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Thematic Annual Workshop

How eco-design of products and services can embrace the use phase?

Opportunities and Challenges to improve the global environmental performance through genuine usage integration during design

Coordination:

Lucie Domingo and Maud Rio, COMUE University Grenoble Alps

Xavier Durieux and Marc Vautier, Orange

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Introduction

Lucie Domingo et Maud Rio [1]

[1] *G-SCOP Laboratory, COMUE Grenoble Alps*

How eco-design can embrace the use phase

This book is based on contributions from international academics and industries covering a variety of sectors and countries. This work provides an introduction to the contemporary issues faced by designers when attempting to embrace the use phase for eco-designing their products and services. This compilation of research results has been made possible due to the funding granted by the EcoSD Network in its annual call for the Annual Thematic Workshop.

The EcoSD network is a French association whose main objective is to encourage collaboration between academic and industrial researchers to create and spread advanced knowledge in the eco-design fields. This initiative aims to help a global sustainable development process on national and international levels. In this respect, each year, an international workshop is organised by an academic and an industrial team to investigate a theme that merges ongoing research results from France and overseas, and highlights the opportunities of research in this field.

Introduction to the topic

The use phase is central to eco-design activities in all sectors. However, there is no unique way of eco-designing products. Various possibilities are offered through usage consideration, matching different categories of products: highly-intensive energy products, technology-driven products, passive products with highly-embodied value, etc.

For intensive energy-using products or active ones, their in-use efficiency is a deciding factor when eco-designing them. The European Commission recommends leading the global improvement of products' environmental footprint by reducing the impacts generated during use [European Commission, 2006]. In addition to environmental benefits, energy efficiency is closely linked to optimising autonomy for transportation systems (automotive in particular), mobile mechatronics products, and many others. This is usually of benefit to the user as well.

For high maintenance products, use-phase integration is critical to the planning of such maintenance operations and to the improvement of their environmental performance. For highly-technical products, from aircrafts to mundane products such as clothes, maintenance can be a major environmental burden.

Even for relatively passive products but with a long “shelf-life”, use-phase integration is critical to the extension of such shelf-life for absorbing the environmental impacts over use time. Furniture, buildings, etc. benefit from usage integration through the development of realistic use conditions for adequate dimensioning of shelf-life. In the food industry, packaging extends the shelf-life of food by conservation optimisation and communication with users [Wikström, 2014]. Considering the total life cycle of producing and wasting food, smart packaging avoids global waste which reduces the environmental footprint of that given food.

On a larger level, the concept of circular economy is focusing on keeping the value and the environmental value in a use cycle [Webster, 2015].

A collaborative contribution: industries and academics

This book summarises the contribution of a one-year process of an academic and industrial collaboration sharing on-going experiences and results in the field of usage integration for eco-design. This process went through the following stages:

- Selection of the topic for the 2016 EcoSD French network annual workshop day;
- Launch of a call open to members from academia and industries, within and outside the EcoSD network. The accepted results of this call are compiled in this book;
- Peer review of the received propositions;
- Elaboration of the workshop programme. The organisers have chosen to foster conversation around three round tables. The papers selected for publication in this book were used to introduce the concept of the round tables;
- And finally the workshop in itself was conducted in Paris in Orange Stadium. It was open to any international participant willing to contribute to the discussion and share successful and unsuccessful experiences of usage integration during product design.

The whole scientific and industrial contribution presented in this book is organised around the products’ categories and their respective potential of usage integration for early improvements, as introduced in this section.

The building sector cumulates two environmental hotspots tied to the use phase. Firstly, when including the individual equipment and the envelope in the building system, it contributes up to 40% to the global energy demand, in the European Union. Secondly, the long life of the system means that anticipation, simulation and evaluation before construction (i.e. during design) are crucial to decreasing the overall environmental impact of each project.

The low level of standardisation among design projects in the building sector makes it also a great application field for design researchers. Feedback from the application and the development of tools and methods aimed at limiting environmental impacts in use of buildings are made available by design researchers.

Electro-domestics have been focusing on energy efficiency, pushed by both regulations and by consumers' awareness and desire for more autonomous products. The presence, at home, of increasingly active products means that the energy demands are slowly decreasing for transportation and energy and rapidly increasing in the home. On top of this challenge, circular economy is pushing designers into considering obsolescence and replacement rates during product development.

Both challenges are being integrated in new design research propositions that focus on the use phase for setting up the design space with the appropriate constraints and methods. Applications in electro-domestic products such as refrigerators, television sets, and coffee machines have been exposed in the literature.

Lastly, telecommunications technologies are key in this discussion, both as a support for the improvements in other sectors and for improvements within its own products and services. Telecom products and infrastructures, by mainly consuming energy, have had to focus on the use phase for eco-design purposes, in the same way as electro-domestic products. Adding to the environmental challenges, some of the newest paths to sustainability rely heavily on telecom solutions. Smart-grid, Smart-cities, the Internet of Things, etc. are part of telecom infrastructures or use them in order to function.

Usage integration in design across such sectors appears therefore as an opportunity at both ends of the environmental challenges of our industrial societies. At one end, it is required for developing solutions that are adequate for usage and environmentally efficient. And at the other end, new developments to support environmental improvements of other key contributors to environmental burdens need to be implemented in industrial processes.

Examples, feedback and case studies in this book reflect the situation of usage integration in eco-design in today's industry, in more detail.

This book is divided into two sections:

1) Towards a use-phase integration during eco-design: good practices

This first section reflects on research experimentation that provides a framework for usage integration in product design for the environment in general or for a specific sector, the building sector.

2) Opportunities to challenge integration.

This second section reflects on the two pillars of usage integration in eco-design: how to capture usage for eco-design activities and how to frame such information for the product design.

TOWARDS A USE-PHASE INTEGRATION DURING ECO-DESIGN: GOOD PRACTICES

There have been many developments in recent years to foster use-phase integration for improving environmental performance. Not all of them labelled themselves as eco-design related but Design for Sustainable Behaviour, Energy Efficiency Management and Design for Resources Efficiency have contributed to clarifying the topic.

In terms of design strategies, the developments in these fields have been placed according to their position regarding time and space as shown in Figure 1:

- Are they located in the product space and / or in the usage space?
- Are they present during design time and / or usage time?

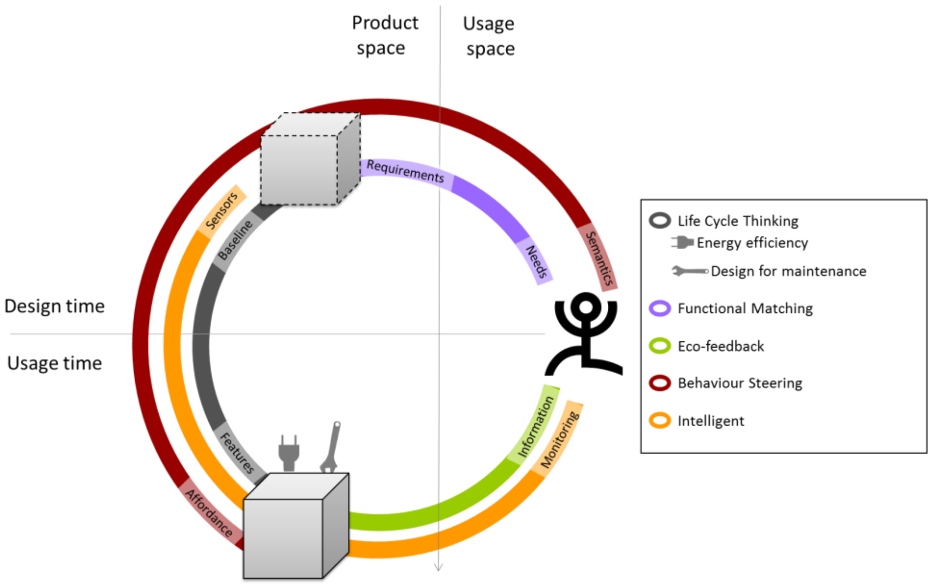

Figure 1: Design strategies for usage integration in design

Aligned with life-cycle thinking principles (grey cycle in Figure 1), eco-design guidelines have focused improvements of the use phase on resource efficiency (energy, water, consumables, etc.) and on extended product lifetime due for example to design for maintenance. These solutions are implemented through the definition of a baseline of product life-cycle scenarios during design, supporting the development of efficient features on the product. These features allow for efficiency management and maintenance during usage.

Another strategy derived for life-cycle thinking is the functional matching (purple cycle in Figure 1). This strategy starts in usage space with the definition of user needs: not more not less. To move to the product space, the needs identified are transformed into the final list of product requirements. This strategy aims at streamlining the product features by only developing those that are tied to an identified user need.

Design for sustainable behaviour also proposes an array of strategies that balances the control of the environmental performance between the user and the product.

Eco-feedback (green cycle in Figure 1) is a strategy that gives control of the environmental performance to the user. The product has the ability to provide information of environmental nature – "eco" feedback – to the user during usage. Environmental improvement is generated by users' actions that are triggered by such feedback.

Behaviour steering (red cycle in Figure 1) is a more subtle approach to triggering environmental improvements. [Lockton, 2009] have developed a guide to support designers in the development of appropriate steering features. Steering is based on the implementation of a product feature that conveys a sense to the user [Norman, 2013]; that guides them into interacting with the product in a responsible way. For example, a red button conveys the sense of "turning off the product". If designers wish to steer users into turning off the product more often, they should add a visible red button as a product feature.

The last group of strategies aims at giving control of the environmental performance entirely to the product: implementing "intelligent" design features (yellow cycle in Figure 1). This is based on automation principles implemented through sensor features. By monitoring usage and identifying usage patterns, the product regulates its operations to consume as little as possible based on the identified patterns.

Inspiration from the building sector: inspiring feedback

The building sector has been driven towards usage integration to support the transition from low to no-energy consumption during use.

Industries and academics from this sector have experimented an array of techniques for usage and user integration in order to decrease the "at home" or "at the office" energy demand.

From complex modelling [Yannou, 2016] to gamification [Abi Akle, 2016], usage is a central element in designing the new user modelling methods in the building sector. Since buildings are complex systems, several approaches to model user interaction in design are being tested, from stochastic-based simulation to models focusing on value creation [Cluzel, 2016; Vorgier, 2016].

All of these initiatives provide useful feedback for product and service design in general. By identifying the specific constraints of the sector, a generalization of good practices could be implemented.

Opportunities and Challenges Addressed

Capturing usage for eco-design activities

Looking back at Figure 1, one of the challenges to address is how to navigate between design time and usage time. Capturing what happens in use in order to implement the adequate features on the product has been a focus of other design fields. However eco-design generates unique challenges by expanding the scope of usage to cover everything that may occur from product acquisition to product end-of-life.

The contributions in this section offer different perspectives on the definition process and the way to capture usage for eco-design activities.

[Cor, 2016] presented an approach that merges User Centred Design principles with Failure Mode, Effects and Criticality Analysis. This proposal aims at covering usage from both usability perspective and robustness.

[Déméné, 2016] illustrated the difficulty in outlining the boundary of usage in eco-design. Using face-to-face interviews, the paper identified how product usage in environmental performance influences the rest of the product eco-system in which it is placed (for instance, changing a TV will imply also changing the furniture on which the TV stands).

[Popoff, 2016] proposed to focus on drifts in user behaviour to start the design. By capturing the non-appropriate usage of products, designers are able to propose design features that can correct usage performance.

Usage modelling during eco-design and product development

Lastly, this book explores how design activities move in and out of the product space and the usage space. The challenge is linked to the representation of both product and usage for design activities in order to support environmental performance improvements.

[Domingo, 2016] proposed a case study on how design activities, for a telecom company, are supported by an expertise in usage (thanks to a user experience expert) and by an expertise in eco-design (thanks to an environmental expert).

[Rio, 2016] made an inventory of some of the models that combine the usage space and the product space for design activities. Based on this inventory, model federation is used to develop some dynamic linkage between the environmental assessment models and available information about usage during design.

The conclusion of this book summarises the challenges addressed to academics and researchers that emerged during the three round-table sessions of the 2016 EcoSD Annual Thematic Workshop.

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Roundtable 1:

Feedback from successful initiatives of use stage integration in the building sector

Evaluation of the influence of occupants' behaviour on Building Energy performance using a stochastic model

Dr. Eric Vorger, Dr. Patrick Schalbart, Dr. Bruno Peuportier

MINES ParisTech, PSL - Research University, CES Centre for Energy efficiency of Systems, 60 Bd St Michel 75006 Paris, France

INTRODUCTION

Designing new or retrofitted buildings with high performance in terms of energy and comfort is a complex task. Since numerous - potentially contradictive - phenomena affect this performance, Building Energy Simulation (BES) programmes (like EnergyPlus, TRNSYS or Pleiade + COMFIE) have been developed to help professionals make appropriate decisions.

BES programmes calculate the indoor temperature, heating and cooling loads, and heating and cooling powers, at every time step and in every zone of a building. The required inputs are: a 3D model of the building with all the materials, a 3D model of its surroundings (to calculate the solar masks), a meteorological file with outdoor temperature, radiation (to calculate the solar gains) and wind; the internal gains due to the occupant's metabolism, the internal gains due to the use of electrical appliances (Joule effect). From these, the model calculates the heat exchanges through the walls and the effects of air movement (ventilation, infiltrations). Deterministic physical aspects are now modelled at a satisfactory level in some of these tools, according to the validation procedures to which they have been subjected. But the predictive capacity of this software is undermined by a poor representation of non-deterministic phenomena, especially those linked to occupants' presence and behaviours.

The objective to reduce the CO_2 emissions in the building sector by 4 leads to high performance targets for new constructions, but also for renovation projects. This raises financial issues that can be tackled by mechanisms based on the (guaranteed) reduction of the energy bills (access to loans for owners, participation of third-party financers). This is why clients increasingly ask for energy performance contracts[1]. But the energy consumption in a building not only depends on the quality of the construction works: it is also strongly influenced by climatic variation and users' behaviour. The process being elaborated is the following: the contractor in charge of the construction guarantees a consumption threshold, but this threshold is adjusted in terms of external temperatures and heating thermostat set point, for example. For instance, the threshold is 50 kWh/m^2 if the thermostat set point is 20°C, but increases by 10% per supplementary °C (i.e. 55 kWh/m^2 at 21°C). After completion of the works, it is then necessary to measure the energy consumption, but also the internal temperature: in the same example, if the measured temperature is 21°C and the energy consumption is 52 kWh/m^2, the contractor does not have to pay a penalty.

Nevertheless, significant uncertainty remains in the calculated energy consumption, due to other aspects of occupants' behaviour. Indeed, performance monitoring experiments have reported major deviations between predicted and measured energy consumption [Sidler, 2011]. It is therefore necessary to improve our knowledge in this field.

A METHODOLOGY TO EVALUATE THE UNCERTAINTIES OF BES RESULTS

The proposed approach

Why do simulation results differ from in situ measurements? Under the hypothesis that the considered BES programme is reliable, the reason is that many input parameters of the calculation are uncertain and are linked to values that do not match the reality. Although easy to state, the problem seems to be impossible to solve. Therefore, the approach presented in this paper proposes to work around the problem. The objective is shifted from "predict the exact performance" to "provide a confidence interval of the performance".

The problem is twofold. Firstly, some phenomena are well modelled but the inputs are uncertain. Secondly, other phenomena are modelled in an unsatisfactory way, so the BES programme must be enriched by new models. Consequently, the proposed methodology consists in calculating confidence intervals of the performance by:

- propagating the uncertainties of the parameters related to the thermal model (building's envelope, systems, meteorology),

- using new stochastic models for human behaviour.

[1]http://www.ademe.fr/expertises/batiment/passer-a-laction/outils-services/garantie-performance-energetique

Indeed, occupancy is currently modelled by conventional ratios and profiles that do not reflect either the variety of the behaviours or even the average behaviour[2]. Given its particular nature and importance, the uncertainty related to occupancy cannot be evaluated through uncertainties propagations based on this conventional representation. It requires a complete overhaul of occupants' behaviour models.

In this approach, the performance can be expressed under the form: "there are X% of chances for the indicator I (for example the annual heating loads) to be between $I_{low,X}$ and $I_{high,X}$". For a given level of confidence X, the scope of the confidence interval [$I_{low,X}$; $I_{high,X}$] depends on the quantity of information provided by the user.

Principle of the method of uncertainty calculation

Instead of one deterministic simulation leading to a unique result, a series of simulations is conducted according to the Monte-Carlo method. In this way, the programme provides the probability distributions of the simulation outputs (heating and cooling loads, specific electricity consumption, thermal comfort indicators).

Figure 2 illustrates the principle of the method. At each simulation, the uncertain inputs are randomly fixed at a new value according to their probability distributions[3]. Furthermore, an occupancy model is coupled to the thermal model of the building (Pleiades + COMFIE). For each simulation, it creates new virtual occupants and these occupants perform different actions, such as changing the thermostat set points, using electrical appliances or opening the windows. Each simulation is unique. Depending on the cases, hundreds to a few thousands of simulations are necessary to obtain stabilized and interpretable output distributions[4].

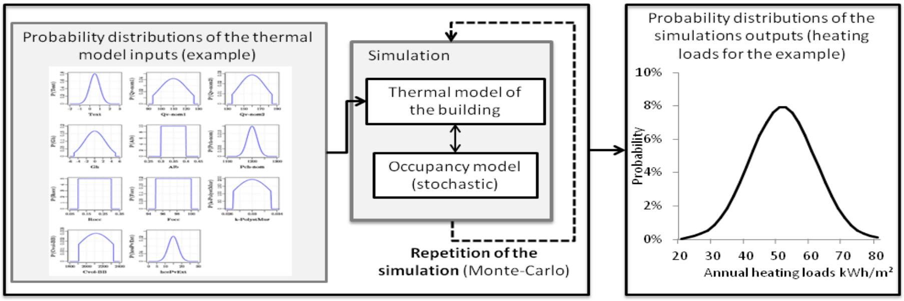

Figure 2: Principle of the uncertainties calculations

[2] Explicit evidence of occupancy variety and influence is provided by studies that observe very dispersed energy consumption for similar dwellings under the same climate, e.g. [Andersen, 2012].
[3] E.g. if a ventilation rate is supposed to be 100 m3/h and the user evaluates a uniform uncertainty on this parameter of +/-20%, then the ventilation rate will be randomly drawn on [80 m3/h; 120 m3/h].
[4] The sampling of the thermal model parameters is optimized in order to efficiently cover the input space (quasi Monte-Carlo) and consequently reduce the number of simulations.

The next section presents the occupancy model in the case of residential buildings. More details about this model can be found in the PhD thesis of [Vorger, 2014].

STOCHASTIC MODELLING OF THE OCCUPANCY (RESIDENTIAL BUILDINGS)

Occupants influence energy consumption and indoor climate conditions of buildings in several ways:

- The presence is a source of heat, humidity and CO_2 due to human metabolism. It is also a prerequisite for the completion of the actions listed below.
- The opening/closing of windows alters the temperature and the quality of indoor air.
- The use of shading devices influences the solar gains, the indoor luminance and therefore, the use of artificial lighting.
- The use of artificial lighting and electrical appliances is synonymous with electricity consumption and internal gains by Joule's effect.
- The management of temperature set points determines the consumption of heating and cooling.
- The Domestic Hot Water (DHW) draw-offs generate energy consumption and alter the indoor temperature and humidity.

Low-energy buildings, heavily insulated and designed to promote solar and internal gains, are particularly sensitive to the interactions listed above.

For all these aspects, specific stochastic models have been integrated in the BES tool. Some of them are adapted from what we identified as the best performing existing models, while new models have been developed on aspects for which no model existed or was satisfactory.

Creation of virtual households

The first step of the simulation is to create virtual inhabitants taking into account the type of dwelling (house or apartment, number of rooms) and its location (postcode). A stochastic procedure generates a set of household members, for each dwelling of the project, with their socio-demographic characteristics (age, gender, income, retired or not, working hours, level of education, health ...). This part of the model is calibrated with data from the 2010 French Population Census and the associated Housing survey[5].

Activity scenarios of the inhabitants

The modelling of the presence and the activities is useful for simulating the use of electrical appliances, water consumption and the adaptive actions (management of windows, blinds, artificial lighting and temperature settings). It also enables to locate people in the different rooms and to assign the corresponding metabolic heat gains. The model, which generates weekly scenarios of activities for each inhabitant depending on the latter's socio-demographic characteristics, is calibrated on the 1999 Time Use Survey[6] (TUS) of INSEE [Wilke, 2013].

Use of electrical appliances and artificial lighting

Knowing the occupants' activities makes it possible to simulate the use of electrical appliances. For example, while a resident is cooking, he/she is likely to use an oven. Thirty types of appliances covering every domestic usage (washing, cooking, cooling, computer, audiovisual, etc.) are integrated. The ownership probabilities depend on household characteristics (age of the reference person, household type, income) or are set at the national average rate. The calibration data come from the Households' Equipment survey of INSEE, from surveys commissioned by industrials[7] and from inventories performed during measurement campaigns[8].

The model assigns a duty cycle and a standby power to each appliance, possibly depending on its technology and dimension. The use of appliances is linked to occupants' activities through pragmatic hypothesis. For example, ovens are linked to the "cooking" activity. Each time a period of cooking begins, a number is randomly drawn on [0, 1] and compared to a starting probability to determine if the oven starts a cycle. For artificial lighting, starting probabilities depend on the activities (the activity related to artificial lighting is just "present and awake") and the time of the day (like for the other appliances), but also on the geographical location and month of the year (which define the sunrise and sunset hours).

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[5] INSEE, Pool Size: French Population (Census) and Sample size: 900 000 (survey))[INSEE, 2010].

[6] This survey involves 15 441 respondents described by a set of socio-demographic characteristics. Each one reported all its activities, in a specific book, during one day with a 10 min time step

[7] E.g. the GIFAM (Groupement Interprofessionnel des Fabricants d'Appareils d'équipement Ménagers): http://www.gifam.fr/page/donnees-par-produits.html

[8] E.g. inventories from the campaigns: REMODECE, ECUEL, IRISE, CIEL, EURECO, ECODROME. Each campaign involves about 100 dwellings. Some are specific to one type of usage, e.g. REMODECE concerns the audiovisual and computer equipments, ECUEL concerns the cooking equipments etc.
Refs can be found on: http://www.enertech.fr/

The appliances' characteristics and the starting probabilities are calibrated with data from measurement campaigns performed by the engineering office Enertech in partnership with EDF and ADEME, e.g. [Enertech, 2008; Enertech, 2004].

