then set up an experiment in which three multidisciplinary groups of participants are engaged in the design, sketching and prototyping of an Energy-Box. Based on this participatory design session, we then analyse the results of this experiment in order to validate the set of requirements extracted. We finally draw some lessons learned for designing eco-feedback systems in large scale contexts, similar to a University Campus.

II. State of the Art

While substantial benefits from the environment can come from the optimization of the infrastructures for the production and the delivery of energy, complementary advantages can come from the awareness of the environmental impact of the personal daily habits. Eco-feedback [4] [6] technology is based on this assumption and aims to provide feedback to people about the consequences for the environment of their lifestyle, for reducing energy consumption.

Eco-feedback systems have been designed for public and private scenarios and for different classes of users. Their success is determined by different factors, among which the data presentation format can play a relevant role for attracting people and making them aware of the situation. While pragmatic visualization is often useful for giving accurate information, a complementary role for engaging and persuading people should be played by artistic visualization. As stated by Pierce et al. [7], both of them are necessary for satisfying communication needs.

An engaging public installation was offered by the laser cloud in Helsinki [8], which represented energy consumption through light beams visualized in the city's sky. A more recent prototype based on a tangible interface visualizes the different sources of energy through coloured vortexes, with the goal of letting the citizens to understand their balance for the different weather and use conditions [9]. Design proposals conceived for domestic scenarios range from abstract representations based on colour patterns, as the *PowerSocket* [10], to metaphorical representations, such as the *7000 oaks and counting project* [8] that displays energy loads through a set of animated tree icons. Another proposal by Nisi et al. [11] takes advantage of artistic outdoor panoramas, trees, clouds and flowers for mapping data related to home energy consumption. Additional information, related to the personal behaviour, can be given by a number of web apps. An example is the one developed by the University of Venice [12], that calculates the personal carbon footprint following the monitoring of the user's activity or the answers to a survey related to the personal life style. Data sharing for triggering collaboration and positive competition mechanisms have been experimented both in domestic context, such as in the chalk-boards positioned on the house facades for displaying family data consumption to neighbours [13], and in public contexts, such as the public large screens that characterized the EU FP 7 IDEAS Project [14]. In both cases privacy is a fundamental issue that should be carefully considered in such projects. Finally, gaming is another useful competitive mechanism for augmenting the energy awareness as well [15].

III. Requirements for an eco-feedback system at a University Campus scale

Based on the existing set of requirements for eco-feedback systems in a home and family context [4], we built a new set dedicated to university campus activities. This set of requirement is structured into seven categories that we introduce hereafter. Some of the requirements are compulsory, while others can be followed at the designers' discretion.

A. Data to be presented

We explicitly asked participants to integrate into their design seven different types of information.

1. The interface is required to present data related to the overall electric energy consumption; presentation of consumption data related to single appliances is considered as a further option.
2. The interface is required to present data related to the energy produced by any kind of device or object.
3. The interface can present data related to water and gas consumption.
4. The interface can present data related to animal population living in the surroundings (e.g. rabbits, insects).
5. The interface can present data related to people distribution in the Campus.
6. The interface is required to present both instantaneous and historical data; presentation of comparisons between consumption and production are suggested.
7. The interface can present data for attracting users, for example information related to room occupation/teacher absence/noise/weather forecast.

B. Visualization style

The second requirement is related to the way the information will be rendered by the Energy-Box: the numerical presentation style is considered as compulsory, but other styles, such as graphical, metaphorical and analogical, can be used. We asked that each prototype use at least two presentation styles.

C. User profile

This requirement is mandatory, as users with different expertise and expectations are intended to use the Energy-Box. Therefore, the interface must be adaptable to different profiles.

D. Deployment context

Depending upon user, time and goal, the Energy-Box may be used in different ubiquitous contexts. The proposed interface must therefore offer personal and sharable versions.

E. Input and output modalities

To manipulate, control or interact with the Energy-Box in ubiquitous contexts, obviously no keyboard or mouse will be available. Alternative modalities must be designed. We encouraged participants to consider multimodal interfaces, involving physical surfaces, physical objects and using two or more communication channels (e.g., visual, aural, tactile).

F. Social features

This set of requirements is related to the specific features supported by the Energy-Box that may contribute to a better engagement of the users.

