This is an Accepted Manuscript of an article published by Taylor & Francis in Ergonomics on 10 April 2019, available online: http://www.tandfonline.com/10.1080/00140139.2019.1600049.

Introducing ergonomics requirements in the eco-design of energy-related products from users' behaviour approach

*Jorge Sierra-Pérez[1,2], Jesús Boschmonart-Rives[1,3] Jordi Oliver-Solà[1,4]

1 Sostenipra (ICTA – IRTA - Inèdit Innovació SL) 2014 SGR 1412. Institute of Environmental Science and Technology (ICTA), Unidad de excelencia «María de Maeztu» (MDM-2015-0552), Universitat Autònoma de Barcelona (UAB), 08193 – Cerdanyola del Vallès (Bellaterra), Barcelona, Spain.

2 Department of Design and Manufacturing Engineering, EINA, University of Zaragoza, María de Luna 3, 50018 Zaragoza, Spain

3 Eurecat, Centre Tecnologic de Catalunya. Carrer de Bilbao, 72, 08005 Barcelona, Spain

4 Inèdit Innovació, S.L. Parc de Recerca de la Universitat Autònoma de Barcelona (UAB), 08193 – Cerdanyola del Vallès (Bellaterra), Barcelona, Spain

*Corresponding author: jsierra@unizar.es, Phone +34 976 761 905

Other authors: jesus.boschmonart@eurecat.org, Phone +34 932 381 400

Other authors: jordi@ineditinnova.com, Phone +34 932 683 476

Wordcount: 5,482 words

Introducing ergonomics requirements in the eco-design of energy-related products from users' behaviour approach

Ergonomics has been a very important activity in the design process. However, ergonomics rarely includes the environmental requirements into the design of products. The article proposes and presents the Eco-Ergo model through its application to a real-world product, a washing machine, to allow designers and ergonomists to establish product design requirements in order to minimize environmental impacts related to user-product interaction during the use stage. This model uses a visual language of representation, Blueprinting-based, that helps designers explore problems they have not previously considered during the market research, when a wide variety of products with different interaction elements is analysed. The application of this model allows direct efforts and attention on the user analysis phase in the most influential user's actions on the environmental performance of energy-related products during use, establishing ergonomics requirements related to users behaviour at the initial design phase.

Keywords: Ergonomics, User centred design, Product design, energy-related products, user behaviour

Practitioner Summary

This study provides a proposal to incorporate ergonomics into the practice of eco-design through the use of human factors in the establishment of initial eco-design requirements. This blueprint-based model combines an empirical and theoretical approach, based on the product test developed by designers, ergonomists and environmentalists.

Wordcount: 5,482 words

1. Introduction

The design process integrates several dimensions, including the technical, human, organisational, social and economic. The main challenge of this activity is to achieve all these tasks in terms of quality, performance, cost, and deadlines. Ergonomics has always been an important activity in the design process, ensuring that the specificity of the human factor is incorporated into the design approach. Based on knowledge, methods and tools; ergonomists advise the designer on who the user is, in order to design products adapted to user needs and help the designer assess the consequences of the design choices made in terms of safety, health, comfort and efficiency (Chapanis 1995; Sagot, Gouin, and Gomes 2003).

The integration of the environmental dimension in the design of products is managed by eco-design. This methodology aims to integrate the environmental aspects into the design process in order to improve the environmental performance of the entire lifecycle of a product (EU Directive on Eco-design) (European Council 2009). Traditional eco-design has a strong focus on the supply side and efforts have focused on minimizing environmental impact on intrinsic characteristics of the product, like weight and mechanical strength, through technology and its efficiency. But for energy-related products, there is another important aspect to be considered at use stage: how users make use of the product (Norman 1988). This type of products may strongly influence the environmental impact and designers can try to influence this behaviour through the products they design (Wever, van Kuijk, and Boks 2008; Hebrok and Boks 2017).

In this regard, the definition of sustainable development and human factors has been slightly complicated by a minor proliferation of similar terms (Radjiyev et al. 2015). The term “eco-ergonomics” (Hanson 2010; Hedge 2008) has also been used, appearing as early as 1998 (Charytonowicz 1998), to take into account the needs of the natural environment with which humans interact. Thatcher (2012; 2013), and Thatcher and Groves (2008) used the related term *Green ergonomics*, highlighting the design of low resource systems and products, the design of green jobs and achieving systemic behaviour change, as areas where ergonomics could contribute to conserving and restoring nature and allowing humans to benefit. Moreover, *Ergoecology* is a scientific and technological discipline that integrates the evaluation and intervention processes used by ergonomics and environmental management systems to establish, analyze, reduce, prevent, control and rectify the impacts derived from the relationship between humans and the environment (Saravia-Pinilla, Daza-Beltrán, and García-Acosta 2016; García-Acosta, Saravia Pinilla, and Riba I Romeva 2012).