Water consumption

As for the electrical usages, the hot and cold water consumption can be simulated on the basis of occupants' activities (e.g. "shower" or "housework"). The calibration uses data from the Water Information Centre (a survey on usages and models of unit consumption). Data from measurements in 300 homes (SCHEFF project) enabled to validate the DHW consumption per capita (mean and standard deviation).

Heating temperature set points

The French thermal regulation considers a heating temperature of 19°C during the periods of occupation and 16°C for the remaining time. Since these assumptions do not reflect the reality of practices, we propose a simple model that incorporates diversity in terms of:

- temperature of comfort (average of 21°C and standard deviation of 2°C according to measures of temperature in many homes in France and in other European countries), influenced by the socio-demographic characteristics;
- management of the temperature set points, through varying probabilities assigned to households to describe their propensity to reduce the set point when they leave the house or go to bed.

Use of shading devices

In the absence of measures enabling to develop a consistent model in a residential context, the management of shading devices in housing is integrated in a simplified manner. For each dwelling, three shading rates corresponding to night, day in summer and day in winter are randomly drawn (on predefined ranges).

Opening/closing of windows

The opening and closing probabilities were calibrated on the basis of measurements in one office building and three dwellings. They depend on the presence status (arrival, intermediate, departure) and on indoor and outdoor temperatures [Haldi, 2009]. The predictions give no indication on opening rates. To reduce the computation time, the air flows are deducted directly using correlations and a random coefficient, and are considered constant throughout the opening period. Variants corresponding to three types of behaviour vis-à-vis the opening of windows (active, middle and passive) have been developed.

CASE STUDY: APPLICATION TO EPG OF A RESIDENTIAL BUILDING

We studied a 4-storey residential building with a 1 048 m² area located in the suburb of Lyon. It includes 16 apartments, modelled by a thermal zone each, plus a central circulation corresponding to a seventeenth zone. This building was retrofitted; its thermal characteristics after renovation are given in Table 1.

Facades	U = 0.22 W/(m².K)	Windows	U = 1.9 W/(m².K)
Loggias	U = 0.23 W/(m².K)	Thermal bridges	Psi = 356 W/K
Low floor	U = 0.49 W/(m².K)	Mechanical ventilation	0.3 vol/h
Roof terrace	U = 0.29 W/(m².K)	Air infiltrations flow	0.15 vol/h

Table 1: Thermal characteristics of the building

The proposed exercise was to estimate the energy consumption for the heating and the DHW after the renovation with a confidence interval allowing the project manager to make a commitment on a guaranteed performance. First of all, only the uncertainties on the thermal model (systems, envelope, meteorology) were propagated[9], whereas occupancy was modelled with the conventional deterministic scenarios. Secondly, calculations considered the uncertainties on the thermal model and the occupancy stochastic models. The vertical dotted lines correspond to the guaranteed thresholds (we considered a risk of 2.5% corresponding to the 95% confidence interval but any other value could be chosen). The consumption measured during the year after the renovation was 110 kWh/m².

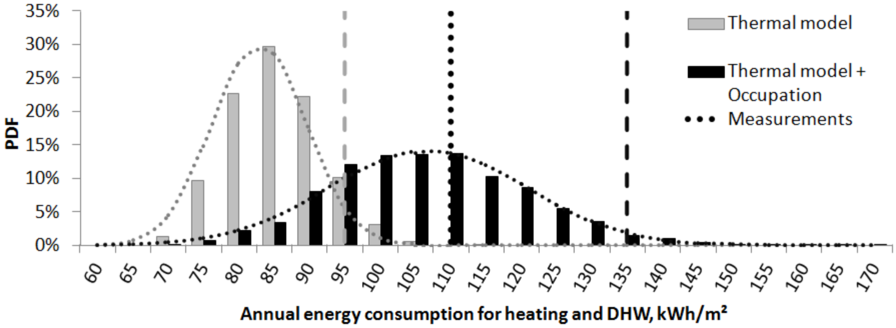

Figure 3: Probability Density Functions of the simulations outputs

[9] The uncertainties on the thermal model concern for example the efficiency of the boiler and the regulation, the outside temperature, the insulation characteristics of the materials, the air infiltration rate, the mechanical ventilation flows, etc. Details on the parameters and their probability distributions can be found in the annex.

When only the uncertainties of the thermal model were considered, the measured consumption was beyond the guaranteed value (96 kWh/m²). On the other hand, the confidence interval of the prediction included the real consumption when the stochastic occupancy model was activated. The guaranteed value in this case was 134 kWh/m², i.e. 24 kWh/m² higher than the measured consumption.

DISCUSSION

Bearing in mind that BES professional users have neither the information nor the time to fill every parameter related to the occupants, and that their knowledge on the envelope and the systems is limited, the models systematically propose default stochastic procedures (occupancy) and default probability distributions (thermal model parameters). In the previous case study, only default settings were used, which correspond to a situation of minimal information held by the professional. This leads to a high guaranteed value.

To reduce the spread of the outputs and lower the guaranteed value, some parameters could be set with more precision depending on the available information. For example, the default calculation considers an uncertainty of +/-30% for the air infiltration rate, but measurements could reduce this uncertainty to +/-10%. The problematic is the same with the occupancy models. By default, the models generate households, assign equipment, assign temperature set points, etc., but the professional can give more information, such as the number of occupants, the type of equipment present, an interval for the temperature set points in winter, etc. Indeed, the objective in an EPG context is to guarantee the lowest possible value (to encourage retrofitting and to maximise financial opportunities), while controlling the risk. There is an interest in this reduction of the uncertainties of the model inputs, since it narrows the confidence interval around the real consumption.

This raises two issues. First of all, it is interesting to identify the inputs that should be targeted as priorities, i.e. those that are the most likely to reduce the outputs' standard deviations. This work was undertaken by deploying the global sensitivity analysis method of Morris [Morris, 1991] after having adapted it to stochastic models [Vorger, 2014], but more work is necessary to confirm the results.

The second issue is practical. It concerns the access to the information in a real project. In this respect, by pushing the design team to seek information from future users, the method tends to develop a collaborative approach. Indeed, if the design team chooses to distribute questionnaires among the users of the building (to gain information on their socio-demographic characteristics, their comfort preferences, the appliances they own, etc.) to reduce the uncertainties of the predictions, why not go one step further and organize meetings (possibly with a specialized chairman) to integrate them into the design process? As respected stakeholders, users will be more likely to respond to the questionnaire, they will certainly have good ideas to share and they will adopt and make better use of the building.

Conclusion

The improvement of BES programmes by adding uncertainty calculations is necessary to increase investors' confidence and to progress towards a process of Energy Performance Guarantee (EPG). This paper tackles this issue by proposing a methodology to calculate confidence intervals on simulations outputs based on uncertainties propagations and stochastic modelling of occupants' behaviour. A case study on a residential building illustrates the approach and focuses on the EPG problematic. It shows how the probability distributions of the energy consumption can be used to deduce the probability (corresponding to a risk) that the real consumption will be higher than a certain value (the guaranteed consumption). The question of the reduction of the uncertainty on the outputs gave rise to a discussion. The participation of the building users in the design stage is suggested as an interesting solution.

There is ongoing work on the models' validation and development. The paper described the occupancy model in a residential context but a similar model was also developed for office buildings (with specific calibration databases and differences in the approach especially concerning the presence or the use of shading devices and artificial lighting which require lighting calculations). However, no occupancy models exist today for other tertiary buildings. This represents large amounts of work in perspective.

An extension of the BES software Pleiades + Comfie is currently being developed to integrate the models and the methodology presented in this paper. A prototype will soon be available for professionals interested in testing the models and the methodology on their own case studies.

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Activity-based simulation of households' energy and water consumption

Bernard Yannou, Yann Leroy, Toufic Zaraket

Université Paris-Saclay, CentraleSupélec, Laboratoire Génie Industriel

Stéphanie Minel, Emilie Chapotot

ESTIA

INTRODUCTION

The building stock accounts for between 16 and 50 percent of national energy consumption worldwide [Saidur, 2007; Masoso, 2010; Hoes, 2009]. Governments around the world are thus rolling out energy directives, national regulations and energy-efficiency labels that set minimum requirements for buildings' performance [EPBD, 2014], and promote the construction of green buildings [Vierra, 2011]. Buildings' stakeholders have thereby started dealing with buildings as products-with-services rather than just simple products. Services may for instance include energy monitoring or equipment maintenance during a building's use phase. Moreover, new market expectations such as "energy performance contracts" have started to emerge in a number of countries [CPE, 2012]. Such services and offers thus require a better control of performance's variability during a building's life cycle. Consequently, a better comprehension and consideration of the key determinants of energy performance has become essential for the design and marketing processes of buildings.

Occupant behaviour is a substantial source of uncertainty in energy modelling since it can impact energy consumption by as much as 100% for a given dwelling [Masoso, 2010; Page, 2008; Yu, 2011; Pachauri, 2004; Fabi, 2012; Swan, 2009; Clevenger, 2006; Seryak, 2003; Emery, 2006]. The reasons are that people generate different quantities of activity (some people take one shower per day, others every two days) and may possess more or less eco-efficient electrical appliances, both aspects depending on the household (further abbreviated by HH) composition, way of living and socio-demographic category.

Industrial energy simulation tools such as Energy Plus and eQUEST propose some simplifications regarding occupants' behaviour (among other simplifications), which may lead to unrealistic energy estimates, and may possibly be one of the reasons behind high discrepancies between predicted and real energy consumption values [Malavazos, 2011; Kashif, 2013; Bourgeois, 2006; Chiou, 2009]. Nowadays, such performance discrepancies are no longer tolerated - especially in the case of green (energy-efficient) buildings. More precise methods are therefore needed to model occupants' influence on buildings' energy performance. Such models should result in more accurate energy estimations, and hence improve building designs and marketing offers.

The authors have proposed an activity-based model of residential energy demand (SABEC, standing for *Stochastic Activity Based Energy Consumption*) in a doctoral dissertation [Zaraket, 2014a]. This paper is not intended to detail the model, but it briefly recalls the adopted modelling methodology. The main focus here is to show how a user-focused model, which accounts for occupants' energy-related needs and activities, can be used within the engineering design, energy management processes, and marketing offers of residential buildings.

A literature review is first presented followed by a brief reminder of the proposed modelling methodology and a sample of simulation results. The possible integration of the proposed model into the design and energy management processes of residential buildings is then demonstrated through a number of use cases.

BACKGROUND AND RELATED WORK

Occupants' Behaviour and Energy Use Trends in Buildings

According to [Ellegård, 2011], energy use is embedded in most aspects of households' daily life. People use energy and water to satisfy their daily living needs and activities such as preparing food and supplying heat and light [Pennavaire, 2010; Kashif, 2011]. Scientific literature points out the major end-use groups of energy, such as space heating, space cooling, domestic hot water, appliances and lighting [Hoes, 2009; Swan, 2009; Yao, 2005]. This energy consumption is highly dependent on the behaviour of occupants [Masoso, 2010; Emery, 2006; Yun, 2011]. Past experience shows that energy usage can vary dramatically from one household to another [Clevenger, 2006; Seryak, 2003; Paauw, 2009]. This variation reflects the heterogeneity in occupants' needs and preferences. Literature confirms the presence of high correlations between household attributes on the one hand, and domestic appliance ownership levels, their energy rating, and their use patterns on the other [Yun, 2011; Weber, 2000; Mansouri, 1996; Lutzenhiser, 2008; Guerin, 2000; Nugroho, 2010; Yun, 2009; McLoughlin, 2012]. This would explain why general assumptions about occupants' behaviour imply ambiguities and inevitably lead to significant uncertainties in energy predictions. Therefore, a better modelling of occupant-related energy consumption must emerge from a better understanding of their needs, preferences and usage-contexts, and, thus from a better representation of their socio-economic and demographic attributes that influence their energy consumption trends.

Existing modelling approaches

Literature reveals the existence of a number of different scientific techniques for modelling energy consumption in residential buildings [Swan, 2009]. Some authors, such as [Seryak, 2003] and [Yohanis, 2008], use real sub-metering data in order to derive representational loads (so-called "diversity profiles") of occupants' energy use, and thus deduce estimates of buildings' total energy consumption. Other modelling methods are those aiming at simulating occupancy patterns and various energy-load schedules by using stochastic approaches (e.g. Monte Carlo Markov Chains) that are based on national time use surveys (TUS) [Chiou, 2009]. Authors such as [Tanimoto, 2008; Richardson, 2009, 2020; Widén, 2010; Muratori, 2013; Subbiah, 2013] have adopted such type of approaches. However, these modelling approaches still have some drawbacks. Firstly, to the authors' knowledge, even though they correlate occupancy schedules to appliance use-patterns and consumption, none of the existing approaches establishes the link between occupants' daily living needs (Maslow's pyramid) and their related energy consumption. Secondly, they do not generate energy demand profiles based on the activities performed in each household and more particularly by each household member. Therefore, they lack the ability to depict use-situations such as the sharing phenomena of appliances and activities (e.g. watching TV). Thirdly, the existing models are not exhaustive in representing household attributes (such as income, age, etc.), where in most cases, the main variable considered for representing households is the number of occupants. Consequently, such models cannot assess energy consumption variability between different population segments and household profiles.

Based on these conclusions, we believe that a user-focused statistically-derived approach which correlates occupants' profiles (socio-economic and demographic) on the one hand, with activities, appliance ownership and use trends, and usage contexts on the other hand, can be very useful for the design process of buildings. The benefits of such a model may not be limited to energy consumption predictions, but it can go further to be used for adapting building design solutions and for energy monitoring and management during the use phase of buildings for instance.

THE SABEC MODEL

Ontology and principles

The SABEC model is developed in the context of forecasting occupant-related energy consumption in residential buildings, while accounting for variability in consumption patterns due to heterogeneity in occupants' socio-economic and demographic profiles [Zaraket, 2014a]. The model accounts mainly for energy consumption related to domestic activities such as watching TV, washing dishes, and doing laundry. The structure of the proposed Activity-Based Energy

Consumption SABEC model is presented in Figure 1, whereas its different objects are very briefly introduced in this section. Occupants' behaviour is characterized through a need-activity-action paradigm. We consider that occupants satisfy their daily living needs (e.g. house-caring) by performing a set of daily activities (e.g. washing dishes), which in turn are conducted through a set of actions (e.g. wash dishes by machine, wash dishes by hand). Exhaustive inventories of energy-use needs, activities, actions and appliances are established in accordance with existing literature and related theories (e.g. Maslow's pyramid, activity theory) [Zaraket, 2014a]. An Activity-based model entails that energy consumption of a household is estimated by summing up the energy use of different activities performed (such as cooking, washing clothes, etc.). The model is of a stochastic nature due to the twofold probabilistic mapping (conditional probabilities) established between household attributes (household type, number of occupants, socio-professional category, etc.), as well as the corresponding appliance ownership rates, appliance characteristics and power ratings, and activity quantities. A household model with an exhaustive representation of occupants' attributes is proposed.

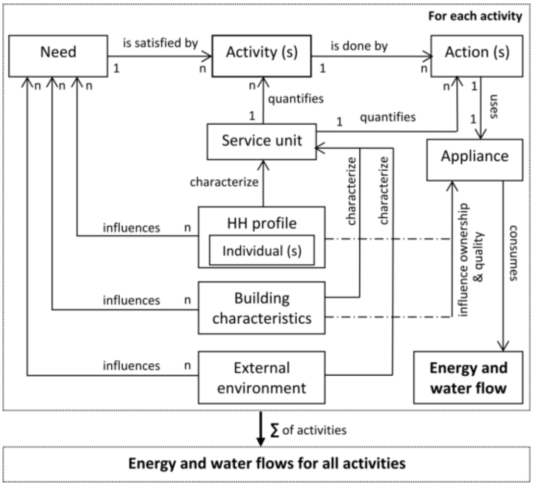

Figure 1: Architecture of SABEC model

Domestic activities are classified according to their nature (shared, additive). Each activity is quantified by a series of units, for instance the *weight of laundry washed with washing machine* and the *weight of laundry washed by hand*. For a given activity, service units are coupled with the appliance's energy and water ratings and elementary consumption in order to compute the resulting energy and water consumption. The proposed model can thus quantify energy consumption per domestic activity at the level of a specific individual or household. We highlight here that the technical and computational aspects of the model are not presented in this paper. For more details, the reader may refer to [Zaraket, 2014a; Zaraket, 2013; Zaraket, 2014b].

Deterministic simulation of energy and water consumption

This SABEC model has been used for stochastic simulations in [Zaraket, 2015] of households' energy and water consumption. The detailed work can be found in [Zaraket, 2014a] (downloadable here: https://hal.archives-ouvertes.fr/tel-01087894).

In the following, the authors present the deterministic energy and water consumption simulation of a household's whole set of domestic activities.

In sum, a parametric modelling principle of the energy envelope of an activity of a household (HH) has been proposed according to its profile and characteristics (HH type, number/age/gender of adults, socio-professional categories of adults, salaries, employment status, number/age/gender of children), see Figure 2-left for an example.

Type de ménage	Couple avec 1 enfant ou plus				
	Age	Genre	Statut d'emploi	Catégorie socioprofessionnelle	Salaire (net/mois)
Parent 1	38	Masculin	Indépendant	Independant (non-salarié)	2000
Parent 2	34	Féminin	Chômeur	Chômeurs	1200
Enfant 1	9	Masculin	Etudiant, lycéen		
Enfant 2	5	Féminin	Etudiant, lycéen		
Enfant 3					

Figure 2: (Left) Example of household profile – (Right) The 28 activities of energy and water consumption

The different stages for assessing the consumption of a household are the following:

- considering the amount of each activity (the service units of an activity are parametric expressions of the household characteristics),
- correlating the quality and eco-efficiency of appliances linked to the activity and possibly linked to the socio-professional category,
- calculating the consumption by additive summation of individual consumption and heuristic estimation of the activity sharing,
- fitting of consumption patterns (electricity and water) related to an activity based on national statistical data of consumption.

In total, 28 domestic energy and water consuming activities have been modelled (see the list in Figure 2-right). These consumption models are expressed with about twenty parameters featuring the household composition.

Each activity has been modelled in an Excel spreadsheet by: a subset of influencing household variables, a causal graph of influence starting from these household variables and ending with activity quantities passing through a number of quantitative intermediate variables (e.g. occupation rate, number of weekly meals, laundry weight…), modelling assumptions used, incoming data from statistical databases or national consumption, and procedures used for model fitting to national consumption data. Figure 3 represents such data streaming for assessing the final electrical and water consumption for the "Washing clothes" activity.

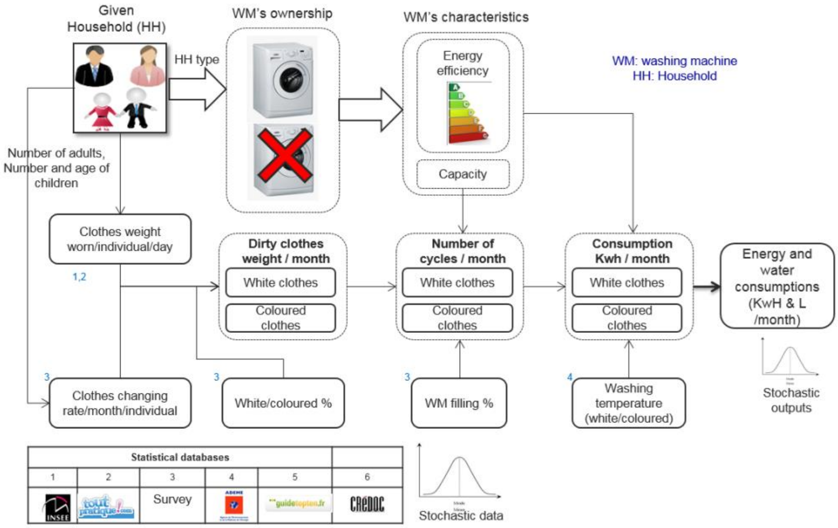

Figure 3: Electrical and water consumption model for "washing clothes"

The household simulation of energy and water consumption is monitored through a dedicated Excel spreadsheet allowing the definition of the household features and of some building physical features (see Figure 4). Some graphical outputs of simulations are provided in Figure 5: for a given dwelling and different households considered. Figure 5.a provides a comparison of both energy and water consumption, Figure 5.b provides such a comparison under each of the 28 activities.

Figure 4: The SABEC simulation dashboard for a given household

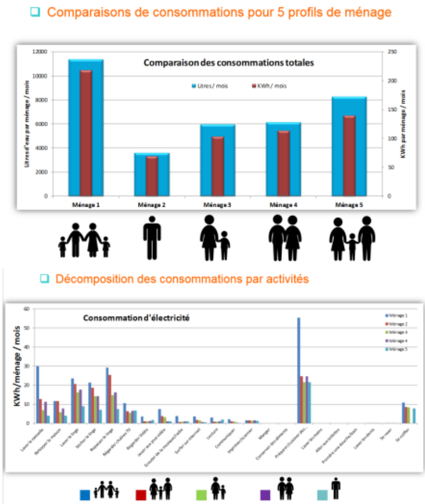

Figure 5: Typical SABEC energy and water consumption of a residential building depending on the household composition

Discussion and Conclusion

Such simulations of energy and water consumption from different household profiles enable:

- possible refinement or increased accuracy of EPCs (Energy Performance Contracts)
- possible simulations of the influence of certain technical solutions of the context (e.g. effectiveness or not of pre-installed washing machines)
- to obtain heat gain estimates by activities that are useful inputs for more accurate dynamic thermal simulations (DTSs).