1. The interface should stimulate collaboration for optimizing the resources and improving the Campus environment, using the skills that are proper to the different communities;
2. The interface could stimulate competition and engagement through communities.

G. Decor integration

This last requirement is intended to ensure that the interface will be perceived as part of the environment rather than being an ICT device, such as a standard flat screen, added in the campus.

IV. User experiment setting

The goal of the experiment is twofold: generate design ideas for presenting energy related data in an engaging way, but also identify how a pluri-disciplinary design team might perform such a complex design process. For this reason, the user experiment study included several starting materials of different nature to work with.

First, given the long list of requirements to consider for designing a device relevant to such context, we provided the participants with three different supports summarising this list:

- A textual list and explanation of each requirement;
- A representative schema of these requirements expressed through a pictorial scenario (see Fig. 1 - top);
- A structured,but abstract representation of the requirements, similar to a Kiviat diagram (see Fig. 1 – bottom).

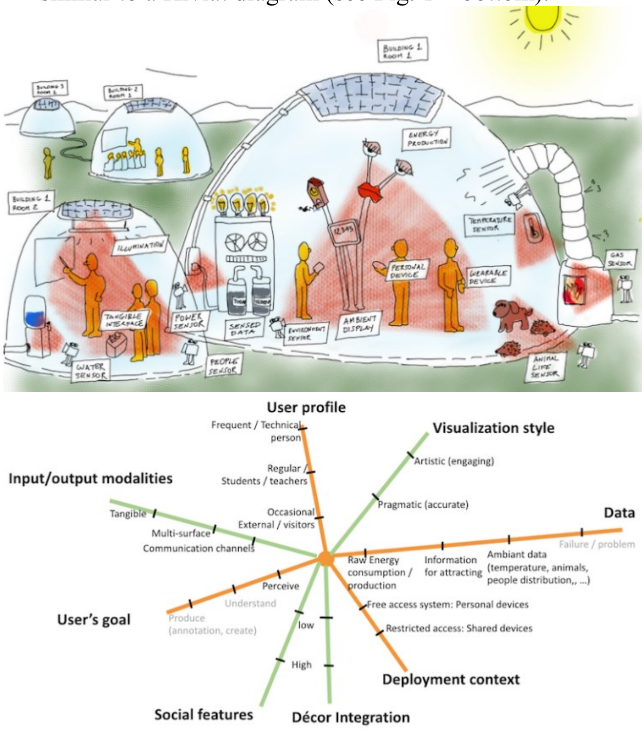

Fig. 1. Pictorial (top) and structured but abstract (bottom) representations of the requirements introduced in section III.

Second, the experimenter provided the participants with an overview of existing eco-feedback systems coming from: 1) the analysis of existing research work published in the literature, 2) the technological scouting focus on industrial tools and software already commercialized and, 3) a selection of the project works developed by the students of the University of Venice in 2015. References to all these materials can be found in [4]. These three sources of existing solutions provided the participants with a large view on what an eco-feedback system is today (industrial tool), could become in a near future (research work) and would be suitable (previous session).

Based on these resources, three groups of participants started working for 1h30. An intermediate discussion was then lead between the experimenter and each group individually to select the most promising design options raised in this first step.

In the following session each group had then to produce a prototype, a poster and a video demonstrating the use of the prototype. Finally, each group gave a short presentation of their prototype in front of the members of the other groups.

After the final presentation of each group, every member of the other groups had to evaluate the prototype through a predefined questionnaire. This questionnaire asked for a rating on a Likert scale (1 = low to 5 = high) of four characteristics of the prototypes (innovative, nice, smart, sustainable), the three best features and the three worst features offered by the prototypes.

At the end of the oral presentations, every participant had to fill in a questionnaire related to the overall design experience. This questionnaire focused on the usefulness of the different design artefacts, the interest for the different information to be displayed by the Energy-Box, the overall interest of the participants towards energy management and reduction.

V. ORIGINAL DESIGNS FOR A USER ORIENTED ENERGY-BOX

27 participants (PhD students and University colleagues) from different domains took part in this experiment: human computer interaction (8), multi-agent systems (8), civil engineering (3), energy management and network (3), middleware (1), design (1) and human factors (1). There were also 1 member of a company developing software for smart cities and 1 energy manager from the university administration. We formed 3 groups of participants, so that the different domains were the best possibly spread over the three groups.