However, the role of ergonomics in sustainability, sustainable development and sustainable design is still seldom reported or considered (Martin, Legg, and Brown 2013; Radjiyev et al. 2015), despite a call for research into ways to get people to modify their behaviour to be more ecologically conserving (Thatcher 2012). Moreover, improvements in the efficiency of products and services in the use of energy and resources could make the change towards a more sustainable behaviour much easier (Tosi 2012).

From a product design approach, Design for Sustainable Behaviour DfSB (Pettersen and Boks 2009) is an emerging research field that opens the analysis on how design can influence users' habits to reduce these environmental impacts (De Medeiros, Da Rocha, and Ribeiro 2018). DfSB is part of product design field, foregrounding how products and their communication interfaces can give users immediate and direct answers to user operations: how they are perceived, learnt or used. From a theoretical approach various theories have been developed, but few authors have materialized them into holistic models or tools to apply on environmentally sustainable innovation practices (Baldassarre et al. 2017). Tang and Bhamra (2012) proposed the *DBIM (Design Behaviour Intervention Model)*, which links these design strategies with socio-psychological theories and models of behaviour, identifying innovative points that allow the design to influence individual behaviour and habits through elements of behavioural change related by the intention, user habits and user control through the own product. In this regard, the *Design for Circular Behaviour* model (Wastling, Charnley, and Moreno 2018) offers designers a structured way to think the main behavioural targets to consider when designing product or business solutions for a circular economy.

From an empirical approach, some authors conducted various experiments with real users, following User-Centered Design methodologies (Maguire 2001), obtaining specific conclusions about user behaviour for tested products. Elias, Dekoninck and Culley (2008; 2009a) proposed the *User-efficient Design* and Lockton, Harrison and Stanton (2010) proposed the *DwI Method (Design with Intent Method)*. The former quantifies the energy efficiencies of product use, from the energy required to deliver the desired function to the amount of energy wasted through careless actions. The latter aims to address the lack of guides applicable by designers working on existing user behaviour problems, suggesting relevant design techniques for influencing types of behaviour, and providing examples of how similar problems have been tackled elsewhere. These models and its strategies are applied within design processes following a user-centred methodology, including: full user analysis, user observation in the environment, establishment of requirements, design, prototyping and testing.

Ergonomics and User Centered Design is essentially the study and application of ergonomics principles throughout the process of design to make it user friendly, safe and cost effective with a view to get optimal human performance (Vredenburg et al. 2002). The ergonomics of analysing the interactions between the user and the product is cognitive ergonomics; discipline that develops specifications of user behaviour with respect to the interface, broadly defined such that interactions produce desired performance. The contribution of cognitive ergonomics is to develop the specification of the knowledge which determines user behaviour (Long and Whitefield 1998). It is important to note that ergonomics have great potentialities in the utilization of valuable human resources and in the identification of scope for further improvements on the existing designs or need for developing new designs for creating better tools, equipment, workspace and work methods to reduce job related injuries, illnesses, and stresses, and to increase job satisfaction, which leads to improve productivity (Stanton, Young, and Harvey 2014). Therefore this is where ergonomics can play a key role in user-product interaction and efficiency in the use of the products (Martin, Legg, and Brown 2013).

The ergonomic approach should start at the initial design phases with a needs analysis and the establishment of design requirements, and be applied throughout the design process. The phase of the product conceptualization is very important due to the high number of characteristics of the product that are defined at this stage, for example over 80% of environmental impacts of a product are determined during the design phase (Umweltbundesamt 2005). Therefore, it is necessary to include in the initial design requirements the user-product interaction approach for a more sustainable product use.

This paper introduces a new model to introduce ergonomics requirements in the eco-design of energy-related products. The organization of the paper is as follows: First, the “Motivation and scope” describe the model objectives and the potential fields of application. Subsequently, the “Material and Method” section presents the model background and the process of model design, introducing the previous information required to build it. Then, this model is applied to a real product to understand better the advantages of using this model. And finally, a comparison between this model with other models are presented and discussed.

2. Motivation and scope

2.1 Objectives

The article aims to propose a model for allowing designers and ergonomists to establish product design requirements for minimising environmental impacts related to user-product interaction during the use stage, by incorporating ergonomics requirements related to the user behaviour at the initial design phase. The Eco-Ergo model aims to complement the disciplines of ergonomics and eco-design.

The aim of the model is to display the using process of energy-related products and the interrelationships between elements of the process, as well as the inputs and outputs they generate in the system. Thereby areas of environmental improvement in the process can be identified and design requirements relating to sustainable user behaviour can be introduced in future product design.