The originality of our work is the decomposition of electro-domestic consumption by activities. This is of the utmost importance since occupants can, and know how to, regulate their activities. This model might be central to the development of a connected building approach, to a smart metering of consumption. Indeed, in the near future, when Internet of Things will be common, it could be possible to allocate elementary electrical and water consumption tracked on appliances to the proposed model of 28 domestic activities. Along with the storage of such activity breakdown consumption in the cloud, feedback on reference activity consumption for comparable households could be provided to occupants, so that they can know if they are over-consuming for given activities. Then, adapted graphical displays and means to voluntarily reduce consumption (incentives, emulation by social network, diagnosis and support to action plan ...) might be proposed to occupants like in [Picon, 2013].

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The DECADIESE methodology Extending usage and value creation perspectives of a building by value and externalities management

François CLUZEL[1], Bernard YANNOU[1], Pascal DA COSTA[1], Christophe GOBIN[2]

[1] Laboratoire Genie Industriel, CentraleSupélec, Université Paris-Saclay Châtenay-Malabry, France

[2] Vinci Construction, Nanterre, France

INTRODUCTION

Ambitious building retrofits are rarely justified by energy savings alone. A previous research project has shown that halving energy consumption of a building (like a school) may lead to a return on investment of more than 25 years [RS4E, 2010]. In this configuration, decision-makers are rarely inclined to invest. Thus, there is a need for more in-depth investigation and highlighting of the benefits of such retrofits or new buildings with a broader point of view.

This is why the DECADIESE methodology has been developed by a consortium of major construction and energy companies (EDF R&D, Bouygues Construction, Vinci Construction, Foncière des Régions) and academic partners (CentraleSupélec, Université Paris Diderot – Paris VII, Mines ParisTech) in the context of a French research agency-supported project (2012-2014).

DECADIESE considers an extended value of a building by incorporating sustainable dimensions through externalities integration, but also by refocusing the value created by a building on the benefits for its users. This paper focuses on the latter. On one hand, costs are broken down into seven usage functions, which highlight possible mismatches between functional objectives and associated amounts of money. On the other hand, the functional performance of the building is assessed due to 95 criteria that are then aggregated into seven usage functions scores. Once these elements have been identified, DECADIESE gives a project owner the ability to compare building variants.

A complete overview of the methodology is given first of all, and the functional aspects are explained in more details. The next section presents the first results and a short discussion. Finally, the last section highlights the main conclusions and perspectives.

METHODOLOGY

A general overview is given first. Then the seven usage functions are detailed to introduce the usage function cost and the functional performance models.

Methodology overview

Figure 1 proposes a simplified matrix vision of DECADIESE. Different objects are manipulated throughout the DECADIESE process:

- **Usage functions**, which constitute the reference basis to represent the characteristics of every building in DECADIESE. The functions are detailed in the section below entitled "Seven usage functions".
- **Stakeholders** involved in the building project, but also stakeholders that could be involved due to DECADIESE.
- **Externalities**, that are defined as "the cost or the benefit that affects a party who did not choose to incur that cost or benefit" [Coase, 1960; Pigou, 1920]; DECADIESE considers environmental, social and economic externalities.
- **Functional performance criteria** that enable to measure the performance of a building, detailed below in the section entitled "Functional performance".
- Investment, exploitation and end-of-life **costs** of the building.

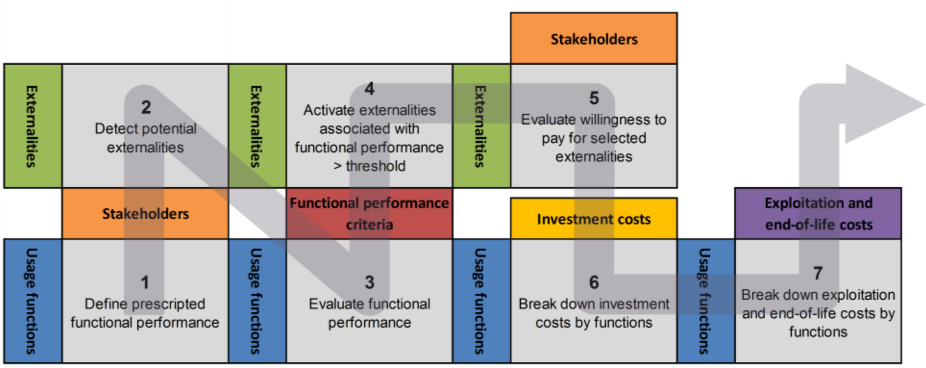


Figure 1. DECADIESE methodology overview

The DECADIESE process is performed following these seven steps. It requires a DECADIESE expert (i.e. a person with good knowledge of building design and trained with the methodology, referred to here as the assessor) able to run the process, the interviews and the different tools:

1. First, the DECADIESE assessor helps the building project owner to specify its project by defining expected functional performance levels. Additional interviews with other stakeholders, like local authorities, insurance companies, etc. complement this stage.

2. Then the assessor detects potential externalities from a list of predefined externalities and interviews with the stakeholders. The idea here is to select relevant externalities associated with the specific building considered in the study (according to its location, its environment…) and that are also interesting for the stakeholders.

3. Then the functional performance of the building option(s) is evaluated. This step is detailed in the section entitled "Functional performance". The output of this step is a score from 0 to 10 on each usage function and for each option that can be compared to the expected performance level defined in step 1.

4. According to these functional scores, some externalities are thus activated: each externality is linked with one or several usage functions. Reaching a predefined threshold on one function may activate one or several externalities that are then studied in more detail.

5. For each activated externality, a willingness to pay is evaluated by interviewing the relevant stakeholders. A concertation process enables to define an extended value vision of the building, where some externalities are assessed with pre-existing or new stakeholders of the project. The business model of the building becomes more accurate.

6. Investment costs associated with this (these) building option(s) are then broken down on the usage functions. This step is detailed in the section entitled "Usage function costs".

7. Exploitation and end-of-life costs are also broken down on usage functions, following the same principles.

At the end of this process, a large amount of useful information is available. The participants have precise knowledge of the functional performance scores of each option considered, as well as the gap (positive or negative) with the targeted scores. The costs of each function are also known, and it is possible to check the consistency of these costs with the associated functional scores. Finally, associated externalities are assessed, and new stakeholders are potentially associated with the project by giving precise information on their benefits and willingness to pay. In this way, all elements are combined to allow an ambitious building project or retrofit with harmonized value creation and costs allocation.

The general process of the methodology is explained in more detail in [Nösperger, 2015]. Functional aspects of this general process are detailed in the next paragraphs.

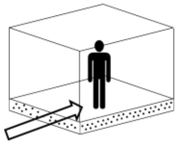
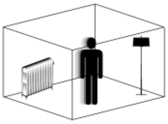
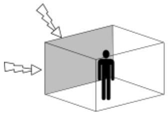
The seven usage functions

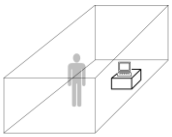
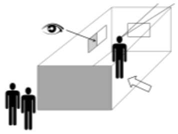
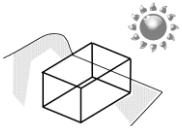
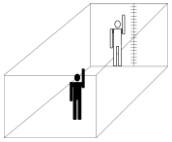
The seven usage functions of a building represent the reference basis of a building project (its performance, its costs, and associated externalities) in DECADIESE. These functions have been identified as an invariant basis on which every building may be represented (whether the performance is good or not). The seven functions are detailed in Table 1 below. They are called "usage" functions as they enable to reveal the value brought to the user. The seven usage functions are used in DECADIESE to centre value creation on usage and users, to share a common language, and to interface the different objects used in the methodology. They are particularly used to position costs and performance in order to compare different building options.

Usage function costs

The breakdown of building costs on usage functions aims at giving the decision-makers a new perception of building costs that complements the classic structural breakdown by systems and components. Figure 2 illustrates this principle, which consists in identifying the contribution (allocation keys) of each system or component to the seven usage functions.

Table 1. The seven usage functions (adapted from [Gobin, 2006])

Functions	Sub-functions	Illustrations
To provide **space**	To have a space in which to conduct wanted activities To allow access to this space from the outside	
To provide **comfort**	To contribute to light and visual comfort To contribute to hygrothermal comfort To contribute to acoustic comfort To contribute to olfactory comfort and in-house air quality …	
To provide **protection**	To preserve the integrity of people and goods To ensure security against vandalism	

To allow the use of **goods and tools**	To create surfaces in which to keep goods and tools To provide resources necessary to supply goods and tools	
To control relationship	To allow the user to come into contact with people or to isolate himself To preserve privacy	
To be part of a **site**	To benefit from the building's location To preserve pre-existing equilibrium	
To have a meaning (**semiotics**)	To express a personal meaning (image) to third parties To cause an emotional load to the user associated with balance and well-being (personal feeling)	

This approach is directly inspired by the notion of function costs proposed in Value Management (VM) and Functional Analysis. The function cost approach is precisely defined in VM standards (see for example [NF EN 12973:2000]). The originality of the DECADIESE approach lies in two main elements:

- Although it is a well-known approach in industry [Ehrlenspiel, 2006], it has never been applied to the construction sector with a perspective of decision-making for more sustainable buildings;
- It is generally applied on specific functions issued from Functional Analysis, whereas here it is applied on the seven invariant usage functions.

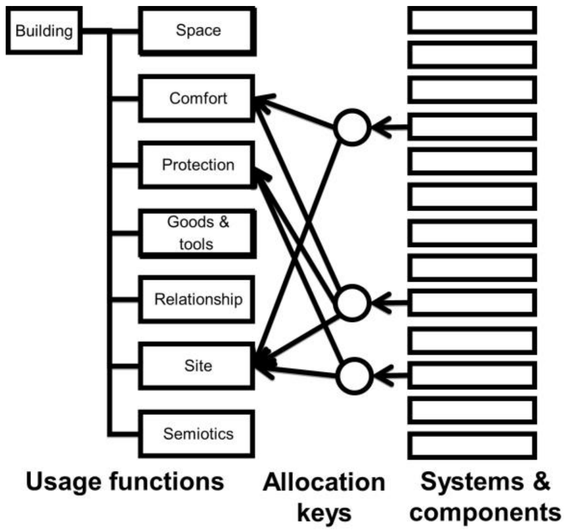


Figure 2. Principle of the usage function costs approach [Gobin, 2012]

In practice, the following process is proposed to apply the approach on a group of multidisciplinary experts from the construction sector. It is based on an Excel tool:

1. **Goal and scope definition:** inspired from Life-Cycle Assessment [ISO 14040:2006], this step aims at defining the objectives of the study, its perimeter, the preliminary hypotheses…

2. **Identification of the contribution of the technical elements to the seven usage functions:** the contribution of each generic system and component of the building is determined by the expert group. For example, a structural pile may contribute at 50% to the "Space" function, and at 50% to the "Protection" function (as it contributes both to creating space and to ensuring the solidity of the building).

3. **Usage function costs calculation:** once the contribution of each element is known, it is then possible to calculate the total cost of each function by multiplying the cost of each element by its contribution to a function.

4. **Interpretation:** interpreting the results may have different purposes, such as ensuring that the cost of each function is in keeping with the requirements of the building project owner. That is why the assessment of the functional performance is another important task in the DECADIESE methodology. It is explained in the next paragraph.

Functional performance

The assessment of the performance of a building proposed in DECADIESE is also based on the seven usage functions. The objective of this part is to propose a rigorous framework for assessing the performance of a building that could be associated with the function cost approach and the externality model.

The proposed model is based on fuzzy logic [Zadeh, 1965]. Fuzzy logic is used here to aggregate several types of functional performance criteria (qualitative and quantitative), based on expert rules with a certain degree of uncertainty.

95 functional performance criteria have been identified to characterize the performance of a building. They are grouped by usage functions and by usage sub-functions (see Table 1). Then, multiple expert rules have been identified to aggregate these criteria and to obtain a performance score for each sub-function between 0 and 10. An example of some criteria is given in Table 2. By giving a value to each criterion as input, the model is able to estimate the most probable score between 0 and 10 as output.

Table 2. Examples of functional performance criteria and expert rules concerning the hygrothermal comfort

Criterion	Type	Levels
PPD (Predicted Percentage of Dissatisfied), see [ISO 7730:2005]	Quantitative	% of PPD in summer % of PPD in winter
Temperature space zoning	Qualitative	Yes/Partially/No
Equipment affordability	Qualitative	Intuitive/Easy to handle/Hard to handle

In practice, the following process is proposed to apply the approach on a group of multidisciplinary experts from the construction sector. It is based on an Excel tool associated with fuzzy logic software:

1. **Goal and scope definition**, similar to the previous section.
2. **Calibration of the fuzzy logic model:** the model is pre-calibrated with expert rules. However, it may be useful, for some specific applications, to control the coherence of the rules, and perhaps to define new ones.
3. **Evaluation of the elementary performance:** the expert group assesses each of the 95 performance criteria for the considered building option(s).
4. **Evaluation of the aggregated performance:** running the fuzzy logic model then allows the identification of the performance score of each functional sub-function. An optional step is to aggregate these scores by function, or even as a single score.
5. **Interpretation:** as in the previous paragraph, interpretation of the results may have different purposes, the most interesting being to control and discuss the relevance of the functional performance according to the

associated function costs. The evaluation of this performance is also the first step for the valuation of externalities, as explained in the section entitled “Methodology overview”.

FIRST RESULTS & DISCUSSION

The DECADIESE methodology has been partially applied to one specific case study provided by the project partner Bouygues Construction.

Skyline is a set of three buildings located in Nantes (west of France), mainly intended for office activities, although the ground floor is designed for shopping activities. Skyline was built in 2011 in an industrial area, near the TGV rail station, in order to create a high standard business district. It has several labels: HQE (standing for High Environmental Quality in French), BBC Effinergie (low consumption building). The global investment cost is 60 million Euros. The interesting point with Skyline as a first case study for DECADIESE is that the entire value chain of the building is controlled by the project partner Bouygues Construction (specifications, design, construction, use (partially), exploitation). Data are thus available. The usage function cost model has been applied to Skyline with a group of five experts involved in the development of the methodology. An overview of the results is given in Figure 3. The feedback of this first application shows the ability of the model to be successfully applied to a real case study. Relevant information was obtained.

The importance of the costs associated with the “Space” and “Comfort” functions is justified (30% and 28%), as providing space is the purpose of a building, and particular efforts were made concerning comfort (highlighted by the labels). The “Relationship” function contribution is small (3%) as it mainly concerns doors, windows and blinds, that have a certain utility but a relatively low cost. The contributions associated with the “Protection”, and “Goods & Tools” functions are in accordance with expectations. The contribution for the “Site” function is negligible, due to the fact that the technical elements contributing to the interfaces of the building with its environment were not mainly taken into account. Finally, the “Semiotics” function contributes to 14% of the total costs, which reveals the luxurious nature of the building.

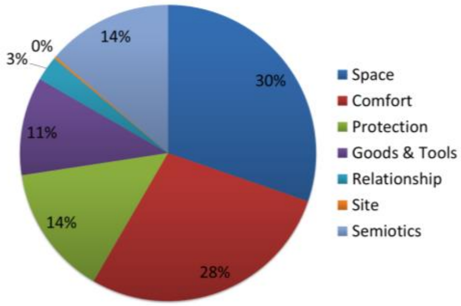


Figure 3. Skyline building and its costs breakdown by usage functions

These first results also show some limitations, for example the variability of the results that could be obtained with one expert group or with another. Further work is needed to develop standardized guidelines. The functional performance model will be applied to Skyline in the forthcoming months.

However, in 2015, the completion of a serious game covering the whole DECADIESE process in a simplified version over one day with experts invited from the construction sector, showed a real interest for this methodology and the relevance of the different parts of the model.

CONCLUSIONS & PERSPECTIVES

The DECADIESE methodology aims at supporting the design of new buildings or the retrofit of existing buildings with a new approach centred on usage and users. Value management and fuzzy logic are used to assess the costs and the functional performance of an option on seven invariant usage functions of a building. Therefore, decision-makers have new information for comparing the benefits and costs associated with this option. This approach is associated with the identification and the valuation of environmental, social and economic externalities, with the objective of enlarging the perimeter of stakeholders contributing to the investment, and thus allowing more ambitious sustainable building projects.

DECADIESE is still being developed. Next steps will deal with the application of the whole methodology to several case studies (already in exploitation, but also in design), to make the process and the tools more usable, reliable and to validate them.

ACKNOWLEDGEMENTS

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Games as measurement tools of the real uses in homes for reducing energy consumption

Audrey ABI AKLE, Emilie CHAPOTOT, Iban LIZARRALDE and Jérémy LEGARDEUR

ESTIA, ESTIA – Recherche, 92 allée Théodore Monod, 64210 Bidart

INTRODUCTION

The requirements for performance and durability for the construction of low-energy buildings complicate the building design process. A key determinant of energy performance is the occupants' behaviour [Zaraket, 2014]. Indeed, occupants use energy to perform various activities of daily life. We can talk about energy use in the private sphere, i.e. the household scope. There is a significant difference between real and theoretical uses of eco-designed products [Chapotot, 2011; Abi Akle, 2013]. Most of the complex processes that occur in buildings are the result of human behaviour in homes. The activities they undertake are stochastic in nature and difficult to predict [Zaraket, 2014]. It is therefore necessary to address the issue of measuring the real energy consumption of the inhabitants in order to identify their behaviour and decrease their environmental impact.

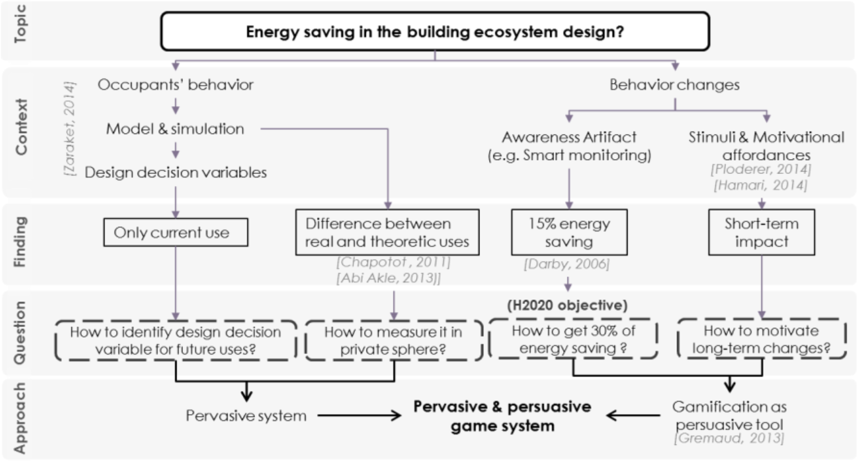

Figure 4: Scope of work and research questions

To do this, we propose using a gamification process through a connected game as a window on the private sphere of inhabitants/users. This study is developed in the framework of a European Union's Horizon 2020 project called GreenPlay. This project is motivated by several issues. First, it meets with Europe's objective, namely a reduction of energy consumption by 30%. But also, the aim is to look through the game in order to measure the real uses of the inhabitants in their private sphere. This line of research has a dual interest, firstly to identify levers to change behaviour and secondly, to be able to identify decision variables for the design of the future building eco-system (building, household appliances and services, etc.). Here, decision variables are considered in a broad sense and refer to user-centred-criteria to be taken into account, e.g. during manipulation of design performance variables. Figure 4 illustrates the scope of our work and the research questions.

ENERGY SAVING IN HOUSEHOLD: AN EXAMPLE

Direct feedback from in-home displays could save up to 15% of electricity [Darby, 2006].

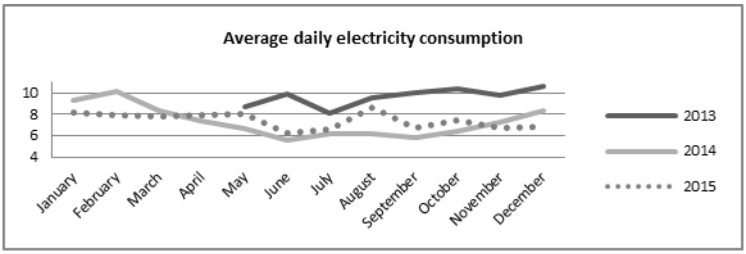

Figure 5: Daily electricity consumption (kWh) of one family involved in the GreenPlay project

First of all, data collected within the Greenplay project goes in this direction (see Figure 2). It includes records from a household user from the platform of the company E-green (with the agreement of the company and user). This data is the electricity consumption of a household consisting of 4 people. Only the overall electricity is measured, i.e. this consumption does not include: heating, water heaters and hotplates which work with gas. Figure 2 shows that the electricity consumption has decreased with the use of a monitoring system. This reduction is independent of the outdoor temperature. This phenomenon might be due to inhabitants' usage/behaviour changes. However, it is not possible to either assert or identify changes operated by this family to reduce their energy consumption. This is why we have oriented our work towards the pervasive games.

GAMES FOR ENERGY CONSERVATION

Pervasive games often refer to games that extend beyond the traditional interface into the real world [Nieuwdorp, 2007]. Nine projects working on pervasive and persuasive gaming for energy conservation have been identified [Gremaud, 2013] (see table 1). All of these games use the principle of “reward” but they differ a lot considering certain criteria: advice generator, quizzes for environmental awareness, the use of cooperation and/or competition and video games. All projects are considered as games but few of them include video or computer games. The GreenPlay project encompasses all the criteria presented in table 1.

Name	References	Criteria of comparison				
		Advice	Quizzes	Cooperation	Competition	Video game
Professor Tanda	[Chamberlain, 2007]	Yes				
Eco Island	[Shiraishi, 2009]			Yes	Yes	Yes
Power Agent	[Gustafsson, 2009a]	Yes		Yes	Yes	Yes
Power Explorer	[Gustafsson, 2009b]				Yes	Yes
Energy Life	[Björkskog, 2010]	Yes	Yes	Yes	Yes	
Gaea	[Centieiro, 2011]	Yes	Yes		Yes	
LEY!	[Madeira, 2012]		Yes		Yes	
Energy Battle	[Geelen, 2012]	Yes		Yes	Yes	Yes
Climate Race	[Simon, 2012]			Yes		
GreenPlay		Yes	Yes	Yes	Yes	Yes

Table 1: Comparison of different games for energy conservation

These criteria represent stimuli as “motivational affordances” [Hamari, 2014] or the 5 key approaches from social interaction and reflection (social traces, social support, collective use, reflection-in-action and reflection-on-action) [Ploderer, 2014].