Each group proposed an original design solution for an Energy-Box that we present hereafter.

A. Flower and Water

This Energy-Box is based on two elements shared by the campus' stakeholders: the use of the flower metaphor and a fountain. Each flower represents the energy consumption of one entity of the campus (a building or a room). The flower is fully standing as long as the consumption is not too high, and fades when the consumption level is too high. Each petal corresponds to one energy flow (water, gas, electricity, etc.). A set of flowers is presented in front of the main university building, thus providing an overview of each building of the campus. Individual flowers are also present in each room, thus reflecting a local view on the energy consumption.

Fig. 2. Flower and water prototype

The fountain is made of several water streams, each one representing one type of information for one building. Stones laying around the fountain can be used to adjust the mapping between one stream and one building. Finally, the group proposed, as a complementary interface, a bracelet for displaying personal data to each user and sharing information.

B. Tree Totem

The tree totem adopts the metaphor of a tree. The branches of a big artificial tree positioned in a public space of the campus end with a display on which real time energy information is displayed. The energy flow changes from one branch to another.

On each branch is drawn a graphical representation of the information type corresponding to this branch (water, CO2, etc.). The color of the display bezel is adjusted to reflect the state of the current consumption of the campus with regards to a predefined goal: as such it provides a global overview of the campus energetics performance. Additional interaction on the tree trunk allows the user to adjust the level of granularity of the information displayed: the tree representation can thus corresponds to the whole campus down to just one building or even just a room. Smaller replica exist for insertion in individual rooms. In such context, displayed information is more detailed, including information related to the different devices, sensors and effectors present in the room.

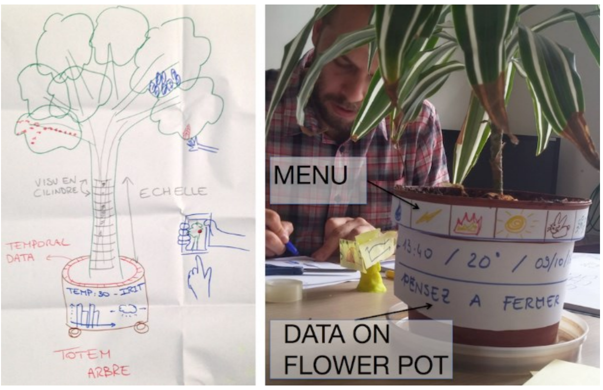

Fig. 3. Tree Totem prototype

C. The Hedgehog

The third designed Energy-Box relies on an identified mascot: a hedgehog. A huge static hedgehog is positioned at the entrance of the campus to provide an overview of the campus energetic behaviour. Speech based interaction upon user's detection is engaged by the mascot to provide detailed information about specific energy flows. From further away, a pedestrian can perceive different faces (sad or happy) and a coloured belly: these feedbacks provide a quick overview of the current state of the campus.

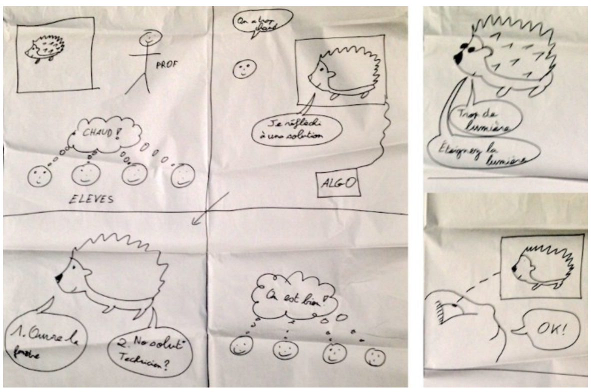

Fig. 4. Scenario featuring the Hedgehog prototype

This mascot is associated to mobile mascots, moving on the campus in order to always be close to groups of persons or on the paths were people should most probably be going through in a short time, according to previous observations. These mobile mascots can collect information from the users (e.g. lack of light in one room, windows remaining opened …), engage users into challenges, or simply display information related to the closest building. This design also includes the use of a personal interface, implemented as an app, for accessing the information in more detail.