2.2 Scope of application

This model has been developed primarily in response to the need of minimising the environmental impact of energy-related products derived from the user behaviour, incorporating ergonomics requirements in the early stages of the product design process. The Eco-Ergo model represents the using sequence of a product from three different approaches:

(1) User-product interaction, what the user-product interaction is like,

(2) User behaviour, what freedom of behaviour exists between user and product, and

(3) Environmental sustainability, how foregoing results turn in environmental impacts through inputs and outputs of system.

Initially, the scope of this study is focused on household appliances (white goods) because of being products whose use stage concentrates most of environmental impacts. Moreover they are products that are part of the standard consumer's daily routine and in which those habits of use are already set.

3. Materials and Methods

3.1 Eco-Ergo model background

Several studies about the efficient user behaviour in the use of household appliances have been already published: fridge and freezers (Tang and Bhamra 2012; Bhamra, Lilley, and Tang 2011; Elias, Dekoninck, and Culley 2009a; Elias, Dekoninck, and Culley 2009b) electric cookers (Oliveira, Mitchell, and Badni 2012) and kettles (Elias, Dekoninck, and Culley 2009b). Moreover, the context of application has been recently extended to more complex systems, in which is part of a system of systems (Thatcher et al. 2018; Thatcher and Yeow 2016), such as buildings (Attaianese 2016; Kalantzis, Thatcher, and Sheridan 2016) or hybrid electric vehicles (Franke et al. 2016), among others.

Focusing on the development of the Eco-Ergo model, a user-centered approach was followed to identify and analyse each product and user's action. To represent adequately and clearly the process of use, the Eco-Ergo model is based on a service design model, blueprinting. Blueprinting was initially introduced by Shostack (1982; 1984) and developed further by Kingman-Brundage (1989; 1993) and Kingman-Brundage, George, and Bowen (1995). This model uses a visual language of interaction based on molecular modelling, in which atoms or entities are connected in a unique molecular. The representation of interaction processes between user and product or service, apart from facilitating the display of all elements that it comprises, helps analyse how they relate to each other.

First versions of the Blueprinting identified the relation between the activities and the standard execution times (Shostack 1984) in which actions were depicted into 2-axis scheme. The horizontal axis represents the chronology of actions performed by the user and the vertical axis indicates distinguishes different areas of action into layers separated by different lines (Kingman-Brundage 1989). The relationships between different elements are represented by arrows linking each other and pointing with their tip in the direction of the action (Figure 1).

[Figure 1 near here]

At first Shostack (1984) and Kingman-Brundage (1989) distinguished only front office and back office areas (the part that a user sees and that which is hidden to them) and the line of sight between them. Later, with the development of the model by other authors, it was extended by adding other areas and lines of separation (Fließ and Kleinaltenkamp 2004). Moreover, blueprinting has been continuously expanding to include different issues (Bitner, Ostrom, and Morgan 2008) such as organizational structure (Biege, Lay, and Buschak 2012), physical and virtual evidences (Morelli 2002; Patrício et al. 2008), customer experience (Stickdorn and Schneider 2011; Bitner, Ostrom, and Morgan 2008; Polaine, Løvlie, and Reason 2013; Berry, Carbone, and Haeckel 2002), or product behaviour (Hara et al. 2009).

The Blueprinting was initially developed to represent services, although it spread to other areas such as software design, Methods-Time Measurement (MTM) in engineering, scheduling PERT/time, or computer systems, as well as designing Product-Service Systems (PSS) (Kingman-Brundage 1993; Boughnim and Yannou 2005; Morelli 2006).

From an environmental approach, there is not a widespread number of studies that uses this model to introduced or analyse product or services environmentally. But Blueprinting is already considered as an adequate tool to describe a service in the same way as a product with the help of a process tree, can be a suitable tool to obtain insight in the visible and invisible elements of a service, such as environmental impacts (Brezet et al. 2001; Costa et al. 2015). Moreover, Geum and Park (2011) proposed a more advanced blueprinting model to illustrate PSS effectively, introducing new areas and symbols. This model is used to visualise in an integrated way the PSS, representing all interrelation between manufacturer-user, product-service. However, the model does not allow the evaluation of either a qualitative or a quantitative service from an environmental point of view.

The representation of the blueprinting model provides a methodology to analyse processes based on the integrated elements and their interrelationships, seeking efficiency of the process itself. It is considered that Blueprinting model is suitable for sustainable design methodologies because the environmental impact that is generated when using a product is invisible to the user, as in the case of services with all activity remaining at back office. Therefore, the use of this visual language that relates each process with its consequences can be used to subsequently analyse of strategies and actions to implement environmental improvement in the new product.