THE GREENPLAY PROPOSAL

The Greenplay proposal is based on a system perceived as a game by the user (because of using elements of game design). It enables to monitor real behaviour and possible long-term changes in the context of energy saving. The system is composed of sensors, a smart monitoring platform and the game as illustrated in Figure 6. The sensors installed at the user's home measure global electricity, heating, water heating and temperature. The sensors are linked to the GreenPlay system. This is a pervasive game, i.e. eco-gestures in real life and thus electricity consumption reduction enable to earn points and evolve in the game.

The game part enables to send stimuli focused on specific activities such as laundry, cooking or watching TV. In parallel, it measures, with the sensors, any differences in the consumption data (reduction or increase). To monitor the behaviour and changes, stimuli are organized by activities and will be sent in distinct phases. Quizzes will also be sent at different times to collect feedback and find out about the participants' (new) habits. A decision tree including the stimuli, the questions and the conditions of their dispatches is designed.

The reliability of this model will be validated through a large-scale experiment based on 200 households located in France and Spain during one year.

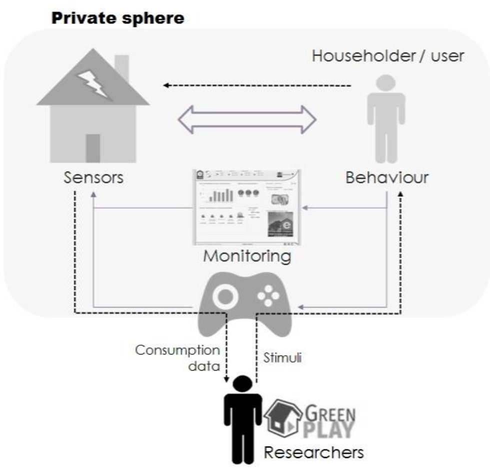

Figure 6: Illustration of the Greenplay proposal

CONCLUSION AND PERSPECTIVES

The gamification as "the use of game principles" aims to increase user involvement. Gamification is often considered as a behaviourist approach limited to adding competition between users with scoring & rewarding systems. [Nickolson, 2012] highlighted that useful gamification focuses on introducing elements of play instead of elements of scoring. The potential of combining game elements and instructive advice for reducing energy consumption into serious games, offers some possibilities for encouraging the immersion in context, the empowerment and the learning appetence of users. Through this approach, the system identifies the use of energy and users' behaviour in the private sphere.

This additional information enables to meet with two main objectives. Firstly, the reduction of household energy consumption by 30%. Secondly, the use of this information as decision variables for product design processes (building, home appliances, etc.), as well as an input for the development of innovative business models for the products and services associated with the building eco-system.

ACKNOWLEDGEMENTS

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Roundtable 2

Capturing usage for eco-design activities

A user-centred eco-design approach to support the design of upgradable products

Emmanuelle Cor; Peggy Zwolinski

Univ. Grenoble Alpes, G-SCOP, Grenoble,

France 46 avenue Félix Viallet, 38031 GRENOBLE CEDEX 1, FRANCE

INTRODUCTION

Mass production and mass consumption models have empowered populations to have access to better standards of living in industrialized countries since the beginning of the 20th century. For companies, mass production presents several advantages such as fewer labour costs, faster rate of production and an increase in capital while the total expenditure per unit of product decreases [Umeda, 2008]. However, this production model can generate a detrimental effect on the environment. The consumers' constant demand for new technologies and new services – especially in electronic sectors such as IT equipment, household appliances, cell phones, etc. - leads companies to design products with shorter life cycles, resulting in new production and disposal of obsolete products. This generates, among other environmental issues, an increase of raw material and energy consumption as well as an increase of waste production [Tukker, 2008].

To address this issue and to meet the growing demand from consumers to new consumption modes that are more in line with sustainable development, companies and researchers are innovating by developing and putting upgradable products on the market. The environmental interests of upgradability are significant: this strategy allows an extension of the product’s lifespan through an evolution of its functionalities according to user needs and expectations over time [Agrawal, 2012]. This could solve the issue of accelerated obsolescence and environmental issues linked to early disposal of products. However, to switch from a conventional products production model to an upgradable products production model, companies have to change the way in which they design products. Design for upgradability (DfUp) strategies have therefore emerged to support designers in this process.

This paper presents the interest of using a user-centred design (UCD) approach to design products for upgradability. Using this approach, designers would be able to redesign a conventional product into an upgradable product. The proposed approach emphasizes the interest of using failure mode, effects and criticality analysis

(FMECA) methodology combined with product-in-use observations to support designers in upgrade planning, life-cycle modelling and environmental evaluation of upgradable products. In the next section of this paper, the main challenges related to design for upgradability identified in literature are presented. A third section presents our eco-design approach which is based on the analysis of these challenges and aims to support designers in the design of upgradable products. The main perspectives of this work and future developments are then presented in the conclusion section of this paper.

CURRENT CHALLENGES RELATED TO DESIGN FOR UPGRADABILITY

Upgradability can be defined as the manipulation of a functional configuration of a product, after the product is sold, in order to adapt the product to changes in customer needs. Upgradability can include adding, removing, replacing functions and increasing or decreasing some performances of particular functions depending on upgrade types implemented on the product throughout its life cycle [Umeda, 2005; Pialot, 2014]. The main objective for companies in designing products for upgradability is to improve products' physical and value life time (PLT and PVT) and avoid the discarding of products due to a breakdown of a function or to a non-adaptation in changes in user needs [Umeda, 2007]. Therefore, design for upgradability can be considered as an eco-design approach because it promotes the lowering of material usage and an extension of the lifetime of the product which can reduce the environmental impacts throughout the life cycle of products [Charter, 2008].

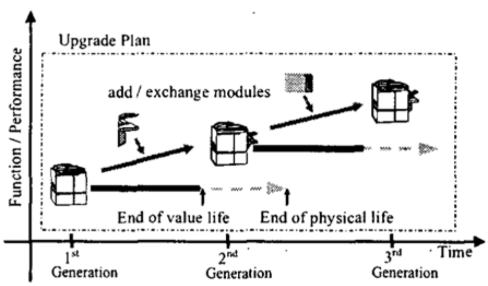

Figure 1: The concept of upgradability according to [Umeda, 2007]

Today, most current research regarding design for upgradability focuses on technical aspects and feasibility of product upgradability such as design products for modularity, reusability, and ability to be dismantled [Xing, 2006; Umeda, 2008]. However, little research focuses on developing methodologies to support designers in upgrade planning throughout the life cycle of upgradable products [Whahab, 2016; Inoue, 2014]. According to [Umeda, 2001], an upgrade plan can be defined as a set of required functions implemented on an upgradable product in each future generation. [Pialot, 2014] define an upgrade plan (or upgrade line) as a planning of upgrade integration with the aim of satisfying value creation on the product. The upgrade plan usually includes information on the rate of upgrade integration along the life cycle of the product and on the typology of potential upgrades. To set up a relevant upgrade plan for an upgradable product, designers have to consider several factors such as trends of user needs and preferences among several generations of products [Umemori, 2001]. One of the major challenges in the development of eco-design methodologies for upgradable products is knowing how to provide designers with some elements related to future user needs which will allow them to plan the upgrades at early stages of the design process, more easily.

Another main challenge related to DfUp involves the environmental performance evaluation of upgradable products. [Pialot, 2014] developed an eco-innovative approach (IDCyclUM methodology), based on five dimensions (technological, functional/usage, economic, environmental and organizational dimensions) to efficiently design products for upgradability. This approach places an emphasis on the difficulty for designers in ensuring the environmental performance of upgradable products throughout their life cycles. Indeed, current methods and tools used for the environmental evaluation of products are not adapted for the evaluation of upgradable products which have complex life cycles. For example, Life Cycle Analysis (LCA) methodology and tools could be used for this evaluation but to be efficiently used, it is necessary to support designers in the development of relevant life-cycle scenarios for upgradable products [ISO, 2006]. The constant evolution of upgradable products during their use phase, due to changes in user needs and behaviour related to upgrades, makes this work difficult.

Finally, [Wahab, 2016] identified that literature lacks comprehensive details on the incorporation of DfUp principles into design processes. It is understood that the improvement of product upgradability should start at the early stages of product development before any detailed design and production plans are established [Xing, 2008]. In the case of an ideal upgradable system, each upgrade cycle would be designed to allow the product to be improved in accordance with changing user needs. To anticipate these product evolutions in line with future users' expectations while maintaining environmental performance of the upgradable product, it is necessary to develop specific integrated design approaches.

To summarize, the three main challenges identified related to the design of products for upgradability are:

- To ensure the environmental performance of upgradable products compared to conventional products throughout the design process;
- To anticipate upgrade planning through the integration of user needs and expectations into design processes;
- To ensure efficient integration of DfUp principles into design processes.

It can be seen here that a structural change is needed in current design approaches to design products for upgradability. There is currently no existing eco-design methodology for upgradable products that is able to tackle these three challenges. In the next section of this paper, we will see how a user-centred design (UCD) approach supported by a FMECA methodology and product-in-use observations could help designers to address these challenges in the design process of upgradable products.

A new approach: integrate user-centred design concepts to design products for upgradability

User-centred design (UCD) is a standardized design approach where the end-user's needs, wants and limitations are the focus at all stages of the design process and development of the product's lifecycle. Products developed using this methodology are optimized for end-users and emphasis is placed on how the end-users need or want to use a product [ISO, 1999]. UCD methodologies have been widely used for the design of interactive systems such as software and are starting to be progressively implemented in the design process of mechanical products. The UCD methodology is built on four main steps which are the following:

1. Understand and specify the context of use (Identify who will use the product, for which purpose and in what conditions the product is used)
2. Specify user and organizational requirements (Identify any company or user requirements that must be met in order for the product to be successful)
3. Create design solutions according to requirements
4. Evaluate design solutions against requirements (cf. Figure 3)

We propose in our approach to use the UCD methodology to have a better understanding and to specify the context of use of upgradable products, and therefore to help designers to propose upgradable solutions in accordance with users' requirements and specifications. In the approach presented, UCD methodology is used for the definition of a global life-cycle scenario for the upgradable product, which will support upgrade planning and environmental evaluation of the design solutions chosen.

For the first step of the approach, we propose to use a failure mode, effects and criticality analysis (FMECA) for the specification of the context of use. FMECA is an analysis method by which each potential failure mode in a system (product, function or process) is analysed to determine its effects and where each potential failure mode is classified according to its criticality. This analysis has to be performed early in the design process in order to be efficient. In our case, the FMECA methodology would be used:

- To identify potential failures that can shorten the "physical life-time" of the upgradable product in order to propose relevant upgrades to ensure its maintenance and extend the physical life-time of the product;
- To identify potential failures that can shorten the "value life-time" of the

upgradable product in order to propose relevant upgrades to ensure that the product's functions are in accordance with the evolution of user needs;

- To identify potential failures in the environmental performance of the product during its use phase and throughout its life cycle in order to propose relevant upgrades that ensure product efficiency in terms of environmental performance, throughout its life cycle.

With the identification of the level of criticality for each failure mode, designers would be able to select the main relevant upgrades to implement on the product in order to improve its physical and value life time as well as its environmental performance throughout its life cycle. Therefore, a relevant upgrade planning based on potential failure scenarios could be defined. Moreover, FMECA results can be used to support the production of design solutions for the upgradable product (cf. Figure 2).

Then, we propose a product-in-use observations phase in our approach to specify user and organizational requirements for the manufacturer (step 2 of the UCD methodology). Product-in-use observations are an interactive, observational method designed to capture people's behaviour in real-life contexts and to provide an account of the behaviour surrounding a product or activity [Evans, 2002]. Therefore, we have developed an experimental protocol that helps designers to analyze individual behaviour of users in relation to future potential upgrades to be implemented on the product. In this protocol, the users' profiles of upgradable products are identified and volunteers test prototypes of upgrades in an “as-at-home” environment. This experimental protocol has several objectives and has already been tested for the development of upgrades on an espresso coffee maker [Cor, 2015]:

- It aims to understand how future users will behave when faced with a new feature/upgrade implemented on a product

- It allows designers to capture environmental data related to the use phase of the upgradable product and evaluate the potential gains or losses in environmental performances in use of the product

- It gives access to users' feedback regarding upgrades on prototypes (e.g. level of acceptability of the upgrades, usefulness, etc.)

The combination of FMECA and product-in-use observations in steps 1 and 2 of the UCD methodology will give enough data to designers on product life cycle. This data is then used to develop relevant life-cycle scenarios for the upgradable product, facilitating step 3 of the UCD methodology which aims to create design solutions according to requirements. The upgrade plan can be defined more precisely due to the integration of users' requirements (e.g. type of upgrades, number of cycles, cycle times). Moreover, a life-cycle analysis could be performed to compare the environmental relevance of different upgradability solutions (step 4 of the UCD methodology). Figure 3 summarizes how the FMECA method and user observations are integrated within the different steps of the UCD methodology according to ISO 13407.

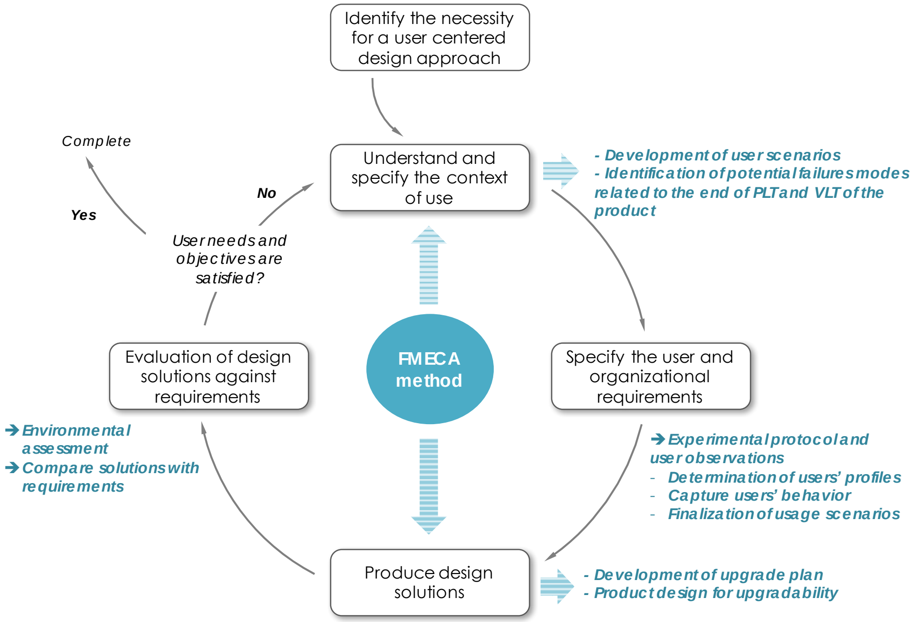

Figure 2: The proposed DfUp approach based on user-centred design methodology [ISO, 1999]

CONCLUSION

Whereas in design processes for conventional products, designers traditionally just design products, we have seen that for more complex products such as upgradable products, it is necessary to design product life cycles at the same time as the technical product design. The DfUp approach based on user-centred design concepts presented in this paper could support this activity through the integration of users' needs, behaviours and other usage parameters into the design process of upgradable products. By taking these parameters into consideration in a design methodology for upgradable products, designers would be able to develop life-cycle scenarios for these kinds of products, and especially for their use phase which is one of the most difficult phases to model in current design for upgradability (DfUp) methodologies. Furthermore, the life-cycle scenarios of upgradable products developed with the integration of FMECA and product-in-use observations concepts could support designers in the environmental evaluation of upgradable products compared to conventional products. In addition to supporting designers in the definition of upgrade plans, the integration of user-centred design concepts in upgradable product design will also support life-cycle analysis (LCA) through the definition of important environmental parameters and hypotheses to consider for modelling the use phase of these products.

The next step of this work will focus on the development of the dedicated FMECA approach for the identification of the different failure modes for upgradable products. A specific tool developed in Excel format will be developed to support this work. Once the FMECA approach has been finalized, the global approach will be tested to evaluate its efficiency in the design for upgradability.

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Exploring users' practices through the use phase of a television to minimize the environmental impact

Claudia Déméné, Ph.D.

Université Laval, École de design, Faculté d'aménagement, d'architecture, d'art et de design, édifice La Fabrique, 295, boulevard Charest-Est, Québec (Québec) G1K 3G8 Canada

INTRODUCTION

Electronic waste[10] (also known as e-waste) generates one of the most dangerous categories of waste both for the environment and for human health, since e-waste contains heavy metals and complex alloys [Tanskanen, 2013]. In response to the growing problem of e-waste, the European Union decided in 2003 to implement the Extended Producers' Responsibility (EPR), through the Waste Electrical and Electronic Equipment (WEEE) Directive [JO UE 2012]. The EPR requires that producers and importers in the European Union countries reuse and recycle e-waste through environmentally-sound methods. In addition to the WEEE directive, the European Commission also passed the Energy-related Products Directive (ErP) in 2005, which aims to improve the environmental performance of products throughout their entire life cycle [Cellura, 2014]; [JO UE, 2009]. Since its implementation, the ErP Directive has mainly focused on the energy efficiency of electronic devices considering the fact that the use phase has caused several adverse environmental impacts [Hischier, 2010; Andrae, 2010]. In this perspective, one of the first ErP measures was to cut down standby power requirements to one watt or less for most electronic devices [Dalhammar, 2014]. This horizontal policy represents a genuine breakthrough, because it covers a broader cross-section of devices rather than individual ones [IEA, 2009].

[10] E-waste is defined as a type of waste, consisting of any broken or unwanted electrical or electronic devices.

While the EPR approach for electronic products has become an established principle of environmental policy in Canada, the ErP directive has not been implemented in Canada in the same way as in the European Union. The Energy Efficiency Regulations focus on approximately 50 energy-using products, which must meet federal energy efficiency standards in order to be imported into Canada, or shipped from one Canadian province to another [NRC, 2015]. Although the Regulations and ErP Directive have been efficient at improving the energy efficiency for certain pieces of electronic equipment, the European approach has tried to take a more holistic approach by increasing the overall environmental performance of the product throughout its entire life cycle [JO UE, 2005].

The European and Canadian legal frameworks, described above, focus mainly on the adverse environmental effects related to the production and end-of-life sides, and not as much on the use phase, with the exception of the ErP Directive, which only focuses on the energy consumption during the use phase [Crosbie, 2008]. Although the legal framework has led to several improvements in product performance, the environmental impact of the use phase has continued to increase due to the over-consumption of products and services leading to the acceleration of the electronic devices' purchase and replacement cycle [Cooper, 2013; Libaert, 2015]. In addition, population growth, especially in developing countries which adopt similar consumption patterns to developed nations, has increased the environmental effects of the electronic equipment. Limited research has attempted to explore users' practices framing the environmental impact of electronic appliances during the purchase, use and disposal of an electronic device (also referred to as the use phase).

Many disciplines, such as marketing, psychology, anthropology, design and sociology have taken an interest in studying consumer behaviour with regard to the use phase. However, most of this current research has generally focused on a single sub-step of the use phase at a time [Van Nes, 2010; Bhamra, 2011; Crosbie, 2008; McDonald, 2009; Pettersen, 2015]. Considering the gap in the literature, the aim of this study is to undertake an exploratory study in order to provide a systemic view of the environmental impact of the television use phase. The understanding of the factors driving the purchase, use and disposal behaviours for electronic products could help to strengthen existing policies and minimize the adverse environmental effects associated with the use phase.

The environmental impact of an electronic device depends on its design, including the type of technology used, and the way in which consumers use it (frequency, intensity of use, for instance) [IEA, 2009]. From the wide diversity of electronic goods, this research has chosen to focus on the television (TV). This device is one of the most popular pieces of electrical and electronic equipment in our society [Hischier, 2010]. As emphasised by several life-cycle assessments, the most significant environmental effects for TVs occur during the use phase [Aoe, 2003; Feng, 2009; Andrae, 2010]. In addition, television aptly illustrates many issues related to the use phase of electronic devices, including the rapid succession of technological innovation, changing trends and product price drop, as key factors of obsolescence [Déméné, 2014]. Moreover, the switch to digital signals and the introduction of High Definition (HD) have accelerated premature end-of-life, and have therefore increased flat-screen TV purchases [Røpke, 2012]. In this context, the TV case in households can be seen as highly relevant in identifying environmental impacts related to the consumption of electronic products.

METHODOLOGY

This research uses a case study format that is one of the five qualitative approaches to inquiry according to [Creswell, 2007]. The exploratory and descriptive nature of a case study provides a deep understanding of how televisions are actually purchased, used and disposed of by users. Two series of interviews were conducted in French among 21 households in Montreal for respectively scoping and targeting the users' practices, framing the environmental impact of the television use phase.

The first set of interviews was an exploratory stage, aiming at clearing the field in order to identify relevant research issues leading to a decrease in the environmental impact of televisions during the use phase. Snowball sampling was used to recruit two women and eight men[11]. The sample was non-probabilistic and the respondents were selected according to their experiences[12] during the television's purchase, use and disposal phases. Face-to-face discussions ranging from one hour to an hour and thirty minutes were conducted. Each conversation was audio recorded, and took place at a location selected by the participant. Given the vast amount of data collected, an analysis based on repeated listening of the discussions was the most effective way to sift through the recorded information while discarding irrelevant data.

The objective of the second series of interviews was to provide a deeper understanding of the research avenues observed in the first set. In this way, new respondents owning one or more flat-screen TVs were recruited. Another snowball sampling was used to select eleven new participants, eight men and three women[13]. At this stage, the questionnaire was more specific and structured around the research avenues in order to find elements of responses. The interviews, ranging from one hour to an hour and thirty minutes, were conducted at the respondents' homes when

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[11] Among the eleven respondents interviewed during the first phase, six lived with their spouse or partner and five were the only members of their household. All single participants lived in an urban area. Of the six participants living as a couple with children, two lived in the suburbs and four in an urban zone. Among the single interviewees, four lived alone and one shared a flat.

[12] Different participants were chosen including recent television buyers (purchase phase), persons having many televisions in the household (use phase) and others willing to dispose of their television (dispose of phase).