VI. Analysis of the Design Session

A. Evaluating the design proposals

Members of each group had then to evaluate the prototype of another group along the characteristics expressed by four adjectives: innovative, nice, smart and sustainable. These are four important characteristics for an engaging Energy-Box. The innovative aspect contributes to foster user's interest and curiosity. Being nice, users will be willing to use the Energy-Box. The smart dimension ensures that information from all around the campus is provided. Finally, when it comes to energy monitoring, if the device itself is a high consumer of energy, this will ruin its interest in this context.

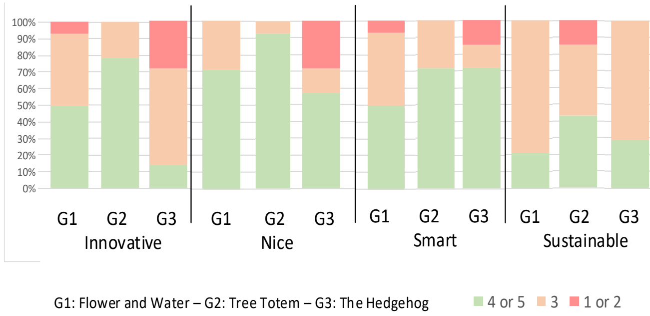

Fig. 5. Evaluation of the three prototypes on a Likert scale (1=low to 5=High) regarding 4 characteristics of the prototypes: innovative, nice, smart, sustainable.

According to this first evaluation (see Fig. 5), the tree totem was the best solution for each characteristic except its sustainability. This is due to the presence of multiple displays, on each branch of the totem, which may induce a high consumption of energy. However, the presence of these displays, also confers to the prototype a very innovative touch: the tree leaves support information display and input interaction. Being integrated in a tree with well embedded information and colour, contribute to render this prototype nice. Finally its ability to represent distant energy consumption data turns this prototype into something smart. As such, it appears that embedding interactive visualisation techniques into a natural object is an appropriate way to create an engaging Energy-Box.

With regard to the seven categories of requirements transmitted to the participants, the three prototypes successfully covered from 72% to 86% of them.

The first and third prototypes did not provide any access to data related to energy production and about the presence of animal and species. The tree totem, on the other hand did not particularly provide features to data related to people, such as collaboration support or people distribution in the campus.

B. Analysing the design method and tools

Based on the questionnaire related to the overall design experience, we identified a set of interesting lessons learned, useful to convey such a complex, participative and multi-disciplinary design session.

First it appears that the list of requirements expressed in a textual form or summarized in a representative schema form were considered useful or very useful by more than 75% of the participants. The structured and more abstract representation, based on Kiviat diagram, was considered useful by only 35% of the participants. Therefore we believe that precise requirements (text) and artistic overview representation of them are more appropriate to help designers keep in mind all the requirements to consider.

Second, regarding the modalities considered for presenting the information to the future users of the prototypes, the three groups mainly preferred the visual medium: 100% of the participants considered the visual communication channel important or very important in the context of the Energy-Box, while only 38% to 47% of the participants considered a vibrotactile or audio communication channel as important.

Third, 80% of the participants considered important or very important to integrate competition mechanisms in an Energy-Box in order to better engage the people living on the campus in the use of the Energy-Box. 60% of the participants also find important or very important to integrate data related to people distribution on the campus. These are two important lesson learned as it identifies important features to integrate in such prototypes for energy monitoring on a campus.

Fourth and very interestingly, 21% only of the participants considered important or very important to show animal life related data through the Energy-Box. And yet the three proposed prototypes were entirely based on objects taken in the wildlife: flower, tree, hedgehog. This antagonism will need further analysis to be fully and correctly interpreted. But as opposed to what they express, participants seemed to consider important the place of the wild life in an Energy-Box as it was really grounding their prototypes.

VII. Discussion

During the 2016-17 academic year the results of the workshop held in Toulouse were shared with the undergraduate students of the Human Computer Interaction course, held at the University of Venice for the Computer Science curriculum.

The 80 students of the course, organized in 20 teams, were engaged in the design of eco-feedback projects for the Scientific Campus of the University that shared the same goals defined for the Toulouse workshop.

The goal of sharing the results of the Toulouse workshop with the students was twofold. On one side, we wanted to give the students some conceptual examples of projects, which had been designed on the basis of a very similar scenario and a set of requirements derived from the same bibliographic references that were given to the Venice students, in order to inspire them. On the other side, we wanted to get a feedback about the Toulouse workshop from an external point of view, for understanding which were the most and least appreciated design results. Moreover, we asked to the students also to focus on the list of the requirements that were given to the attendees of the Toulouse workshop, check the compliance of the three projects with them and to propose also changes to the list of requirements (i.e. relaxation and enforcements of the available requirements or introduction of new ones).