3.2 Design of the Eco-Ergo model

A team of experts in product design, eco-design and environment develops the Eco-Ergo model in a co-design process between them. The process has actively engaged researchers and users during iterated group dynamics when Eco-Ergo model was adjusted according to the conclusions of the sessions. The Eco-Ergo model is based on the Blueprinting visual language (Figure 1) adapting it to the products actions and the interactions of user with energy-related products, and also extends the original Blueprinting to the user behaviour and the environmental implications related to the user-product interaction. The new representation proposal has the scheme presented in Figure 2. To represent the process of use of an energy-related product by the Eco-Ergo model the following steps have to be followed.

[Figure 2 near here]

3.2.1 First step: Actions of user

First of all, the process of use has to be defined, putting the different steps of the process in the first line of the model, in the user area (Figure 2). These steps are represented in the Eco-Ergo model by rectangles, following a chronological order divided in: beginning of the process, process preparation, process execution, post-processing and end of process. All the user actions will be placed in the first row and linked to an user-product interaction in the interaction area and/or to an action of the product in the product area.

3.2.2 Second step: Interaction related to the user action

Between the line of behaviour intervention and the line of interaction, there is the interaction area. The latter, separates the action to perform from the actual interaction through elements of influence on behaviour and the former, limits the area where the user can interact with the product.

The elements of behaviour intervention are all features included in the product to influence the behaviour of the user during the product use. This model distinguishes between audible and visual warnings, suggestions and specific functions. These elements are represented in the Eco-Ergo model by an ellipse, indicating the type of element of intervention in the product and are placed in the second row (Figure 2).

The elements of interaction are the elements that the product has to allow the interaction between user and product in order to use the product. This model distinguishes between: Buttons (2 positions), Switch (2 or 3 position) and Rotary (several fixed positions of continuous rotary adjustment). Moreover, Drive also indicates if products show signs and what type: visual, audible or tactile. These elements are represented in the model by rounded rectangles indicating the type of element and are placed in the third row (Figure 2).

3.2.3 Third step: Actions of product

Below the line of interaction, is the product area, where actions are out of reach from user. The product area is between the line of interaction and the line of environmental impact. The line of visibility, separating the actions that are visible to the user, divides this area.

The actions that the product does in response to the user-product interaction are located in this area. It includes automatic adjustments of the product when a user selects a specific operation program. Moreover, some of the product actions are conditional actions, which occur only if a condition is met. For example, if an element of product (a door) is not correctly closed, the product does not work. These actions are represented in the model in the fourth row (Figure 2).

This area includes inputs (energy, water and resources) and outputs (emissions from energy and resources consumption and waste derived from the product use) in the using process; not every action has necessarily an input. It has to establish an inventory, quantifying the inputs and outputs during the process. Then, inputs are represented in the model in the fifth row and outputs are placed in the sixth row. The line of visibility separates inputs and outputs.

An important step in the representation of the model is the correct attachment of different elements related to each other by arrows, indicating the progression of the using process (Figure 2). These data represent the effect of the action performed: user actions with the action of the product, the product action with another product action or a user action, etc. If there are multiple actions coming from the same element, the arrow is branched out placing a circle in the joint to point out where it comes from.

3.2.4 Fourth step: Environmental impact analysis

Finally, the line of environmental impact presents the environmental impacts generated by the emissions and waste generated, which are quantified using Life Cycle Assessment (LCA) methodology (ISO/EN 14040 2006). This methodology quantifies and identifies the potential environmental impacts throughout a product's life cycle. The Simapro software (PRé Consultants 2010) and Ecoinvent database 3.1 (2009) are used to simulate these impacts from a detailed inventory of inputs during the product life cycle. In order to present results in a comprehensive manner, the model uses qualitative results, using a degree of high/medium/low and are placed in the last row (Figure 2). The degree of the environmental impact depends the total environmental impact of the using process, and each environmental impact has more or less contribution in total.

3.2.5 Fifth step: Identification of the improvements areas

Once the using process of product is represented into the Eco-Ergo model, the most significant environmental impacts will be identified, and the upstream of these impacts will be analysed. Therefore, it can know how these inputs have been incorporated in the process and who has the control of that action.

3.2.6 Sixth Step: Requirements proposal for a sustainable user-product interaction

Since then, the valuation of the most impacting interaction steps will results in new design requirements to reduce the environmental impacts. The requirements should incorporate measures of behaviour intervention and product design to increase the efficiency of the use of product.

4. Application of the Model to a Real Product

4.1 Case study: The washing machine

The model is introduced being applied in a real product to facilitate the understanding of the model. The product chosen is a washing machine, a conventional product that exists in the majority of homes, and that an average user can use and understand how it works. The specific model selected as case study is already on the market and is the top selling in the washing machine sector. Moreover, this product had been also selected due to having the most efficient energy label, A+++. The selected washing machine is the model Bosch WAY28740EE (Robert Bosch 2013), world leader in the production of appliances.