[13] Among the eleven respondents interviewed, six lived with their partner and children, and five were the only members of their household, with no children. Among the six respondents in couples, three resided in an urban area, and the other three in the suburbs. Of the single participants, four lived alone and one shared a flat. They all lived in an urban area.

agreed to. The data saturation was rapidly archived, since the second sample was a homogeneous group of participants and certain research axes had already been explored through the first set of interviews. For the data analysis, the gathering material was transcribed in full and then coded using a qualitative data analysis software to perform a thematic analysis [Creswell, 2003; Savoir-Zajc, 2009].

FINDINGS AND DISCUSSION

Although this exploratory research aims to offer an in-depth understanding of users' behaviour through the use phase, all of these findings need to be addressed from the perspective of a larger number of participants in further research. Considering the exploratory nature of this study, the influence of the variables (gender, age, marital status, social conditions, and geographic classification) cannot be analysed (thoroughly) in the participants' responses. Accordingly, any aspects of the sample diversity are not relevant to the findings, and are presented only to better contextualize the participants' world.

Factors leading to the proliferation of electronic products in households

Proliferation of electronic and non-electronic goods

After the TV acquisition, most respondents (nine out of 11 people) replaced their functional peripheral equipment[14], such as Digital Versatile Disc (DVD) players, with new ones, in order to take full advantage of their new TV display technology: "*After the TV purchase, I bought new peripheral appliances because I wanted to take full advantage of my new TV. I bought a Blu-ray player and a digital video recorder. I had a DVD player. It was still working and I keep it in storage! […] I also bought an additional sound system*" [Male respondent living with his wife]. In addition to the acquisition of peripheral electronic equipment, more than half of the participants (six out of 11 people) purchased other goods, such as furniture and decorative items, after a TV purchase: "*The aesthetic quality of our interior space has been greatly enhanced following the purchase of the new TV. [….]. After the TV acquisition, we decided to redesign the TV corner. We bought a stand and a new sofa. We have also changed the colours by buying a new carpet and cushions for the sofa*" [Female respondent living with her husband and two children].

In the literature, such a phenomenon of multiple purchases is well known as the Diderot effect, in honour of its first observer, the French philosopher Denis Diderot [McCracken, 2001; Park, 2005]. These purchases are typically intended to harmonize the setting and all of the equipment, both aesthetically and

[14] All of the electronic devices hooked up or used in conjunction with the television, bringing new functionalities and/or enhancing the existing ones, are defined as peripheral equipment.

technologically. The Diderot effect has already been associated with several consumer goods, such as cars, clothing, furnishings and cosmetics [Mc Cracken, 2001; Shove and Warde, 2002], but never with electronic devices. Beyond television, the Diderot effect can be observed across many other electronic goods. For instance, the smartphones can be hooked up to accessories, such as a Bluetooth headset, a car charger or a dock station. With the constant technological innovations, consumer purchases induce the desire for other purchases, which in turn induce further desires, and so on [Alexander, 2012]. Through the TV digitalization, electronic goods, such as display devices[15] and TV peripheral equipment, are complements and are usually used together leading to a growing consumption of goods. In sum, technological innovations have created a favourable environment for the purchase of electronic and non-electronic goods and the implementation of the Diderot effect.

TV transformation into a multi-tasking device

Through technological innovations, users have progressively changed their TV-use practices: "*I plug my computer into the TV. I put a CD in my Blu-ray player and I listen to the music through the television speakers. If I have a party, I plug my "playlist" into the TV and let the music run*" [Male respondent living with his wife]. The interviews reveal that almost half of the participants (five out of 11 people) use their television for activities that were formerly handled by desktop computers and laptops. The same pattern applies to computers, laptops, smartphones and tablets, which are used by seven out of 11 people to watch TV content.

Following the TV transformation into a multi-tasking device, the number of electronic goods in homes would have been expected to decrease, leading to a significant environmental benefit. However, the results reveal that the more multi-tasking devices available, the more users tend to buy different ones and the more energy consumption occurs: "*I download TV shows on my laptop, then I watch them on my TV screen. The thing I do the least with my TV is watch TV! I have connected my laptop and my TV to the same network*" [Male respondent living with a roommate].

The consumer behaviour that shapes growth in energy consumption

Towards a horizontal policy for display devices

As highlighted above, the respective roles of the television and all display devices have become increasingly conflated during the use phase. In this convergence context, political authorities should move towards a horizontal policy. The

[15] The display devices regroup several electronic products, such as desktop computers, laptops, smartphones and tablets.

horizontal measures define targets covering several product groups [Dalhammar, 2014; IEA, 2009]. This approach could provide the advantage of lightening the existing regulatory procedures, such as energy efficiency policies, by avoiding legislating for each type of product. As mentioned in the introduction, this horizontal policy has successfully been implemented for standby power for most electronic devices. Beyond the standby mode, there are other opportunities for the electronic products to establish interesting horizontal implementing measures. In the case of energy efficiency policies, the main challenge remains on the classification of display devices in order to allow the implementation of the horizontal policy. Common features shared with other display devices could be defined, such as content nature, screen size and portability. In spite of certain difficulties, implementing horizontal measures may become relevant in the future.

Directions to support television's energy performance

Several studies have already emphasized an increase in television size among households [IEA, 2009; Crosbie, 2008]. The size of the average television screen in Switzerland, which is the only available indicator of longer term EU trends, doubled between 2000 and 2008, equivalent to a 60% higher on-mode power consumption [IEA 4E, 2010]. A similar pattern in European and North American countries is highly expected. An increase by 4% of the growth in screen size would add roughly 7% to energy consumption for the same usage and efficiency [IEA 4E, 2010]. Furthermore, the findings of this research point out that consumers are not worried about the TV energy consumption: "*This [the energy consumption of TV] was a detail and not what led to my purchase! It would be several variables, such as the size and the price of the TV*" [Male respondent living with his girlfriend].

In the European Union member countries, specific policies for large televisions are non-existent, except for regulation No.642/2009, called ErP Directive (presented in the introduction), which defines standards related to the size of a television; consequently a TV twice as big will still consume twice as much energy. In Canada, only television-off and standby modes have been subject to Energy Efficiency Regulations (presented in the introduction). Current policies rely on standards related to size, but to be effective with regard to large televisions, absolute standards should be adopted. Current regulations will not prevent increases in energy consumption, as long as the legislative gap regarding larger televisions remains. Considering the fact that consumers tend to purchase larger TVs and do not pay attention to the TV energy consumption, political authorities should focus on the increasingly popular televisions, 40 inches and up, in order to strengthen existing energy efficiency policies.

Directions to support the energy performance of complex set-top boxes[16] (CSTB)

The acquisition of larger TVs and the proliferation of peripheral equipment in homes make energy savings difficult. The interviews revealed that nine respondents out of 11 paid no attention to the energy consumption of CSTBs: "*For the CSTB, my TV provider only offers one model I suppose [...]. I have to admit that I did not really examine if there are other models. This device [CSTB] probably consumes a lot of energy, since it is functioning 24/7*" [Male respondent living with his girlfriend]. The International Energy Agency (IEA) estimates that the global consumption of electricity by complex set-top boxes may rise from 34 TWh in 2007 to 415 TWh by 2030 [IEA, 2009].

In the European Union, standards have already been set for standby mode power for simple STBs through the ErP Directive [European Economic and Social Committee, 2014]. Instead of a mandatory measure for complex STBs (CSTBs), the European Union has reached voluntary agreements and a voluntary Code of Conduct with manufacturer groups in order to improve energy efficiency [IEA's 4E, 2014; European Economic and Social Committee, 2014]. In Canada, the Energy Efficiency Regulations (see introduction) do not take into account STBs[17] and CSTBs. Only premium efficiency CSTBs are differentiated in Canada through Energy Star certification [IEA's 4E, 2014]. Beyond these voluntary measures, there is a need to legislate for the CSTBs in order to encourage producers to adopt a high standard of energy efficiency in Western countries, which are significant consumers of CSTBs.

Consumer disposal behaviour regarding electronic equipment

Which alternative for obsolete and functional electronic products?

The findings reveal that more than half of the respondents (six out of 11) store their functional electronic goods, even if they have already purchased a new product fulfilling the same function: "*I have a CRT television and a DVD player. They are both still working. I was willing to donate my CRT television, but nobody wants this obsolete technology. For now, it is in the closet*" [Male respondent living with his

[16] A Complex Set-Top Box (CSTB) is a standalone device equipped to allow conditional access that is capable of receiving, decoding and processing data from digital broadcasting streams and related services and providing output audio and video signals. A CSTB incorporates a great deal of functionalities not present in Simple STBs, including (but not limited to) the ability to schedule recordings, the ability to record remotely, the ability to push VOD content to customers, the ability to maintain up-to-date complex viewing (conditional access) criteria and an ability to maintain large schedule tables, distribute content to other devices within the home, provide high-speed internet access [European Economic and Social Committee, 2014].

[17] The set-top boxes (STBs) converting an incoming TV broadcast signal to one that can be seen on a screen, continuously consume energy in both power-on and standby mode, since they are designed to receive information 24/7 [European Economic and Social Committee, 2014].

wife]. While recycling is a preferable option for broken electronic products, what could be done with functional, but unused electronic devices? Some research proposed to resell functional and obsolete products from Western nations, such as desktop computers, laptops and televisions, to the reuse market in developing countries including Mexico and the Philippines [Kahhat, 2012; Kahhat, 2009; Yoshida, 2010]. These exports to emerging nations could be an alternative to extend the lifespan of electronic products, but should be framed by regulations to prevent the shipping of e-waste. Few regulations have focused on the positive environmental and socio-economic impacts, such as the reuse of personal computers or mobile phones or economic aspects and the employment generation related to the refurbishment and trade of used electronics around the world [Kahhat, 2012]. Given this context, more studies are needed to evaluate the environmental, economic and social impact associated with the export of functional and obsolete electronic devices from developed to emerging nations.

From physical media to the absence of physical media

As emphasised by the participants, the question remains on what may be done with their unused but functional media players and physical media: "*I don't think we're going to throw it out [video-cassette recorder]; it still works well! […] We have a big box with several VHS cassettes and we keep them in case we want to watch a movie […]. Honestly, we do not know what we can do with our functional unused products. They are stored in a corner of our home. I know for the computers, I can bring them to Bureau en Gros, which has a reuse program*" [Female respondent living with her husband and two children]. While media players like DVD players and video-cassette recorders are managed by the ERP, physical media such as VHS cassettes are not considered as e-waste. Therefore, these media are excluded from the European and Canadian legislative frameworks. So far, no policy deals with physical media end-of-life, which represents a recycling challenge (especially the VHS cassettes), given the diversity of materials they are made from and the necessary human resources to recycle physical media. Considering the rising popularity of non-physical media, like video-on-demand, there is a need to develop a more sustainable way to manage the end-of-life of VHS cassettes, DVDs and Blu-Rays, which have already ended up in landfills.

CONCLUSION

The findings of this study reveal that, after the TV acquisition, participants have purchased new peripheral equipment and/or have redesigned their interior space. In fact, technological advances of the TVs have encouraged the Diderot effect, leading to the consumption of both electronic and non-electronic goods. Following the TV transformation into a multi-tasking device, users' practices have changed. While participants use their television for activities that were formerly handled by desktop computers and laptops, other respondents use their computers, laptops, smartphones and tablets to watch TV content. The findings also emphasized the growing number of unused televisions, media players (video-cassette recorders, DVD players) and physical media (DVDs, video-tapes) stored in homes, and point out the need to find a sustainable alternative that could optimize the reuse of obsolete devices that no-one in developed countries wants any more.

In response to these environmental issues, the paper suggests directions for supporting reflections and actions, among political authorities, to reduce the environmental damage related to the use phase, such as horizontal policies for display devices, the establishment of energy consumption standards for large TVs and CSTBs and the possibility of exporting functional and obsolete electronic devices from developed to emerging nations to support the reuse.

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Development of usage models for the eco-design of products: the concept of usage eco-drift

Alexandre Popoff

University of Toulon, 83957 LA GARDE – FRANCE

INTRODUCTION

The use phase of products is the source of a great accumulation of environmental impacts on a global level [Ardente, 2014]. As shown by [Tang, 2008], people often find their own ways of using products, and risk deteriorating their environmental performance. These practices are called non-optimal usages if they generate unnecessary electrical over-consumption [Lilley, 2009; Tukker, 2006] and/or abnormal wear and tear of products (meaning the service life of the product will be shorter than normal) [Barré, 2013]. In this study, we call these usages, which deviate from the best available environmental practices, "Usage Eco-Drifts" (UEDs). UEDs do not yet have a common shared definition among the scientific community. Given their importance on the environmental performance of products' use phase, it appears necessary to clarify this concept. The UED concept has already been studied in the scientific community under other names. Studies have mainly focused on eco-driving and household sustainable practices regarding water and heating/cooling [Guerra-Santin, 2011; Gulbinas, 2014; Jain, 2012, 2013; Jamson, 2015]. The aim of this study is to demonstrate that the UEDs can be modelled to be taken into account during the design stage of products. There, they can be dealt with to improve the environmental performance of the use phase of the product. To evaluate the pertinence of the UED concept, we used the case of a wireless vacuum cleaner. We studied its usage by observing a panel of users and conducted several environmental evaluations of the product itself and of different usage scenarios.

In section 2, the UED problem is developed, section 3 details the research method, section 4 gathers the results obtained during the field and laboratory experimentations. Finally, the results are discussed and future research problems are suggested.

THE BEHAVIOUR-CENTRED DESIGN CHALLENGE

Taking users' behaviours into account during the design process is not easily done. For a given product, the diversity of users induces a diversity of usages and thus, a diversity of UEDs. This diversity is due to several factors such as need, culture, consent, etc. [Pierce, 2014].

The UED concept

Our definition of the UED concept is based on previous research conducted by [Serna, 2014]. Here, the UED concept takes into account both "real-time environmental impacts" (REI) (due to over-consumption) and "delayed environmental impacts" (DEI) (due to abnormal wear and tear) [Barré, 2013]. The following definition is proposed: "For the usage of a product with a given functional unit, a UED is defined as a usage practice which, in comparison to a reference usage, causes: (i) an increase in energy consumption and/or (ii) an increase in materials consumption and/or (iii) abnormal wear and tear of the product (and so the need to replace it earlier), thus generating additional environmental impacts".

This definition underlines the fact that diverse behaviours can be associated with the diversity of users [Guerra-Santin, 2009]. Hence, instead of considering only the "average user" as seen by the product designer [Guerra-Santin, 2011], the concept requires studying a wider panel of usages.

Considering users and usages

A first step of the problem concerns the way people learn how to use products. As products become increasingly complex and user guides increasingly complicated, it is not given that users will instinctively adopt a sustainable behaviour. Later on, the usage pattern may evolve throughout the service life of the product. Social and design scientists such as [Pierce, 2014; Bedford, 2011; Perrin, 2001] or [Tonglet, 2004] have identified four obstacles likely to lead to UEDs: habits, beliefs, comfort and time.

User behaviour is influenced by these four obstacles simultaneously but some might be stronger than others. Grouping people according to their predominant behavioural obstacles is a way of categorizing users. Segment-specific technological solutions may then be developed to guide users towards a more eco-friendly behaviour [Buchanan, 2014].

APPLICATION OF THE UED CONCEPT

To evaluate the impacts caused by UEDs, we set up a six-step research protocol: (1) definition of the designed usage (DU), (2) user segmentation, (3) identification of UEDs, (4) experimentation, (5) modelling impacts and (6) environmental evaluation.

Step 1: Definition of the DU

The DU has been defined as the usage free of all UEDs, offering the best environmental performance. The DU is useful in two ways. Firstly, to have a value that can be used for comparing the environmental performances of the UEDs. Secondly, to have a targetable goal that can be used to orientate users' behaviour.

When the product is simple to use, common sense and discussions with users and with the designers should be enough to define the DU. LCA and sensitivity analysis may help if finding the optimal usage is not trivial. If the optimal usage requires a precise setting of numerous variables, techniques such as Design of Experiments should be employed to determine the best environmental usage patterns.

Step 2: User segments

A way of establishing different user segments is to explore the diversity of usages directly. To do so, a sufficient number of users and usage situations have to be observed. Data collection can be done in various ways. More important is the choice of the data collected and the ways of analysing it. The data has to be pertinent to represent the diversity of usages. Then, using segmentation techniques enables to establish coherent user groups [Wu, 2009; Khobzia, 2015].

Step 3: Experimental identification of the UEDs

UED identification requires a broad and objective vision of the diversity of usages. Furthermore, when a UED is identified, it is crucial to know its level of occurrence among the users. A seemingly good way to have these broad and quantitative views of usages is to observe a large variety of users in a large variety of situations. Before observation, protocols have to be set up to define when a usage is out of the DU boundaries.

In our method, we propose an experimentation consisting in two use sessions separated by a feedback intermission and concluded by a debriefing. The feedback is given to the user directly to be sure that the information is heard. The second use session allows us to measure the reaction to the feedback. Finally, the debriefing is useful in order to know whether the user understood the feedback they were given and how they interpreted it.

The use session is the opportunity of identifying the UEDs by the users. It enables to quantify two of the UEDs' negative consequences: over-consumption of energy and, also using information from the manufacturer, decreased lifetime (LT) of the system.

Steps 4 & 5: UED models and environmental evaluation

In order to perform the environmental evaluation of the system, it is necessary to apply the results found during the experimentations to the whole of the product use phase. To do so, for each UED, we measure the electrical over-consumption and define, using inputs from the manufacturer, a value of LT decrease. These values are used to model the use phase of the product and calculate its impacts. First, the environmental impacts of each UED are calculated, then, the same calculations are conducted for several combinations of UEDs (each UED with a specific coefficient), defined to correspond to observed usage patterns.

Results

Case study

The case study concerns the usage of a household wireless vacuum cleaner (12V). The vacuum includes a dust canister (bagless system) and a dust filter. The control is a single three-position slider button that can be moved by the user's thumb when holding the handle. The three positions are (1) Stop, (2) Run (low power) and (3) Run (max power). The battery LT is 500 cycles.

The results from this section were obtained following the method described in section 3.

Step 1: The DU

The DU has been defined by the research team using information provided by the manufacturer in the user's manual. When the information was insufficient, the best usage practices were arbitrarily determined after discussion. The DU elaborated is summed up in the four following actions:

- Use low power vacuum on hard floors and max power on soft floors.
- Empty the canister once the marked level is reached.
- Clean the dust filter after 2 running hours.
- Unplug the battery charger when the charge is complete.

Step 2: User segments

To identify user segments, we conducted a survey among a population of users (people buying a new vacuum cleaner in France and in Spain). We designed a questionnaire with 60 questions to characterize the respondents' usage practices. The questionnaire also allowed us to determine participants' environmental awareness. The survey provided us with 350 completed questionnaires. Analysing the results allowed us to define three different user segments.

C1. **Hygiene (40%):** They are not interested in how much electricity the vacuum cleaner needs. It is an everyday tool that must be efficient. People in this group are efficient and well organized for doing chores. Some know about the environmental consequences of their actions but they do not consider this as a priority.

C2. **Comfort (51%):** Their priority is their well-being. Chores need to be done, the quicker the better. They favour easy-usage efficient products. Their choice tends towards silent and automatic products.

C3. **Eco-sensitive (9%):** They are concerned about the consequences of their everyday actions. They often seek advice to improve their behaviour. They do not favour high-product performances if this means consuming a lot of electricity.

Step 3: Experimental identification of the UEDs

We chose to observe a panel of twelve persons while vacuuming "as usual" a 10 m² room. The experimentation was monitored so that users could be observed without being disturbed by the presence of a member of the research team. Usage practices that deviated from the DU were marked and, if relevant enough, labelled as UEDs.

Observation of users and comparison with the defined DU led us to identify 5 UEDs:

D1. Charging time management (battery left plugged in even when charged)
D2. Dust filter cleanness (vacuuming with an obstructed filter)
D3. Canister dust level (vacuuming even if the canister is already full)
D4. Vacuum power management (always vacuuming using max power)
D5. Preparing the room before vacuuming (moving furniture when vacuuming)

Not all users contribute towards these UEDs in the same proportions. The survey enabled to identify UED tendencies for each user segment. Proportions were extrapolated using the answers to the questionnaire. These proportions are approximated in the following table 1 (meaning that 50% of users from C1 are doing D1, 100% are doing D2, etc.).

	Hygiene	Comfort	Eco-sensitive
D1	50	100	0
D2	100	100	50
D3	50	70	50
D4	50	70	50
D5	50	100	0

Table 2: UEDs distribution depending on user segment expressed in percentages of persons doing the UED

Steps 4 & 5: UED models and environmental evaluations

Each of the UEDs was reproduced in the laboratory to measure and calculate their environmental consequences caused by energy over-consumption and/or abnormal wear and tear. The results of the measurements and calculations are listed in the following table 2. The electrical over-consumption is the difference between the reference usage electrical consumption and the value measured when reproducing the UED. The value is given for 500 usage cycles. The LT decrease is estimated using after-sales data gathered by the manufacturer.

The environmental evaluations carried out for this study were conducted using the SimaPro v8.0.4.30 software and the EcoInvent v3.1 database. The LCAs were performed according to the ISO 14040 and ISO 14044 norms.

UED consequences, in terms of over-consumption and LT decrease, are translated into mathematical equations in order to calculate environmental impacts. We consider that the LT decrease of a product part induces the same LT decrease for the whole product. As said earlier, usages are in fact combinations of several UEDs. Taking into account UED distribution depending on user segments enables us to obtain results that are closer to reality. The results of table 2 are used to create the UED coefficients of occurrence used in the calculation. The results of the calculation are displayed in figure 2 below. It shows that summing UEDs according to observed usages has significant consequences. We can see that the score of segment 2 (C2 being the one with the most UEDs) is 64% (+4.1 Pt) higher than the ideal use score without UED (C0).

Conclusion

We conducted an experimentation to identify the UEDs from people of three different user segments (hygiene, comfort and eco-sensitive) when using a wireless vacuum cleaner. We showed that depending on their segment, users have specific usage tendencies associated with a specific combination of UEDs. We estimated that UEDs, when summed up, can cause a raise up to 64% of the environmental impact. It must be taken into account that usage is often a sum of UEDs. Their weighting varies according to user behaviour. To counter the UEDs, designers must find a balance between considering the “average user” (which is inaccurate) or considering every type of user (which is impossible). Creating several user segments based on their behavioural tendencies seems to be an effective way of addressing this issue. In order to increase products’ LT, designers must anticipate UEDs and the wear and tear they generate. Technological solutions should be designed in this way.