Each group of students gave separate comments for the three projects, which we synthesized in the rest of the section. Concerning the appreciation of the Energy-Boxes proposed by the three Toulouse projects, we distinguish the comments related to the public part of the prototype from the comments related to the personal part of the interface.

Regarding the public part of the designed Energy-Box, the students were more prone to appreciate novel solutions departing from the ordinary ICT data visualization (e.g. numerical visualizations on big screens), for engaging people while providing information.

For this reason, the students appreciated the flowers with coloured petals, that were perceived as a friendly and attractive interface for conveying qualitative information.

Students appreciated also the introduction of mascots such as the hedgehog, appreciated by most students for voice interaction and for its capability to present information to people through changes to its appearance.

The students appreciated also the big tree totem, an attractive artefact capable of conveying both qualitative information, that could be seen at a distance, and quantitative information, that could be seen when the users went near to the artefact. However for the totem tree there were some concerns about the cost and the energy consumption of this artefact. These concerns were even greater for another unconventional interface, the fountain proposed by the first group, that was criticized by a number of students because of the required amount of energy for making it work.

Resuming, the students had a marked preference for public interfaces that coupled an attractive shape, a clear presentation of information and low energy requirements for making them work.

In the case of the personal interfaces, students appreciated a lot the bracelet solution of the first project, compliant with the diffusion of smart-bands that has characterized the last years. Students appreciated also the standard smartphone interfaces proposed by the third project.

However, they had some doubts about the use of some paradigms that are becoming mainstream, such as augmented reality for mobile devices proposed in the second project, when they judged that they were not useful or that they required an unnecessary effort.

Finally, we noticed that when the personal interface did not require the users to wear it or to bring it with them, as in the case of the small tree placed on the desks as a part of the decor, the students were again more prone to appreciate unconventional solutions.

Digital social connections are an important part of the students' experience. For this reason, they did not forget to underline the lack of social features and collaboration in proposals that were otherwise judged as interesting (i.e. the tree totem). Students appreciated a lot the competition mechanisms introduced by the third project and the fact that the personal achievements could have practical consequences for the realization of projects for the community, made possible by energy savings. The students required also to extend such mechanisms also to other projects, avoiding competition without specific goals.

Students demonstrated also to be aware of the different categories of humans inhabiting the Campus, and therefore, although they appreciated the interface adaptivity introduced in the second project, they required extending further the categories of users that could interact with the eco-feedback receiving information appropriate to their profile, such as people involved in cooking and cleaning activities.

Finally, one requirements that was not well understood by the students was the relation with the animal life emphasized in the list of the requirements, maybe because none of the projects included useful examples or maybe because of the technical background and interests of the students, more focused on technology rather than on a holistic view.

VIII. CONCLUSION

In this paper, we reported about an ideation session that aimed to design original interfaces, related to the energy monitoring on a university campus and intended to be engaging for the people present on the campus: student, teachers, technicians, staff, etc. We introduced the design process with an original set of requirements to consider in such context. We proposed different ways to communicate these requirements to the participants of the ideation session. Three groups proposed three different Energy-Boxes. Despite the large set of requirements to consider and the pluri-disciplinarity of the groups, mutual evaluation of the proposed designs revealed that about 80% of the requirements were taken into account.

This study also seems to reveal that when the data is only accessible in one single place (in front of the main building, the tree totem itself) it is not well accepted, because it requires to go to this place to catch the information. Conversely, having multiple devices displaying data everywhere is also badly accepted because it induces too many devices and it may have a bad influence on the energy consumption. This experiment thus clearly highlights the need for a compromise between having access to the information everywhere and being annoyed by the insertion of too many devices.

Furthermore, the different evaluations performed raised the importance of the coherency of the global Energy-Box. If the system is present in different places (e.g. rooms and campus entrance), under different forms (e.g. trees and plants), then it should always stick to the same metaphor, adopt similar behaviour and offer the same interactive features to increase its acceptance and make it a unique Energy-Box.