In order to establish the standard process of use in the case of the washing machine, the authors carried out the washing process following the user manual published by the company in order to follow the ideal using sequence.

The interaction panel is on the product front with the scheme presented in Figure 3. The interface is divided in two parts, the rotary selector to select the specific programs and the screen with the buttons to set program and options. By default the product selects a basic washing program for cotton with a medium soil with the following parameters: 60 °C, 1400 RPM (Revolutions per minute) and 2:31 hours. From the point of view of environmental sustainability, the product has two additional options: energy saving (Eco) and another shorter wash for partial loads (speed). The user is who has the final decision of selecting them.

[Figure 3 near here]

The detergent and the softener are introduced in two separate compartments for different stages of washing with specific symbols (Figure 4). The product suggests on the display the quantity of detergent necessary for the amount of clothes to wash.

[Figure 4 near here]

In relation to the consumption of energy, water and resources (detergent and softener in this case) during the washing process, the product datasheet points the following data for a cotton wash program at a temperature of 60°C (the default program). The energy consumption at full load (8 kg of clothes) is 0.75 kWh. Water consumption in this program is 45.4 liters of water and 88 milliliter of detergent per wash. Wherein the total washing time is of 2 hours and 31 minutes. Based on this inventory of energy and resources consumption, the environmental impacts will be assessed.

4.2 Application of the Eco-Ergo model

The washing process by default is the selected one to present the Eco-Ergo model. This process is explained in the user manual step by step and the resources and energy consumption is also declared. Moreover, the additional options are also taken into account, because they can be selected in addition to the default washing process. Following the steps described in section 3.2, the Eco-Ergo model is applied for the case study (Figure 5).

[Figure 5 near here]

4.2.1 First step: Actions of user

First of all, the washing process is defined using the user manual and with a real washing machine all steps are identified and placed in the first row in chronological order. In this case, the washing process follows the usual as it can be noted in Figure 5.

4.2.2 Second step: Interaction related to the user action

The washing machine includes a great variety of elements of interaction, especially drives that alert the user to the correct or incorrect execution of an action or an action is over. Moreover, there are also the typical elements such as buttons, rotary and symbols, in addition to a LCD screen where the information about the washing process and different elements of behaviour intervention is showed. Once all these elements are identified, each user's action is connected with an arrow with its corresponding elements of interaction and, if any, with its elements of behaviour interaction.

4.2.3 Third step: Actions of product

The actions of products respond to users actions and/or their interactions; so each action of product is connected to an user's action. In this case all the product's actions are directly driven after the user executes the corresponding action. Unless in this case, after a product's action the product executes another action and, if applicable, the user is notified. For example, when the washing machine is inactive during a period of time or the washing process is finished. Moreover, the unique conditional action is the properly closure of the door, if not the process cannot start. Regarding the inputs of energy, water and chemicals required by the washing machine, as commented before, the user's manual specify them. So an inventory of inputs is possible to establish, with which to environmentally assess and obtain the corresponding outputs.

4.2.4 Fourth step: Environmental impact analysis

The contribution of each output is expressed from a relative manner with respect of the total impacts: using the nomenclature high (more than 50% total impacts), medium (between 25 and 50%) and low (less than 25%). The impact categories used are Global Warming Potential (kg CO2 –eq) and Cumulative Energy Demand (MJ).

4.2.5 Fifth step: Identification of the improvement areas in using process

Once the using process of the washing machine is represented on the Eco-Ergo model, it has been identified two "ways" or improvement areas on which incorporate eco-design requirement related to a more sustainable user-product interaction (Figure 6).

[Figure 6 near here]

The first improvement area (A) is related to the impacts of emissions from the energy use during the washing process. This process is connected with the action of the washing program selection, and indeed with the user action. This choice determines the temperature, the washing time and the amount of water to be heated for example. The interaction between user and product is performed through various interactive elements:

LCD display screen, a series of buttons for specific options on the contour of the screen and a knob with default programs. Washing programs are determined by three parameters: temperature, RPM of centrifugation and time. To select a different, the washing machine has a rotary knob with some positions marked that adjusts 3 data directly but it can also be modified each one individually. From the point of view of environmental sustainability, the product suggests two additional options, more sustainable, to the user: eco (energy saving) and speed (shorter wash for partial loads). These features use an intervention strategy in guiding user behaviour for sustainable behaviour, but the user is who has the final decision selecting them.

The second improvement area (B) is about the impacts of wastewater generated during the washing process. This way is related to the action of the detergent and softener addition in the wash and rinse water. In this process, the information provided by the product, suggests an amount of detergent: a portion or percentage of detergent in relation to the total capacity of the drum. The device indicates this on the screen in function of the load of clothes introduced in the drum. The recommended amount of detergent is shown in the display, and works as a feedback strategy, giving all the freedom of behaviour to the user. In this way the product is intended to guide the user to a more sustainable behaviour.