UED	Consequences	Consumption	LT
DU	-	12.4 kWh	500 cycles
D1: charge management	Charger plugged in 24/7	+3.3 kWh	Battery LT down to 360 cycles
D2: filter cleanness	Hard on the motor, more running time	+1.3 kWh	Motor LT decrease of 10%
D3: full canister	Less vacuum power, more running time	+2.6 kWh	-
D4: power management	Accelerated battery aging	+3.2 kWh	Battery LT down to 400 cycles
D5: room preparation	More running time	+3.1 kWh	-

Table 3: UED consequences in terms of electric over-consumption and LT decrease of product parts

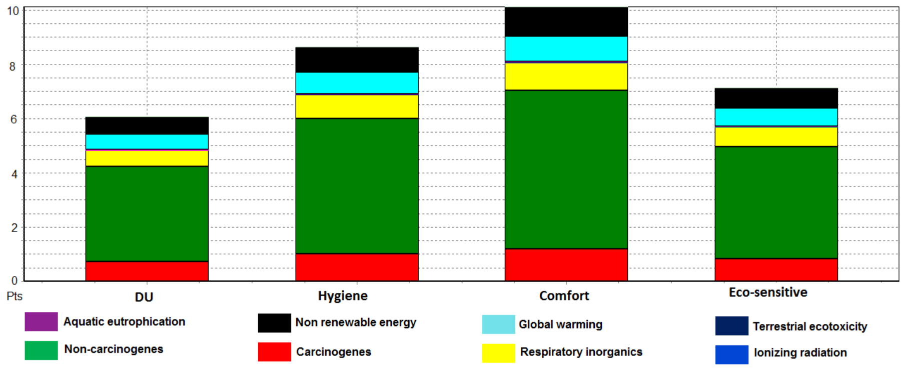

Figure 7: environmental impacts of the UED sums corresponding to the pattern of each user segment

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Roundtable 3

Representing usage in in eco-design and product development

Towards an ergonomic and environmental ideal for telecom products

Lucie Domingo[1], Marc Vautier[2] and Cedric Bertolus[2]

1. G-SCOP Laboratory, COMUE Grenoble Alps; 2. Orange France

INTRODUCTION

Plethora of expertise is used to envision product use phase during product design. But each expert has his/her own agenda and background to shape what usage or the use phase means to him/her. Several models and tools have been used to mediate the integration of usage into the design process: personas, scenarios, marketing brief, task analysis test results… Expertise in usage is also conveyed by different professionals: marketers, ergonomists, Human Machine Interaction – HMI – specialists, designers…

This diversity of models, tools and expertise makes it a double-edged sword when wanting to integrate usage into the environmental improvements of design. On one hand, it provides a variety of information to shape the use phase for environmental improvements, but on the other hand, it may convey contradictory or unreliable data to build upon.

This paper aims at illustrating how two experts, one in environmental design and one in usage, have been building up a collaboration aiming at strengthening the joint effort of increasing usability and environmental efficiency of a product. It aims at identifying a common ground for both and elaborating a strategy for the development of new products with a lower impact in use over the entire life cycle.

RESEARCH CONTEXT

Literature review

Eco-designers noticed the potential of use-phase improvements early on in the deployment of eco-design in industry. Strategies on use-phase improvements have been focusing on more efficient technology, decreasing losses of energy, water, and consumables over use cycles. This means that use-phase eco-design effort has been focused on energy efficiency and nuisance control (smells, noise…). New approaches have been made in the integration of a key actor of use: the end user. [Elias, 2009] made a proposition aimed at clarifying the user's contribution to product losses by defining a theoretical minimum for energy consumption, enriched with two sources of inefficiency: technology and user behaviour. Putting a more positive spin on the topic, Design for Sustainable Behaviour, DfSB has aimed at using the product as a support for the promotion of more sustainability-friendly habits. Based on concepts from ergonomics, such as affordance or providing feedback to users, they proposed a methodology that makes user behaviour the starting point of the eco-design effort [Lilley, 2009; Tang, 2012].

Other approaches, such as [Sauer, 2003], rely on ergonomics tools, such as activity observation, to broaden the scope of eco-design strategies towards a more user-focused approach.

In parallel to the effort to integrate the environment into design, designers have been focusing increasingly on User Experience (UX) to provide a competitive edge to products, especially interactive products [Hassenzahl, 2006]. With both issues being on top of the design agenda, it is a great opportunity for design teams to join efforts in making products that are less harmful to the environment and more in tune with the user, as a whole. Nevertheless, very little literature reflects on the industrial implementation of both concepts at the same time. This contribution is aimed at exemplifying how this could be implemented by reflecting on the feedback from two experts, starting to collaborate on a new product design project, one specialising in user experience and the other in eco-design.

Industrial setting

Orange is a telecom company with around 283 billion clients worldwide. Its commercial activities span from internet provider to professional services through its Orange Business Services unit.

The two interviewees are employed in the Innovation Marketing Technology entity, also called Technocentre. This entity leads the innovation strategy at Orange and employs around 500 people.

METHODOLOGY

The main material for this paper is a two-hour face-to-face interview held at the Orange Technocentre with three persons: a researcher from the G-SCOP laboratory, as the interviewer, and two interviewees, a usage expert, hereafter referred to as U and an environmental expert, E.

Beforehand, experts were briefed by the researcher on the topic of design for sustainable behaviour and the potential interaction between Life Cycle Thinking and User Experience.

An interview grid, detailing the four parts of the interview was sent to the participants one week before the actual interview: General Information (1), Objectives, Barriers and Drivers for Usage integration (2), Environment Integration (3) and Description of the common ideal of U and E, to clarify the potential common targets for both interviewees through discussion (4). The interview was recorded and the results are based on its transcript.

Interviewees are currently working together on several projects of product design (set-top boxes and residential gateways) and this current collaboration is the reason why they were selected for the interview.

U is a usage expert with a background in psychology and ergonomics of HMI and E is an environmental expert with a background in telecommunications engineering. Both have been working for Orange for more than 20 years.

All quotes have been translated from French to English. Translation by the researcher has been validated by the experts in the review process.

The results were grouped into four main topics for clarity. All citations directly from the transcript are in quotes.

RESULTS

The experts' role in the product development process – PDP- of Orange: submarine and long-term strategies

They identified 30 to 40 persons working exclusively on UX and 5 to 6 persons working exclusively on eco-design. The Technocentre is undergoing a re-organisation that will make the UX department more visible and with additional human resources (to go up to 160 people).

The current organisation of the Technocentre activities means that they are not directly involved in the "production" of the final product. They work on innovative solutions that might be implemented in future generations of products. This means that their timeline is more long-term oriented than that of product designers. This can be a barrier for solution implementation on current products but reorients the expert towards providing thorough documentation for next generations of products and services.

Nevertheless, this organisation means that U and E are not directly involved in the product development process – PDP – of Orange products. This is why they have to "hijack" or work in parallel to the development process to get access to the PDP activities:

U: "It [UX] cannot exist in the current structure of the organisation, so, actually we are always working under the radar"

E: "You have to provide turnkey solutions to […] our product manager"

Marketing is the key actor in transferring the information from the Technocentre to the design teams. But it is anchored in a risk averse culture that means that it could sometimes be difficult to pass on "innovative" or "against the tide" ideas to product or service designers.

A clear strategic agenda on UX and the environment, but then what?

There is a clear strategic agenda at Orange for both topics. In terms of environment, the target of minus 50% of CO_2 emissions per usage by 2020 and the term "circular economy" are mentioned in the latest strategic plan. And in terms of experience, Client Experience is presented as the central pillar of the strategic plan for 2020. The downside of this is that, for E and U, respectively:

- For environmental targets, it is focusing on scope 1 and 2 of the carbon footprint, meaning that the end-users' CO_2 emissions are not taken into consideration,
- For the experience, firstly, it refers to the client and not the user, which can be two different persons and secondly, it does not explicitly mention what focusing on client experience entails.

The elusive definition of what is expected in terms of client experience makes it difficult to define clear objectives for design teams (in terms of Key Performance Indicators – KPI).

The objective-driven design process is a key tool for the expert to push for product design improvements. Talking about a speech made by a lead designer on software eco-design, E stated that if he was making such an eloquent case on the topic, it was because he had a clear financial incentive related to the issue.

Progress on standardised methods, in terms of ISO standards, in user experience measurement is seen as a good opportunity by U to advance the cause for a better interface design. As today's incentives, like having wall stickers with gimmicks like "do it simple", convey ambiguous messages that can get in the way of a usable product, U stated that "[UX] is a bit blurry, see, it is the shape, it is what people want…". U suggested that if Orange were to put metrics on UX improvement, it should use the triptych of usability: efficacy, efficiency and satisfaction (including hedonism).

For the environmental side, the main strategic and organisational barrier is that it is always considered last minute in the design process. As the main drivers for eco-design implementation are regulations and public image, it is often a low-level priority if the product is already compliant with the minimum standards.

A wide array of tools and methods is available to get evidence on what is happening to current products in use or to be used in the testing of new products and is accessible to designers.

Interviewees mentioned the following possibilities:

- General documentation and statistics on consumers, like statistics from Mediametrie (marketing study on French media).

- User testing with a small sample of 40 persons in an activity analysis fashion
- Survey through the Lab. Orange panel. These surveys are sent to a panel of 5000+ Orange clients that are solicited from time to time for this type of initiative.

The limits in terms of reproducibility, truth-worthiness and generalisation process of the latter, listed by U, make them rather unreliable sources to build upon for the enforcement of design strategies.

One of the most promising tools for data collection on usage is trace analysis. The specificity of the telecom industry makes it possible to collect numerical traces that can be linked to usage. For example, to measure how often people actually turn off their set-top box (in a questionnaire, clients self-reported a box turned off 80% of the time, yet the traces of communication between the box and the orange servers revealed that it was never off, except when the user had to "reboot it"). This type of analysis enables the assessment of the entire population of product users, giving it statistical robustness to be used in design decision-making.

U is looking at the possibility of implementing more sensors or specific software routines to report more often on specific traces of usage. For E, this means a robust data set when assessing the potential environmental improvements associated with the scaling-up of a design solution.

Design improvements: common ground and opposing view

The first outcome of the collaboration is to construct shared argumentation in favour of one design solution over another. Since cost is the number one priority, a solution that is cost effective and beneficial for both UX and the environment has a greater chance of being implemented on a product (even though if it is sometimes not enough).

One of the directions that both experts can build upon is the "less is more" dimension. Deleting unnecessary functions, the associated product parts and over-consumption of energy has a positive impact on both environmental and usability performance. This convergence was exemplified through the debate, among the design and marketing teams, of the on/off button on the set-top box. Initially aimed at steering users into turning the product off, its placement at the back of the box made turning it off an unlikely action. This was confirmed by trace analysis.

Another important aspect of the collaboration between U and E is the critical viewpoint that usability can bring to an eco-design solution. For example, U has advised giving up the LED signal on set-top boxes because it does not provide any useful information to the user, as it cannot be used without the television being switched on. If the product is not providing functionality, it should be turned off and providing confusing eco-feedback does not help the environmental cause.

Yet, on specific issues, the experts contrast. This is the case for the power supply:

- from a usability point of view, the supply should be inside the product, in order to decrease the number of connexions required when installing the product and to reduce the length of hanging cables,
- from an environmental point of view, it should be easily accessible in order to be replaced quickly in the refurbishment process.

In any case, it provides the experts with the opportunity to discuss individual claims and to back up their argumentation with additional data.

What's next

The next big project for E is the scaling up of circular economy initiatives that are currently applied essentially in the take-back loop for cell phones. Modular design solutions are currently looked upon for environmental purposes. In terms of usability, previous work shows that, for some product usage, there is a distribution of use patterns that could benefit from different product configurations. U mentioned that modular products could be a valid solution for customising the service production to use patterns.

DISCUSSION

Organisational barriers in the integration of expertise in the design process

The organisational barriers mentioned in the interview are pretty common in the PDP process of big companies [Boks, 2007]. The specificity here might be on the key role played by marketing. They are the ones making the cut on whether or not a solution developed at the Technocentre is actually going to be implemented on a product.

Clarifying the viewpoint of marketing on the topic of joint development in the field of eco-design and user experience is a promising research perspective.

A common ground for usage and environment integration in design

Life cycle thinking, one of the core principles of eco-design, is focusing on providing functionality to a user through the product, and ergonomics has to consider eco-design because they are mediating the interface between humans, a part of natural eco-systems, and technology.

Additionally, in the current organisation of the design process at Orange, they are faced with the same challenges to get their point across to designers.

This convergence of viewpoints and techniques makes this collaboration a good example of how inter-disciplinary work can advance the agenda of two subjects that are deemed crucial to maintaining a sustainable business.

This positive collaboration at Orange illustrates that User Experience and Eco-design can be bound together in design activities, supporting the research developments in areas such as DfSB [Lilley, 2009] and eco-Kansei [Bouchard, 2010].

FUTURE WORK

This paper presented how two specific experts have been collaborating on the topic of environment and use. It provides an interesting example of how the two fields could work together to foster more environmentally and user-friendly products.

More industrial feedback has to be collected on the subject of collaboration of experts in user experience/ergonomics and eco-design. This paper is limited to the experience of two individuals working in a sector where use has always been a central point for PDP.

A first direction for future work would be to see, in the same company, in the same sector, if another set of individuals or a larger group of experts will have the same perceptions on the design process of telecom products. An interesting example might be to audit how environment and usage is dealt with in companies that manufacture products for Orange (like the set-top box manufacturers). Integration of other expertise, such as production, marketing and software development, into the discussion might open up new research perspectives.

A second direction for future work would be to look at what happens in the mechatronics sector in general and in other industries, where the design agenda is less focused on use.

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Interoperability of usage models

Maud Rio and Lucie Domingo

University Grenoble Alpes, G-SCOP, CNRS, 46 Av. Felix Viallet 38031 Grenoble

INTRODUCTION

Usage information is required as early as possible during product design to assess environmental impacts of the product under development. However, several usage models co-exist during the product design process (e.g. [Lilley, 2006] mentioned ten of them only for user-centred design). Usage information can be difficult to access for the environmental expert and potentially conflicting. Information exchange about usage during design therefore needs to be improved between the environmental expert in charge of performing the Life Cycle Assessment - LCA and the other experts intervening during design that influence the product use. This paper proposes to apply the FESTivE method [Rio, 2014] to federate use stage models and life cycle inventory models (LCI) during the design process to help product designers be pro-active regarding the product's environmental performance.

A case study based on the design of a mountain bike has been used to illustrate:

(1) how knowledge about usage needs to be formalised to improve knowledge sharing between experts, and (2) how model federation supports the environmental expert in gaining access to the evolving usage models during product design. A roadmap of potentially available usage models along the product design process from stakeholders' working material is proposed to support systematic transformation for environmental assessment.

RESEARCH ISSUE

Information about the product's usage is created by various stakeholders during the product life cycle - LC: the design brief to define product's functionalities, mechanical and material engineers to design the product's mechanisms for a given lifespan and solicitations, ergonomics expert to model interactions of users with the product, retailer to advise clients, after-sales agent to receive user feedback, waste treatment agents to plan product's end of life, etc. Different information about the product usage would be accessible at different times of the product LC, including during the product design development. The product usage is central in LC thinking: first, it may generate a significant amount of the environmental impacts and second, it is when the user benefits from the provision of the functional unit.

Industries and researchers insisted on the necessity to integrate the global LC environmental expertise as early as possible during design with adapted tools (e.g. [Millet, 2007]) to provide specific feedback to each expert. A multi-criteria and

multi-impact Life Cycle Assessment of the product under development can be conducted by the environmental expertise as long as the Life Cycle Inventory (LCI) of the product is made available (cf. ISO Standard 14040-44 [ISO, 2006]). This research seeks to make usage information available to the LCA practitioner to fulfil LCI as early as possible during the design process to optimise cost [Dewulf, 2005].
During design, the available data on usage (to build usage scenarios representing each dimension of the product usage from acquisition to decommissioning) could be contained in:

- The product's Bill Of Material (BOM), which is generally accessible through the Product Life Cycle Management (PLM) software. It gathers information about the product: material chosen, parts and components, assembly, manufacturing processes, etc. The associated material and components' providers or suppliers are referenced in the Enterprise Resources Planning (ERP) software of the company. In particular, the design brief, Functional Analysis, fatigue calculation, etc. contain product usage information;
- Existing documents spread across the company's departments: ergonomics reports, user manual, Failure Mode and Effect Analysis, after-sales strategy, etc.

There is currently a lack of specific method to link such examples of available usage information to the environmental expert activity (and their specific software tools) to support the elaboration of usage scenarios along the design process of the product.

PROPOSITION: FEDERATE USAGE MODELS AND LCI MODELS

The approach proposed in this research is to use model driven engineering - MDE (e.g. using the Unified Modelling Language - UML) to federate such available information about usage (e.g. existing usage models from in-use software, i.e. usage *source* models) to LCI (usage *target* models), using an existing method, called "FESTivE" for *Federate EcodeSign Tools mEthod* [Rio, 2014]. This method provides a structure to clearly define: the existing usage source models, the target usage models, and the links between them (called *knowledge transformation*).

In this research, *knowledge* is considered as intrinsic to the person that owns it [Miled, 2011]. The so-called *knowledge transformation* is the description of the links between individual stakeholders' knowledge. It addresses potential conflicts, or difficulties between those occurring during the product LC and the environmental expert willing to elaborate usage scenarios (LCI, stage 2 of LCA [ISO, 2006]).

Introduction to the case study: the design process of a mountain bike

This paper considers the development process of a mountain bike involving multi-domain expert engineers, such as an ergonomics expert, a mechanical design engineer, or a manufacturing expert (named here "product designers"). The person in charge of addressing the environmental performance of the bike and supporting product designers in minimising the environmental footprint of the final product is named the "environmental expert". The development process of the bike follows the usual stages: from the early development to market launch. The bike components are subject to relatively important mechanical solicitations during usage bringing potential material fatigue, corrosion, etc., and leading to component deteriorations. Riders are recommended to carefully maintain their bikes to avoid injuries (e.g. during downhill runs, jumps). Safety is therefore an important concern for product designers, regularly conducting Failure Mode and Effects Analysis (FMEA). Each bike is designed for a specific type of use defining its category, or range (e.g. enduro, cross-country – not specified in this illustration). New bikes are launched every year with slight improvements and upgrades.

The application of FESTivE

Figure 8 describes the three steps of FESTivE as presented by [Rio, 2014]: (1) modelling the design process as a sequence of activities and usage data shared between the product designers and the environmental expert; (2) modelling the usage information coming up as outputs from the product designers' activities and used as input by the environmental expert activity (LCI); and (3) modelling the knowledge transformation to link available usage information and LCI.

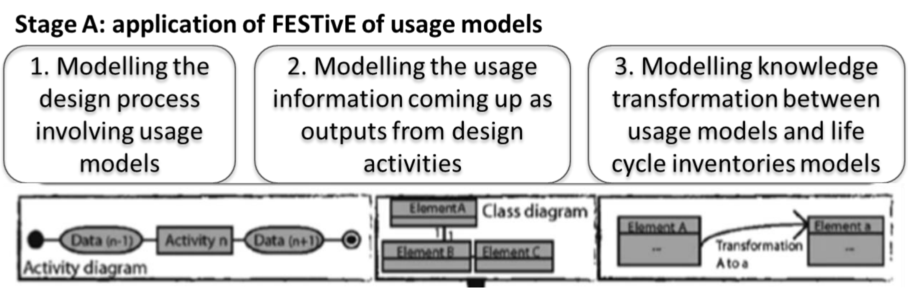

Figure 8: Application of FESTivE for usage model federation during design

Step 1: Design process modelling of a mountain bike (extract)

Usage information is required as early as possible from the moment product designers have begun to design the mountain bike to completion of the LCI. Early design stage LCAs are streamlined: lacking inventory, high assumptions on life cycle stages, etc. However, they provide an overview of potential hot spots. Usage information is therefore required as it can significantly influence LCA results. Figure 9 illustrates three successive design stages (round corner square). First, product designers perform the early product design activities. Then a streamlined LCA is performed based on the data generated by those design activities. Finally, LCA feedback is provided to product designers to help them reiterate their design choice while minimising the global environmental impact generated over the estimated LC stages of the bike under development.

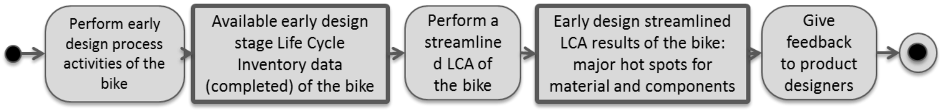

Figure 9: Stage 1 of FESTivE for early design stage

Step 2: Activity input and output data modelling

Step 2.1: Target models: the use stage in an LCI

In this case study, the target model is the use stage of the LCI. Usage covers material and energy flows over specific habitudinal usage practice, such as maintenance (cf. Figure 10).

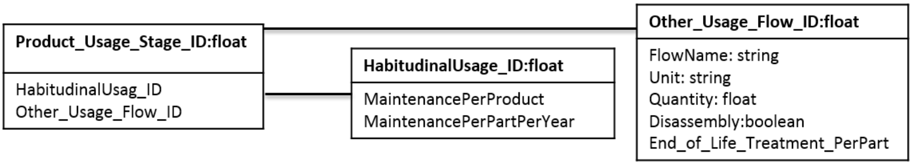

Figure 10: Target Model: usage inventory for LCA inputs

Source models: the design brief, the user manual and the Failure Mode and Effects Analysis (FMEA) report

In this case study, the available usage information at the early product design stage has been obtained from two sources: (-1-) the **design brief,** defining the mountain bike ranges for a targeted user, referring to user basic characteristics. Different profiles of bike's users are described based on frequency of usage (e.g. frequent, occasional), as well as the type of use (enduro, trail, cross-country, raids, jumps, free ride, etc.). Such information, documented in the brief, is based on observing users and by studying the product characteristics (parts, etc.); (-2-) the **user manual** for the same range of bike (previous season), comprising maintenance guidelines.