Finally, we identified two limits that are structuring on-going and future works. First in terms of design methodology, it is necessary to show examples to the participants because Energy-Box today are not a well known concept. To generate ideas, participants need some starting points, otherwise they will only find their inspiration in the existing professional energy monitoring systems. Nevertheless, such example may influence the design session. We therefore need to evaluate how much the users were influenced by the provided example and how to avoid this potential bias. Second, regarding the designed prototypes, the design session stopped at a very early design step. Further iteration and refinement are required to really appreciate the benefits and limits of the proposed prototypes. Such iteration and beginning of implementation might affect positively or negatively the initial design. Therefore, we plan to further investigate the design of these prototypes and tend toward their implementation to insert them as interactive probes [16] into the campus.

ACKNOWLEDGMENT

Authors would like to thank the néOCampus project committee and members for taking part in this experiment. This work was partly funded by the Erasmus+ program and the ANR project AP2 (ANR-15-CE23-0001).

REFERENCES

[1] D. Lee, C. Cheng, "Energy savings by energy management systems: A review," Renewable and Sustainable Energy Reviews, vol. 56, April 2016, pp. 760-777

[2] B. Neenan, J. Robinson, and R. Boisvert, "Residential electricity use feedback: A research synthesis and economic framework," Electric Power Research Institute, Tech. Rep. 1019319, May 2009.

[3] EE 11 2014/2015 - New ICT-based solutions for energy efficiency, http://cordis.europa.eu/programme/rcn/664688 it.html.

[4] J. Froehlich, L. Findlater, and J. Landay, "The design of eco-feedback technology," in Proc. of CHI '10. New York, NY, USA: ACM, 2010, pp. 1999–2008.

[5] F. Pittarello and T. Pellegrini, " HCI and education: a blended design experience,"Multimedia Tools and Applications Journal, vol. 76, no. 4, pp. 4895–4923, 2017

[6] S. Darby, "Making it obvious: Designing feedback into energy consumption," in Energy Efficiency in Household Appliances and Lighting, Springer Berlin Heidelberg, 2001, pp. 685–696.

[7] J. Pierce, W. Odom, and E. Blevis, "Energy aware dwelling: a critical survey of interaction design for eco-visualizations," in Proc. of OZCHI '08. New York, NY, USA: ACM, 2008, pp. 1–8.

[8] T. G. Holmes, "Eco-visualization: Combining art and technology to reduce energy consumption," in Proc. of C&C '07. New York, NY, USA: ACM, 2007, pp. 153–162.

[9] F. Quintal, C. Jorge, V. Nisi, and N. Nunes, "Watt-I-See: A Tangible Visualization of Energy," in Proceedings of AVI '16. New York, NY, USA: ACM, 2016, pp. 120-127.

[10] F. Heller and J. Borchers, "Physical prototyping of an on-outlet power-consumption display," interactions, vol. 19, no. 1, pp. 14–17, Jan. 2012

[11] V. Nisi, D. Nicoletti, R. Nisi, and N. J. Nunes, "Beyond eco-feedback: using art and emotional attachment to express energy consumption," in Proc. of C&C '11. New York, NY, USA: ACM, 2011, pp. 381–382.

[12] Sustainable Ca' Foscari, Carbon Footprint Calculator, http://www.unive.it/nqcontent.cfm?a_id=135062

[13] A. V. Moere, M. Tomitsch, M. Hoinkis, E. Trefz, S. Johansen, and A. Jones, "Comparative feedback in the street: Exposing residential energy consumption on house facades," in Proc. of INTERACT'11. Berlin, Heidelberg: Springer-Verlag, 2011, pp. 470–488.

[14] M. Short, M. Dawood, T. Crosbie, and N. Dawood, "Visualization tools for energy awareness and management in energy positive neighborhoods," in Proc. of 14th International Conference on Construction Applications of Virtual Reality, 2014.

[15] A. Spagnolli, N. Corradi, L. Gamberini, E. Hoggan, G. Jacucci, C. Katzeff, L. Broms, and L. Jonsson, "Eco-feedback on the go: Motivating energy awareness," Computer, vol. 44, no. 5, pp. 38–45, May 2011.

[16] W. W. Gaver, A. Boucher, S. Pennington, and B Walker, "Cultural probes and the value of uncertainty," Interactions vol. 11, issue 5, pp. 53–56, September 2004