4.2.6 Sixth step: Requirements proposal for a sustainable user-product interaction in washing machines

The selection of the washing program by the user action is where most impacts are concentrated. Accordingly several opportunities for improvement were identified:

(1) Excess of washing programs and selectable options by user: pre-set programs are very specific and unusual, and additional options (eco washing) should be

integrated into other programs but marketing reasons may be the cause of adding extra functions to communicate environmental sustainability. Recently, new models of washing machines control themselves the loading of laundry, having in this case a weight sensor installed.

(2) Subjectivity in the interpretation of washing parameters: the replacement of the current washing parameters (temperature, RPM of centrifugation and time) by more comprehensible ones by the user, such as the type of tissue or the dirt level. These parameters are complex for the users, and they not have the information about the necessary RPM or the water temperature to clean properly an item of clothing depending on its dirt level.

(3) Lack of control in detergent dosing: the goal of users is to get clothes completely clean, so they prefer to increase the amount of detergent in the washing process in order to ensure this goal. The capacity of the dosing drawer is well above the amount needed. It should transform the recommendation given by the product into an adjustment by the product itself. Recently, new models of washing machines dose themselves the quantity needed in function of the type and the amount of clothes, meanwhile the user only has to fill the detergent tank and select the type of clothes. This is not necessarily a good measure; maybe users feel that lose control in the process and reject the technology.

The previous improvement opportunities can be set into the following design requirements to set a more sustainable user-product interaction:

- Synthesize different washing programs by reducing the number of options to choose.
- Visually rank programs according to regular use.

- Using more comprehensible washing parameters to allow user to have some control over the process.
- Establish a measurement system or chemicals substances dosage in device depending on washing factors, taking into account the user's behaviour intervention approach.

5. Results and Discussion by Comparing the Eco-Ergo Model with Other Models

The Eco-Ergo model is not intended to replace previous models within the scope of the Design for sustainable behaviour such as Design Behaviour Intervention Model (DBIM) (Tang and Bhamra 2012), *Design for Circular Behaviour* (Wastling, Charnley, and Moreno 2018), User-efficient Design (Elias, Dekoninck, and Culley 2008; Elias, Dekoninck, and Culley 2009a) and Design with Intent (Lockton, Harrison, and Stanton 2010). These models work from a methodology of user-centred design focused on user behaviour change through design with the aim to be as sustainable as possible. For both models, DBIM and User-efficient Design, the conducted case study is also for a white good: a fridge. DBIM model was centred in general aspects of the use of a fridge, such as the distribution of food regarding the functional aspects of fridge and the cultural and social values that conduct the ordinary consumption behaviour. Tang and Bhamra (2012) proposed a wide variety of design options to change the user behaviour and also highlighted the need of improve the communication of the energy use and efficiency of fridge due to the lack of information about that. On the other hand, the User-efficient Design model was focused in the determination of the fridge's energy losses, the intrinsic losses of product and the user-related losses. This model is more focused in determine the significance of user-related losses as a proportion of total product energy use than in the proposition of design requirements. Meanwhile Design with Intent model provides to designer a range of potentially applicable design patterns and examples, with short explanations, to inspire the generation of concept solutions to the brief. The analysed product has to be adapted to provide examples and perhaps they are not well suitable to the needs. Summarising, these models analyse the sequence of use of products generally from a theoretical approach, rethinking the traditional mode of use. The proposed changes can imply a high investment in the manufacturing of products and can also suppose a risk for the user acceptance. In contrast, the Eco-Ergo model it is less ambitious and is designed for being used in specifics models of a product, more focused in the particular options, programs and operation settings.

Eco-Ergo model is intended to be a complement to this type of models at first stages of a product design or redesign process, when the initial design brief is set (Gilbertson 2006; Smith and Wyatt 2006), and the design requirements have to be established. This allows direct efforts and attention on the user analysis phase in parts of the process that represent greater environmental impacts.

6. Conclusions

A team of experts in product design, eco-design and environmentalists has developed the Eco-Ergo model, in a collaborative process, including group dynamics with others researchers from different areas. This model uses a visual language of representation, Blueprinting, to identify the more influential user's actions on the environmental performance of energy-related products during its use. The main objective of Eco-Ergo is to allow designers and ergonomists to establish product design requirements in order to obtain a more sustainable behaviour of users.

This model has the potential to help designers explore problems they have not previously considered during the market research, when a wide variety of products with different operating modes and interaction elements is analysed. With this regard, the Eco-Ergo model allows to analyse quickly different type of products from user behaviour approach, concluding in the most and least ways of efficient interactions. This article introduces the model describing step by step the application of the model in a washing machine, identifying some opportunities for improvement during the process of use, such as the excess of washing programs and selectable options by user, the subjectivity in the interpretation of washing parameters and the lack of control in detergent dosing.