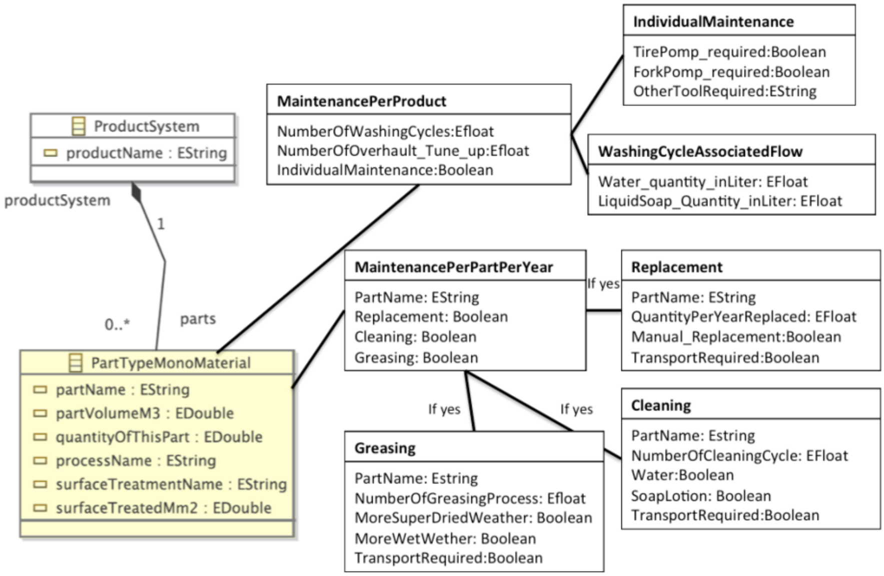

Figure 11: Usage information based on the mountain bike user manual.

Note: this class diagram is not instantiated (meta-model provided only)

Mechanical design engineers involved in designing the mountain bike use a standard Computer Aided Design (CAD) environment. Usual CAD outputs are described on the left side of Figure 11, composed of two classes: ‘ProductSystem’ and ‘PartTypeMonoMaterial’. When instantiated, they provide the Bill of Material (BOM), the product structure (the product is composed of X parts), some assembly processes (e.g. screw bolts on stalks thread), surface treatments for instance (e.g. coating, greasing). Except for radical design innovation, mountain bikes from the same range usually refer to similar user manual instructions during use. The user manual recommends that the user replaces some components (e.g. the chain), and maintains them through washing, drying, oiling, and greasing. It is therefore possible to link the associated usage flows (e.g. water or detergent for washing) to each component defined in the BOM, as well as replacement components, with a given frequency (e.g. each year). The BOM can therefore be completed with usage information based on the user manual.

In this case study, the design brief described a type of user for a range of bike. The user manual from the same range of the previous bike model contains usage information that is used to start LCA modelling of the use stage. A single class diagram has therefore been considered to provide usage sources information.

The target model in Figure 10 is to be detailed using complementary usage sources, available later in the design process such as:

- Results from Failure Mode and Effects Analysis (FMEA) that were obtained by recording and detailing the user actions associated to failure (cf. Figure 13). When available, such information is directly transmitted to the environmental expert in charge of performing the LCA. This information is then used to iterate the number of parts replaced during use, refining the hypothesis made using the user manual from the previous product.
- After-sales and maintenance garage information is recorded on worn or broken parts.

Some safety factors are also involved in user manuals. A balance between the evaluation of the risk taken by the manufacturer if users get hurt by inadequate bike maintenance, and the real usage of users provided by after-sales records, would be required to define this safety factor. LCA sensibility analysis on the influence of part replacement in use at the early design stage could be based on this factor. Common components to be changed during use are from bike's components suppliers (e.g. Shimano©). Therefore, the information on the Maintenance market is not easily available to the bike manufacturer.

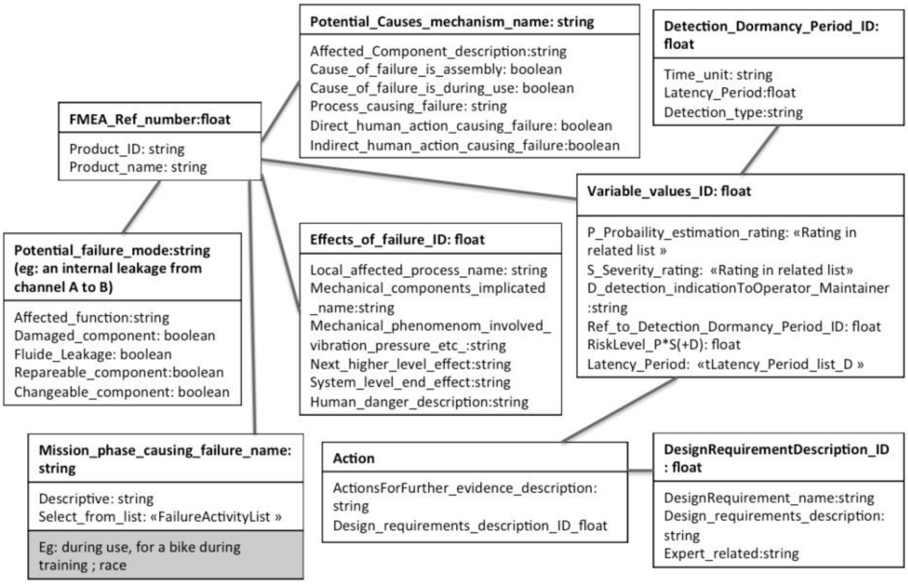

Figure 12: Failure Mode and Effects Analysis (FMEA) data about usage

Note: lists of variables are not presented in this diagram

Step 3: Knowledge transformation modelling

Figure 11 describes the usage information contained in the user manual and does not require specific transformation to be used as LCI inputs covering the use stage. Only database equivalences of terms are required to link the usage material flows (e.g.

water, liquid soap) to LCA input databases (e.g. from Ecoinvent© database). Some suggestions are made for this step:

- The assessment would provide more accurate results if information contained in the maintenance guide of similar ranges of product is kept as inputs for an early streamlined LCA. FMEA results (or other usage models available) could be used to conduct sensibility analysis when design choices about the product are more settled.
- A detailed LCA would then be performed.

A roadmap of potential usage source models available along the design process has been identified as useful during the case study to get an overview of the entire use phase for the environmental expert (Figure 6).

RESULTS AND DISCUSSION

Results based on a case study of the product design of a mountain bike show that: (1) knowledge transformation specifications about usage are required to ease the communication between LC stakeholders, and then (2) model federation has the capacity to support the environmental expert in accessing the evolving usage models during product design if a roadmap of usage source models is available to guide him. LCI instantiations can then be generated to support the environmental expert in his provision of feedback to product designers.

Usage blocks during the design process

In the case of the mountain bike, usage environmental impact has been restricted to maintenance operations because it is an “inert” product, i.e. it does not need environmental flows to be functional, except from maintenance flows. But it would be interesting to consider a more complex LCI usage model.

A unified usage method to cover all usage dimensions of the product is still not available in the LC research community (e.g. [Serna-Mansoux, 2014; Pettersen, 2008]). The proposal of Hasdoğan is based on a chronological definition of usage [Hasdoğan, 1996], which is compatible with the LCA approach of product life cycle. The concepts involved in this definition come from the field of industrial design and not from the field of environmental assessment. [Hasdoğan, 1996] defined usage in 3 *blocks*: (a) the *shop window:* when the user is a consumer – a stage-gate distribution of use stage for LCA; (b) The *initial usage*: when the user gets accustomed to his/her product. This period is more or less long depending on the product complexity (from the user point of view); (c) The usage per-se that has been called *habitudinal usage*: when the user is an expert and the product is operating “normally” (from the user point of view). An additional block is added in this research work to harmonise the usage models with the stage-gate to end-of-life stage covered in an LCA. This fourth usage block is referred to as *decommissioning*: when the product is not in habitudinal usage anymore, or handled by the end-of-life network yet.

Design-To-Environment road-map during the design process

Figure 13 proposes a roadmap of potentially available usage models along the design process stages (given by [ISO, 2003]). Usage blocks coverage is shown on the right side, targeting a full LCI completion at the end of the design process. The usage information is established by stakeholders in different models, such as the *Marketing Brief, Persona, Functional Analysis results, User Manual* (to name but a few). Streamlined LCA followed by full LCAs can be conducted along the design process aligned with the level of completion of the LCI (cf. [ISO, 2003] – last column of Figure 13). Feedback would be ideally provided by the environmental expert performing the LCA to the stakeholders and would be linked to different usage information available in the iterations of the design process. It aims at designing a product with better environmental performances (from the global LCA results: multi-impact and multi-stage analysis – including the "best available" usage data).

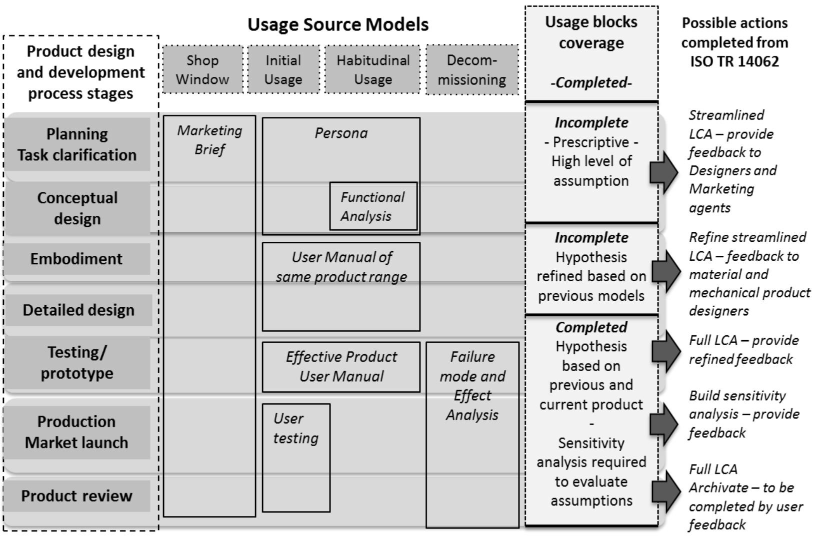

Figure 13: Proposition of a roadmap of potentially available usage models along the product design process from stakeholders' working material

From Figure 10, transformation rules can be established to link usage information contained in available source models during design to the four usage blocks required to fulfil the LCI use stage model. Figure 14 presents the types of rules depending on the model type to link available usage information to the usage LCI.

Source model from	Knowledge transformation links to environmental expertise	Types of rules
The marketing brief	From marketing department	Difficult to automate: environmental expert needs to interpret and translate material and energy flows related to the "shop window" use stage of the product, and estimate quantities
Designers' model of Persona	From product designers	Pre-defined persona could be associated to initial usage and habitudinal usage blocks flows (energy and material) and quantities, based on similar product range, or estimated from user feedback and benchmarking
User testing records	From ergonomics designers	Initial usage block to be filled by "real" values recorded from test benches and user feedback. General rules required: (1) appropriate matching between material and energy flows denomination from different databases; (2) formulas for value calculation (e.g. energy consumption on a timeframe)
User manual (can include a maintenance guide)	From after sale experts, and retailers, and ergonomics designers	Transformation rules between the Bill of Material contained in the Product Life Cycle Management System and the LCI model (e.g. number of parts replaced)

Figure 14: Transformation rules to link usage source model to LCI usage target model during the product design process

CONCLUSION

This paper applied the FESTivE method to federate use stage models and life cycle inventory models (LCI) during the design process to help product designers be pro-active regarding the product's environmental performance, especially over the use phase.

Results based on a case study of the product design of a mountain bike show that knowledge transformation specifications about usage can be defined to support model federation.

A roadmap of usage source models has been proposed to guide product designers and the environmental expert in a pro-active design-to-environment process. The usage data are made available for an environmental analysis. Establishing transformation rules, to link available usage information, is to be defined specifically for each industrial context (e.g. depending on the different stakeholders involved, the products and technologies).

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Conclusion

Conclusion

Lucie Domingo[1] and Maud Rio[1]

[1]. G-SCOP Laboratory, COMUE Grenoble Alps

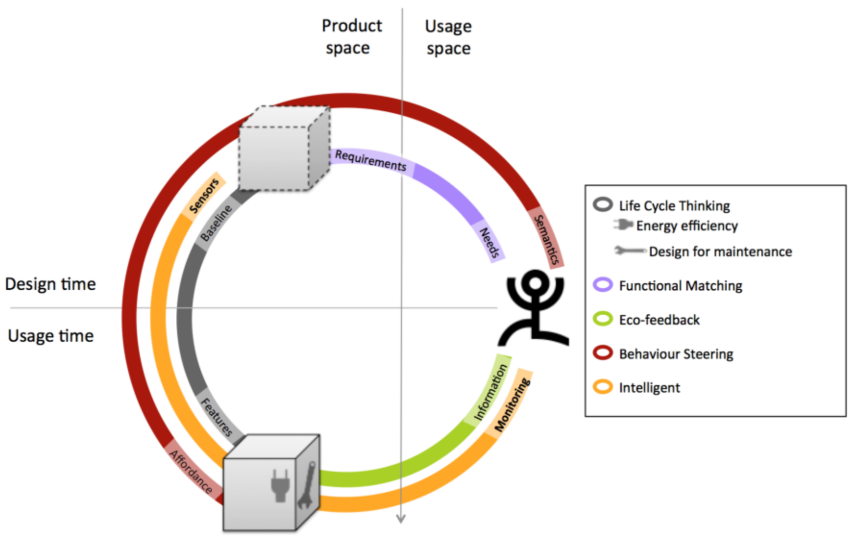

Figure 15: A general context for strategies in usage focused on eco-designing: combining product and usage space with design and usage time

The 2016 Annual Workshop of the French EcoSD network co-organised by the Community of Grenoble Alpes University and Orange Group aimed at sharing research results and industrial expertise around the question of how eco-design of products and services could embrace the use phase. The following synthesis summarises the discussions and the exchanges that took place around the three thematic round-table sessions. Figure 1, presented in the introduction of this booklet, is used to structure and to encompass the different topics into the bigger picture of usage integration for eco-design. The main outputs and opportunities for further research are summarised using this representation of design spaces and time.

First and foremost, usage is an opportunity to foster the role of design (and product designers) in the transition to sustainability.

However, there are still a couple of challenges ahead of us. Data collection and data sharing have been identified as central issues to ensure this transition (second axis). The issue of designing the user instead of the product and its usage is the second challenge introduced (third axis). User grouping and targeting is also addressed in the fourth axis.

Finally, to open up the discussion, circular economy based on usage integration is an important driver for eco-designing products and services for the next decade.

USAGE: AN OPPORTUNITY TO FOSTER THE ROLE OF DESIGN IN THE TRANSITION TO SUSTAINABILITY

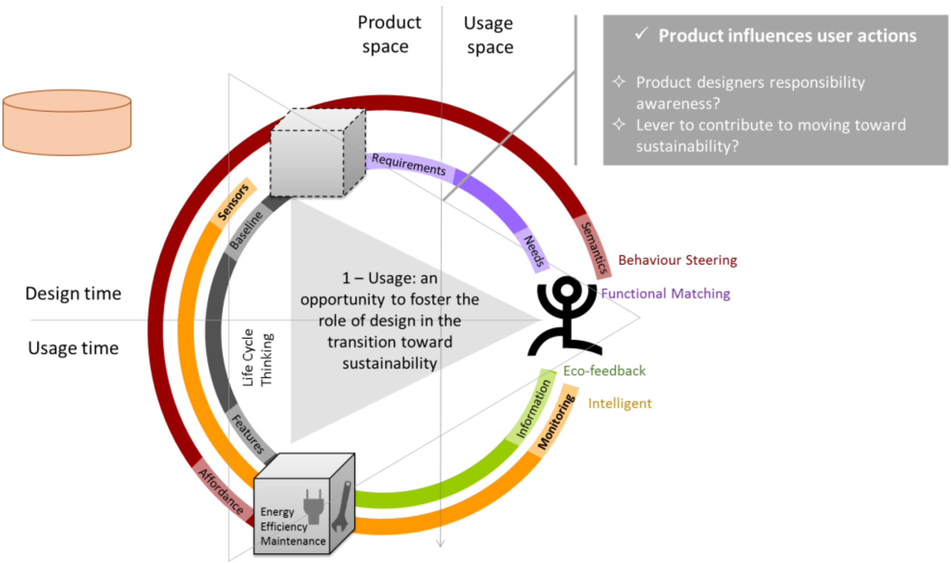

Figure 16: Creating awareness around products influencing user's actions

Since the beginning of the 20th century, design has moved from being the birth place of a product to the place where the decisions taken affect the environment (resources and energy consumption, generating pollution) along the value chain, thus fostering the need for stakeholders' involvement.

The question of the responsibility of product designers towards sustainability has been embraced by the community of product designers (cf. [Brezet, 1997] for instance). Tools and methods to assess the environmental impacts of products and services over their life cycle have been (and are still) developed and integrated in product designers' activities. Yet, unsolved questions remain in terms of causal effects between the product design and its consequences in terms of sustainability – in particular – during usage and end-of-life stages.

This workshop has raised the following question: if product designers are aware of their responsibility towards sustainability, then what are the levers to design a product that contributes to build a sustainable society?

Making designers realise that product design influences people's actions

From a practice-oriented design point of view, the keynote speaker, Ida Nilstad Pettersen from NTNU, introduced the debate clarifying that change is likely to happen; however, it should not be a deterrent to design activities. Product designers cannot completely prescribe a given behaviour through the shape and mechanisms of their product. However, they can pave a way to change. By adopting a transition management perspective, small but consistent and regular design modifications can support the transition towards more sustainable practices.

In their daily activities, designers stated that they cannot influence what people do. Even if it is very political to influence someone's behaviour, products influence behaviour anyway, even when there is no intent from the designer. Yet, contact with end users, or experienced users, are limited today, as well as having access to coincidental information on product use.

But things are changing. In the building sector, participants of round table 1 stated that increasingly participative building initiatives were emerging: users collaborate with designers to bring their contribution to the design. This type of initiative comes with its own set of challenges. It raises the question among designers of how people should behave (e.g. in a "low consumption building"). Conversely, end-users can feel as if they cannot change or influence product (/building) specification.

Two questions are therefore emerging in terms of research in Design:

1) How can we increase awareness among designers of the influence that their product has on users?

2) How can we ensure that the influence of product design tends towards more sustainable behaviour?

Product design: a means to support transition to sustainability

Several research contributions and examples provided during the discussion bring a first scientific response to the second question stated above.

Policy makers have long realised that product design is a key to building a sustainable future. Integrated Product Policy encourages this practice: CO_2 emissions for automotive, RT2012 for buildings, Eco-design directive for Energy related Products (ErP) to give just a few examples. They are all rooted in improving primarily the product usage environmental performance.

Additionally, participants, during round table 3, advocated for products designed for lead-environmental users. These products will inspire the more environmentallyfriendly people to be even more sustainable in their practices, by integrating other dimensions of sustainability (social sustainability for example) or with more ambitious environmental targets.

As presented in the keynote, aligning design with specific usage considerations requires involving stakeholders from different areas of expertise, potentially unknown by policy makers. Pettersen therefore questioned the efficiency of the process of giving general limitations to companies in a top-down scenario established by policy makers. This is in contrast to the scenario where the company strategy, culture, and organisation, in addition to bottom-up initiatives, and exploratory projects, are first analysed to observe tendencies and identify opportunities for change, and provide this feedback to policy makers for them to establish appropriate rules.

DATA COLLECTION AND DATA SHARING

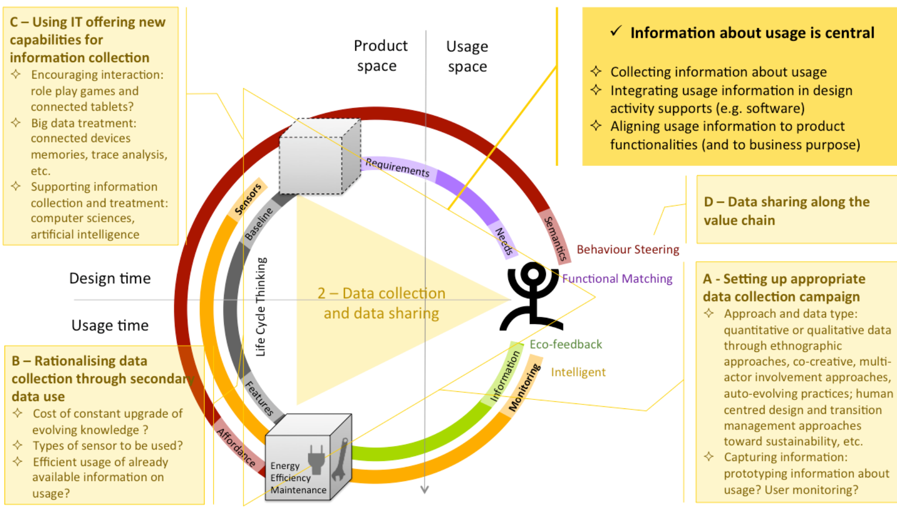

Figure 17: Collecting and sharing usage data as a central topic

Any modelling activity is data dependent. However usage data brings very unique challenges for designers. Information linked to usage has been a central topic for all round tables covering various aspects, such as:

- collecting information on usage (big data treatment);
- integrating usage information during design (tools and method for designers);
- aligning usage information to product functionalities and marketing goals.

Setting up appropriate data collection campaigns

Data can be quantitative, such as timing data or data on the amount of resources used. Data can be qualitative as well, linked to performance for instance (e.g. in

[Shove, 2003]). Most of the data collection tools from users can be classified as non-predictive because they only record part of what usage is about. Diary keeping for example is limited to the collection of information that the user deems important to him. Interviews and observations can also be classified in this group.

Different approaches can be used to capture data about usage (mixing qualitative and quantitative values): ethnographic exploration, co-creation approaches, multi-actors involvement, etc. (for a complete overview, see contributions by [Daae, 2015; Lofthouse, 2006]. Such approaches cannot always be prescriptive, as people change, and practices evolve independently from product design.

Resources in design for sustainability, human-centred design and transition-management approaches can provide tools and methods to capture usage information.

Round table 2 specifically targeted the question of capturing usage data. Participants discussed the process of monitoring user habits with a product or service, and how to give back the information to the company designing such products or services. Despite the wide complementarity of available approaches, participants gave evidence that the main criteria for selecting the data collection tool would be the cost of such a tool and the process involved around it. A company searching for usage data would go for the most adapted tool but would also consider the available resources to be spent on the project, both in terms of cost and time to collect and process the data.

Prototyping could be used to get access to information from a panel of users during a product in use observation at a low cost. More usage focus observation with products is possible nowadays due to rapid prototyping capabilities (3D printing, rapid software programming, etc.). Participants mentioned the use of mass questionnaires based on simple questions and answers completing more detailed studies. Some warnings were raised during round table 3 about the shortcomings of self-reporting methods. For example, questionnaires tend to provide less reliable information due to users' tendencies to report on pro-environmental behaviour with a more positive twist than the reality. Every data collection has its pros and cons and practitioners should account for bias and shortcomings when processing data.

Participants also mentioned opportunities in taking a usage-driven innovation perspective. Instead of looking at the interaction of one person with one artefact, observing what people actually do to then design the adequate product provides new opportunities for designers. For eco-design, the challenge would be to identify pro-environmental emerging behaviour and to be inspired by this behaviour to provide adequate products.

Yet this challenge raised the question of data collection tools: are they offering what the eco-designer needs? Or should researchers develop new data collection techniques suitable for the new challenges of eco-design?

Participants also stressed that companies actually owned usage information internally in marketing or ergonomics departments. Such data could be used for internal environmental assessments. However sparse and scarce, usage information from multiple sources may require discussion between departments of the company to unify such usage information for LCA and for eco-designers.

Rationalising data collection through secondary data use

The need to reuse information about usage emerged during round table 1, mainly for cost reasons. Deep-level multi-agent simulation may appear as a utopia, both for financial and epistemological reasons. Important costs are associated with knowledge capitalisation and updating databases about people behaviours, essential to agent-based simulation. It may be too expensive for a company to update data regularly and reusing past usage data could be a *less-bad* option.

The generalisation and the decreased prices of sensors provide new opportunities to rationalise data collection on usage as well.

Practitioners from the automotive industry attested that they have access to important amounts of data about usage, but rarely use them for eco-design purposes. Indeed, the focus of eco-design on usage is mainly driven by legislative purposes. In aeronautics, a practitioner explained that maintenance operations are also an opportunity to have a glimpse at what is happening during product use.

Secondary data is a great source for rationalising data collection for eco-design activities, providing a baseline to set up their own campaign with a focus on environmentally-related topics.

Using the new IT abilities for data collection

New devices are creating opportunities for collecting data, especially smart phones and digital devices. [Abi Akle, 2016] presented how they intend to use games to collect data on usage patterns. People are currently frequently using connected products. For the same stimuli, occupants know about the impacts of their energy consumption, in existing houses. They can regularly observe the evolution of their consumption in keeping with their own behaviour changes [Abi Akle, 2016]. Getting the data through specific smartphone applications is also a great opportunity to gain usage-specific data.

New smartphones will soon have the appropriate sensors to gain data and also have the abilities to transfer them, as reminded by an engineer from the telecom industry. Additional sensors, like Volatile Organic Compounds sensors, could be embedded in devices to provide information on this specific air pollutant. Even bar phones can provide information. Practitioners from the telecom industry recalled how they use the number of mobile phone signals in an area to evaluate traffic jams, in megalopolis in Africa. Drivers are given advice on better routes to be taken in regard to their location, monitoring constantly (in live, or synchronously) the state of the network.

Nevertheless, it raises completely new challenges as well. And the main one is: what about people that have no connected devices (phones, games consoles, etc.)?

Domotics systems today are likely to be driven by tablets and digital games. So what can be done for people who do not have or dislike the use of digital interfaces?

Lizzaralde argued that IT interfaces could be a major issue in the building sector. It seems that domotics systems stress the habitant in using electric systems. Various digital tools are indeed available. A majority of approaches to capture usage data invite the user to participate in (entertaining) role-play games.

Another challenge is about privacy. Some of the data collected offers great information for product designers. However, inhabitants might not be willing to share every detail of their private behaviour with them.

Big data[18] treatment would theoretically increase usage knowledge. Round-table 1 and 3 participants indeed illustrated that some statistical trends could be captured (or deduced and calculated) from these big data flows. Yannou wisely advised that we have lots to learn from computer science, for modelling and designing tools software to get information. Artificial intelligence could be of great support, as well as any other information systems to get access to user information during usage (e.g. getting feedback from user forums, Twitter, Facebook).

Data sharing along the value chain

Sharing data with and about users and usages across the value chain may be partially integrated in product design or building sectors. Stakeholders' integration is still difficult today, especially the client/supplier relationship, as illustrated by one participant from the aerospace industry. She reflected on her company's experience with aircraft manufacturers that were reluctant to share more than requirements on usage. Even though they have access to a large quantity of information on usage (from flight tracking or direct contact with airlines), they are unwilling to share it with their suppliers.

Yet, participants of round table 2 stressed the importance of data sharing, especially on usage, when available. But one specific challenge is emerging for practitioners. Companies are starting to monetise data on usage. Examples from the building sector were provided in round table 1. Nevertheless, data sharing among companies, especially among suppliers and industrials of the same sector is crucial when it comes to usage. This data is not company-dependent and it needs to be shared with all the value chain parties.

[18]For a presentation of Big Data as a management revolution: McAfee, A., Brynjolfsson, E., Davenport, T. H., Patil, D. J., & Barton, D., 2012: "Big data", The management revolution. Harvard Bus Rev, 90(10), 61-67.

The fact that usage data becomes a new source of revenue for companies emerged during round table 1: data about usage is not only providing better devices to users, such data is also sold to future industries. Usage during the whole value chain brings real values to stakeholders. Cor certified the need to gain access to usage information during design and to share such information between industries during round table 2 [Cor, 2016]. Further on, during round table 3, Lescaut from Zodiac Aerospace complained about the difficulty for the first, second, or even third suppliers to gain information about usage. The aircraft manufacturer is indeed in contact with the users (the airlines). Then, this manufacturer provides information to suppliers (mostly the first one) in the form of requirements.

A process of data circulation in the value chain has been proposed and can be summarized as follows:

- Step 1 – data collection from users;
- Step 2 – data sharing internally and with suppliers (first layer);
- Step 3 – data translation into product requirements (specification for designers).
- A step 4 can be included for routine products (e.g. cars), where the related usage information can be influenced through alternative medium, i.e. different from product specification.

This four-step process needs to be explored and implemented in order to validate whether or not it supports information sharing along the value chain.

AVOIDING DESIGNING THE USER

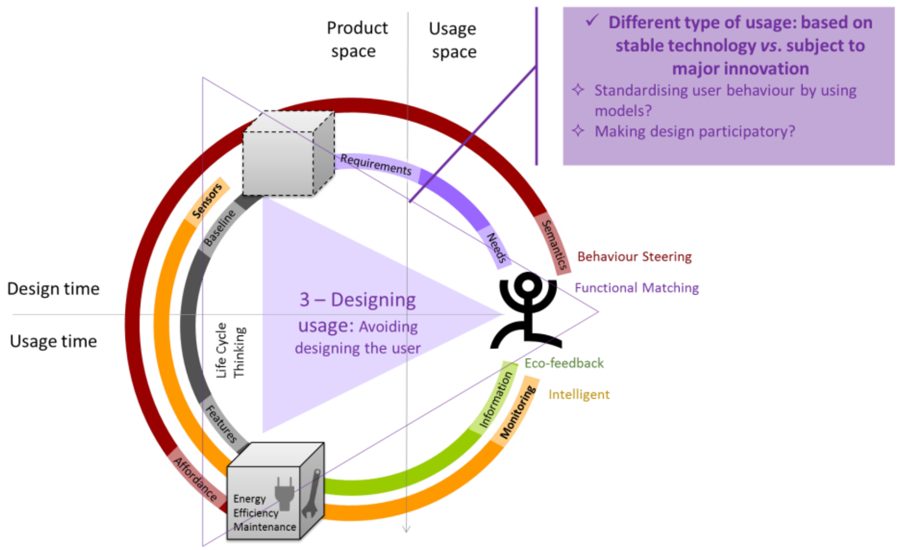

Figure 18: Different types of users to take into account

Standardizing user behaviour in modelling

A common risk with modelling systems is to simplify the reality too much, to the point where the model and the reality are so far apart from each other that using the model hinders decision making. This is crucial for the topic of usage integration for eco-design. The main question is: what is the appropriate object to model about usage, to fuel the development process?

In the building modelling approach (round table 1), two alternatives were presented. The first one excluded the user from the scope of modelling, including it by proxy of a probability of action [Vorgier 2016]. The second one was based on listing seven usage functions of the building [Cluzel, 2016].

In round table 2, Popoff proposed to define the ideal usage of the product, in order to elicit the ideal usage patterns from a design point of view [Popoff, 2016].

Moving away from agent-based simulation, the actions, activities, and behaviour were the objects mentioned during this workshop to be able to model the usage space in the design space. But many more are available, like practice. Trialling and testing the different modelling units for usage integration in eco-design have to be put on the research agenda.

Participatory design

To avoid modelling the user in the design space, a solution is to invite him/her in the design space, through participatory design.

In the building sector, where there is a low level of standardisation between products, this can be done by inviting the future occupants to a design meeting. The difficulty in this situation can be linked to the definition of the future occupants themselves. This specific case is simplified for rehabilitation processes where the future occupants are the current ones.

In the telecom sector, the participation of users is eased with customer test centres built on a community of volunteer users to test products (as reminded by Durieux from Orange Group). This illustrates the first step of participatory design: sharing prototypes or mock-ups to see how the user responds to the current design.

Gamification [Abi Akle, 2016] is another participation strategy: involving users into driving the environmental performance of systems through fun or serious games. The game also enables to open a window into the usage space and time by providing data in use. This data can then be used for the next generation of system designs, in the case of [Abi Akle, 2016] for the design of a new housing complex.

The difficulty encountered by the research team is the representativeness of their participants. In the context of gamification, the data collected might be restricted to a category of occupants (the ones that play games, cf. previous section about collecting data).

Another barrier to participatory design is the data sharing along the supply chain: including users in the development means allowing them to learn about the product design.

The difficulty faced by the repair community (repair café, Ifixit, etc.) illustrates the barrier to data sharing with users. They have trouble in getting access to basic instructions, such as how to dismantle a product, the availability of spare parts or getting access to diagnosis tools to evaluate the functional state of the product.

Nevertheless, data sharing, transparency and building trust with users is crucial, if designers wish to reach the full environmental potential of solutions like upgradable products. In this design case, the necessity and the type of upgrades for products depend on the functional state of the products and their alignment with user practices. The decision to go for a specific type of upgrade has to be negotiated with the users, making it necessary to include him/her in the design of upgrades.

Two types of usage: with a stable technology and with innovative solutions

Two types of design situation can be differentiated from each other:

- Development of innovative solutions, where assumptions about usage and its potential environmental consequences are highly uncertain. For example, smart-meters have been branded to enable users to decrease their energy consumption but the newness of the product makes it difficult to assess exactly how much.
- And the development of products associated with establishing good usage patterns. Even if products have an influence on usage just by their mere existence [Shove, 2003], if this type of product has been domesticated, usage simulation in design can be based on the behaviours identified today.

This has major implications in terms of environmental product policy. The standardisation effect of regulation can be powerful for stable technologies, leading an entire sector on the path to environmental efficiency. But standardisation also hinders innovation, especially if the new product and/or service is likely to transform usage itself. To foster innovation related to the transition towards sustainable behaviour, legislation needs to be adapted to design solutions that can create new usage patterns. This is also true for innovation in general, where environmental performance in usage is based on an uncertain scenario. It is for this type of evaluation problem that the concept of precautionary principle was proposed. Careful evaluations and multiple scenarios assessment have to be tested to make sure that the cure is not worse than the disease, even in the case of innovation.

This is an opportunity for researchers to work on models and simulation tools that can support the application of the precautionary principle without stopping innovations in industrial products.

TARGET USER GROUP DEFINITION

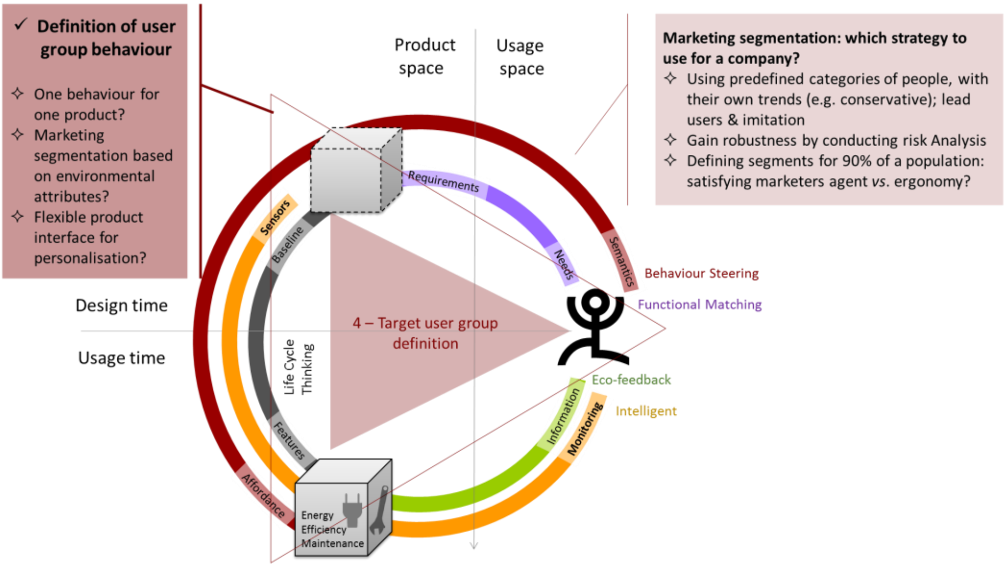

Figure 19: Targeting user group definition

One behaviour = One Product?

One of the explanations of why the building sector is so far ahead of other sectors in user integration is that every "product" is different from the other, allowing for mass customisation. This means that one product is designed for a limited number of users or occupants.

Craftsman production and tailor-made products are a way to adapt products to usage but all the benefits of industrial standardisation in decreasing the environmental impacts of production and end-of-life are lost.

This brings back the debate to a central issue: is product design aimed at feeding the industry with new "stuff" for products or aimed at fulfilling user needs?

The latter is the answer of the eco-design community. So, if design is aimed at fulfilling user needs, it has to be equipped to identify them (through feedback, consumer reports...). This might mean moving away from mass production and building the case for mass customisation. This transition is now supported by all the abilities of software interface to control the actions of products depending on the context of use and additive manufacturing for small batch production.

Researchers and their industrial partners have to assess the environmental and financial benefits of mass production, mass customisation or personalisation. It is only by internalising all the costs (environmental and financial) of product life cycles, that a wise decision can be made on whether to go for one-size-fits-all or for one product for one person.

Marketing segmentation based on environmental attributes

Influenced by marketing approaches, segmentation can be a means to finding the right balance between mass-produced and personalized systems. Segmentation means that users can be clustered in a group with similar attributes and that a specific product that fits these attributes specifically is to be designed.

Some have been using segmentation based on the willingness to act on environmental issues such as that developed by DEFRA [DEFRA, 2008] and ADEME [Ethicity, 2011]. This results in groups spanning from the positive greens (so-called *Bobo* in French), who are willing to act on environmental consumption, to the honestly disengaged (conservative), who are relatively distant from environmental challenges.

This first approach to segmentation, based on environmental attributes, has been used by several attendees of the workshop (CETIM, University of Grenoble Alps and University of Toulon).

Some specific design interventions, such as serious game development, are targeted at geeks and techies, regardless of the environmental attributes. This provides a new perspective on grouping users for eco-design purposes. In this case, the segments are defined based on their perception of the medium of intervention, here a game, rather than based on the message conveyed, i.e. energy conservation [Abi Akle, 2016].

Contrary to the segmentation approach, ergonomics is aimed at addressing the problems of 90% of the population. Applying this concept to environmental improvements, it means developing design solutions that are robust to a wide range of behaviours and, on average, improves the performance. It can be considered that all approaches that are not based on segmentation are supported by similar premises: gathered to the maximum of users' practices. This approach can be found in the preliminary reports for the implementation measures of the eco-design directive by the European Commission.

Both approaches are valid from an environmental standpoint. The segmentation approach is useful, especially when a push for more environmentally responsible behaviour is needed. In this case, product designers need to focus on a specific user group, to push them into adopting more sustainable practices. The ergonomics approach is powerful when design solutions are aimed to be "user-profile" proof. In this case, the feature has a positive influence on the environment regardless of the users' actions.

Flexible product interface for personalisation

As mentioned in the first paragraph of this section, new technologies offer a wide variety of personalisation solutions.

Two solutions were mentioned during the last round table:

- The possibility of IT-based customisation,
- The customisation through service provision on top of the product.

In the first category, software adjustments can be done first when acquiring or installing the product, by choosing the appropriate global setting of the device. This is done for a thermostat for instance. In this case, the product setting is customised by the user who schedules the temperature controls depending on his/her routine. Later, if a data collection mechanism is in place, through sensors or user surveys, the device can adjust its performance to users' activities. This type of customisation has been used to increase customer satisfaction in internet-based services for media content, such as Netflix or Youtube.

A second means of personalisation is through the addition of services, available throughout product usage. This method is used in a lot of approaches aimed at expanding product shelf life, such as upgrading.

What's next for eco-design and usage integration

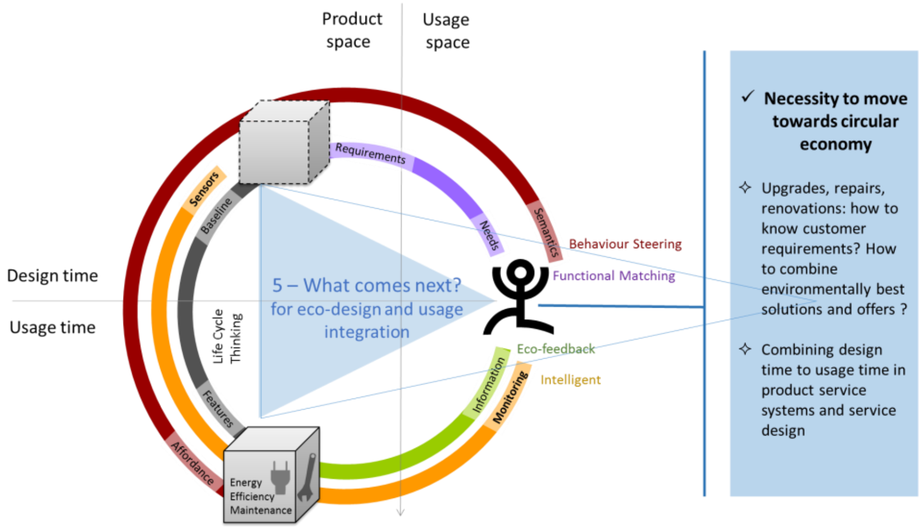

Figure 20: Towards circular economy-based usage information

Moving towards circular economy solution: upgrades, repairs, renovation…

Efforts to improve efficiency in use are starting to pay off. Excluding potential rebound effects, consumer products and buildings are consuming less energy than they used to.

For the building sector, the challenge has moved from “keeping it warm” to “keeping it cool”. Now that solutions exist to improve insulation (new insulation materials and technologies, controlled ventilation...), a new challenge arises: how to evacuate the heat from the numerous appliances in the home. Heating was, and still is to some extent, a problem but cooling homes in warmer seasons has appeared as an additional environmental challenge.

In parallel, and to follow the transition towards circular economy, renovation is the way forward for buildings. The RT 2012 law (building consumption) is focusing much of this effort on existing housing and monuments. It aims at improving the energy efficiency for existing constructions, through external insulation, vents, etc.

In order to go a step forward in the eco-design process, a number of solutions have to be explored.

Integration of usage and of the user is expanding the value chain in design activities and is supporting the transition towards circular economy. The challenge for industries is to fully understand the need of users to get involved in keeping product value longer.

The burgeoning community of repair cafés and online forums on how to fix products needs to be seen as an opportunity for industry to support service provision rather than a threat to the current product-based business model.

The eco-design research community is getting ready to support the transition. The main focus is on developing tools, assessment methods and design methodology that can support designers and users in choosing between the different paths and/or a combination of the different paths:

- Should the product be maintained preventively?
- If the product stopped working, how to diagnose what caused it?
- Based on the diagnosis, should the product be upgraded, repaired, dismantled for parts, recycled…?
- Where can the parts, tools and materials be found to upgrade, repair, dismantle or recycle the product correctly?

Moving towards circular economy expands the value chain to new actors like repair networks, the second-hand market for products or remanufacturers. More importantly, the new value chain fully encompasses usage in its loop. Integrating this life-cycle phase in design activities is even more crucial today, when the most important path to circular economy relies on the implication of the users.

Combining design time to usage time in product service system and service design

The main scheme used in this conclusion separates design time from usage time to represent the asynchronous activities of designing a product and using it. However, advances in service design are synchronising these activities; it allows for design and usage to happen at the same time, improving user experience dynamically.

Most industrial feedback from the workshop associated or was considering associating their product with service in use.

Upgrades [Cor 2016; Popoff, 2016] are gaining a lot of attention for their ability to address potential losses of interest from the user by modifying product layout and features due to an upgrade service.

The fact that the workshop was co-organised with Orange Group, a service provider, illustrates the joint interest for service-focused design to make design and usage happen at the same time.

Additionally, transition to the functional economy, one of the pillars of circular economy, is benefiting from the move towards a more service-focused product design.

Even in the building sector, the transition is supported by initiatives such as energy performance warranty. Such contracts guarantee an energy-efficient home for the user. Occupants get money back if their home is not as efficient as advertised. This new service pushes both builders and users to analyse usage patterns in greater detail to make housing have less of an impact on the environment.

Usage-focused eco-design developments have to be compatible with those from the eco-design of product service systems' fields. Collaborations between these fields are much needed to support the transition towards circular economy.

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