In contrast with previous user behaviour intervention models, the Eco-Ergo model can be a complement to other user behaviour intervention models at first stages of a product design or redesign process, being used in specifics models of a product, more focused in the particular options, programs and operation settings

Future research can extend the application of the model in other areas of ergonomics and design where human factors has an important role, such as sound design, services design or design innovation. This model can allow to explore new consumption patterns, new concepts of services and products; helping to design more sustainable systems but at the same time taking into account the user behaviour and its implications.

References

Attaianese, Erminia. 2016. "Enhancing Sustainability Embodying Human Factors in Building Design." In *Ergonomics in Design: Methods and Techniques*, edited by CRC Press, 447–464. doi:10.1201/9781315367668-29.

Baldassarre, Brian, Giulia Calabretta, Nancy Bocken, and Tomasz Jaskiewicz. 2017. "Bridging Sustainable Business Model Innovation and User-Driven Innovation: A Process for Sustainable Value Proposition Design." *Journal of Cleaner Production* 147: 175–186. doi:10.1016/J.JCLEPRO.2017.01.081.

Berry, Leonard L, Lewis P Carbone, and Stephan H Haeckel. 2002. "Managing the Total Customer Experience Managing the Total Customer Experience." *MIT Sloan Management Review*. doi:10.1371/journal.pone.0015090.

Bhamra, Tracy, Debra Lilley, and Tang Tang. 2011. "Design for Sustainable Behaviour: Using Products to Change Consumer Behaviour." *The Design Journal* 14 (4): 427–445. doi:10.2752/175630611X13091688930453.

Biege, Sabine, Gunter Lay, and Daniela Buschak. 2012. "Mapping Service Processes in Manufacturing Companies: Industrial Service Blueprinting." Edited by Michiya Morita. *International Journal of Operations & Production Management* 32 (8): 932–957. doi:10.1108/01443571211253137.

Bitner, Mary Jo, Amy L. Ostrom, and Felicia N. Morgan. 2008. "Service Blueprinting: A Practical Technique for Service Innovation." *California Management Review* 50 (3): 66–94. doi:10.2307/41166446.

Boughnim, Nabil, and Bernard Yannou. 2005. "Using Blueprinting Method For Developing Product-Service Systems." In *International Conference of Engineering Design (ICED)*. Melbourne, Australia.

Brezet, Han, Arianne S. Bijma, John R. Ehrenfeld, and Sacha Silvester. 2001. *The Design of Eco-Efficient Services. Ministry of VROM–Delft University of Technology*.

Chapanis, Alphonse. 1995. "Ergonomics in Product Development: A Personal View." *Ergonomics* 38 (8): 1625–1638. doi:10.1080/00140139508925214.

Charytonowicz, Jerzy. 1998. "Ergonomics in Architecture." In *Human Factors in Organizational Design and Management, VI: Proceedings of the Sixth International Ssymposium on Human Factors in Organizational Design and Management Held in The Hague*, 357. The Netherlands, August 19-22.

Costa, Filipa, Sharon Prendeville, Katharine Beverley, Giulia Teso, and Chris Brooker. 2015. "Sustainable Product-Service Systems for an Office Furniture Manufacturer: How Insights from a Pilot Study Can Inform PSS Design." *Procedia CIRP* 30: 66–71. doi:10.1016/j.procir.2015.02.109.

De Medeiros, Janine Fleith, Cecília Gravina Da Rocha, and José Luis Duarte Ribeiro. 2018. "Design for Sustainable Behavior (DfSB): Analysis of Existing Frameworks of Behavior Change Strategies, Experts' Assessment and Proposal for a Decision Support Diagram." *Journal of Cleaner Production* 188: 402–415. doi:10.1016/J.JCLEPRO.2018.03.272.

ecoinvent. 2009. "Ecoinvent Database 3.1." *Swiss Centre for Life Cycle Inventories*. http://www.ecoinvent.ch/.

Elias, Edward, Elies Dekoninck, and Steve Culley. 2009a. "Quantifying the Energy Impacts of Use: A Product Energy Profile Approach." In *16th CIRP International Conference on Life Cycle Engineering*. Cairo (Egypt).

Elias, Edward, Elies Dekoninck, and Steve Culley. 2009b. "Designing for 'use Phase' Energy Losses of Domestic Products." *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* 223 (1): 115–120. doi:10.1243/09544054JEM1295.

Elias, Edward, Elies Dekoninck, and Steven Culley. 2008. "Assessing User Behaviour for Changes in the Design of Energy Using Domestic Products." In *2008 IEEE International Symposium on Electronics and the Environment*, 1–6. IEEE. doi:10.1109/ISEE.2008.4562920.

European Council. 2009. "Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 Establishing a Framework for the Setting of Ecodesign Requirements for Energy-Related Products (recast)." *Official Journal of the European Union*, 10–35. doi:10.1016/j.cirp.2012.03.121.

Fließ, Sabine, and Michael Kleinaltenkamp. 2004. "Blueprinting the Service Company." *Journal of Business Research* 57 (4): 392–404. doi:10.1016/S0148-2963(02)00273-4.

Franke, Thomas, Matthias Georg Arend, Rich C. McIlroy, and Neville A. Stanton. 2016. "Ecodriving in Hybrid Electric Vehicles – Exploring Challenges for User-Energy Interaction." *Applied Ergonomics* 55: 33–45. doi:10.1016/J.APERGO.2016.01.007.

García-Acosta, Gabriel, Martha Helena Saravia Pinilla, and Carles Riba I Romeva. 2012. "Ergoecology: Evolution and Challenges." *Work* 41 (Suppl 1): 2133–2140. doi:10.3233/WOR-2012-1017-2133.

Geum, Youngjung, and Yongtae Park. 2011. "Designing the Sustainable Product-Service Integration: A Product-Service Blueprint Approach." *Journal of Cleaner Production* 19 (14): 1601–1614. doi:10.1016/j.jclepro.2011.05.017.

Gilbertson, Alan L. 2006. "Briefing: Measuring the Value of Design." *Proceedings of the Institution of Civil Engineers - Municipal Engineer* 159 (3): 125–128. doi:10.1680/muen.2006.159.3.125.

Hanson, Margaret. 2010. “Embracing the Challenges of Climate Change.” *The Ergonomist* 480: 12–13.

Hara, Tatsunori, Tamio Arai, Yoshiki Shimomura, and Tomohiko Sakao. 2009. “Service CAD System to Integrate Product and Human Activity for Total Value.” *CIRP Journal of Manufacturing Science and Technology* 1 (4): 262–271. doi:10.1016/J.CIRPJ.2009.06.002.

Hebrok, Marie, and Casper Boks. 2017. “Household Food Waste: Drivers and Potential Intervention Points for Design – An Extensive Review.” *Journal of Cleaner Production* 151: 380–392. doi:10.1016/J.JCLEPRO.2017.03.069.

Hedge, Alan. 2008. “The Sprouting of ‘Green’ Ergonomics.” *Bulletin of Human Factors and Ergonomics Society* 51 (12): 1–3.

ISO/EN 14040. 2006. “Environmental Management - Life Cycle Assessment - Principles and Framework (ISO 14040:2006).” CEN European Bureau fos Standarization.

Kalantzis, Anastasia, Andrew Thatcher, and Craig Sheridan. 2016. “Mental Models of a Water Management System in a Green Building.” *Applied Ergonomics* 57: 36–47. doi:10.1016/J.APERGO.2016.04.007.

Kingman-Brundage, Jane. 1989. “The ABCs of Service System Blueprinting: Designing a Winning Service Strategy.” In *Proceedings of the 7th Annual Services Marketing Conference*, edited by M. Bitner and L. Crosby, 30–33. Chigaco: AMA.

Kingman-Brundage, Jane. 1993. “Service Mapping: Gaining a Concrete Perspective on Service System Design.” In *The Service Quality Handbook*, edited by W.F. Christopher E.S. Eberhard, 148–163. New York: Amacon.

Kingman-Brundage, Jane, William R. George, and David E. Bowen. 1995. “‘Service Logic’: Achieving Service System Integration.” *International Journal of Service Industry Management* 6 (4): 20–39. doi:10.1108/09564239510096885.

Lockton, Dan, David Harrison, and Neville A. Stanton. 2010. “The Design with Intent Method: A Design Tool for Influencing User Behaviour.” *Applied Ergonomics* 41 (3): 382–392. doi:10.1016/j.apergo.2009.09.001.

Long, J., and A Whitefield. 1998. *Cognitive Ergonomics and Human-Computer Interaction*. Edited by Cambridge University Press.

Maguire, Martin. 2001. “Methods to Support Human-Centred Design.” *International Journal of Human-Computer Studies* 55 (4): 587–634. doi:10.1006/ijhc.2001.0503.

Martin, Kim, Stephen Legg, and Craig Brown. 2013. “Designing for Sustainability: Ergonomics--Carpe Diem.” *Ergonomics* 56 (3): 365–388. doi:10.1080/00140139.2012.718368.

Morelli, Nicola. 2002. “Designing Product/Service Systems: A Methodological Exploration.” *Design Issues* 18 (3): 3–17. doi:10.1162/074793602320223253.

Morelli, Nicola. 2006. “Developing New Product Service Systems (PSS): Methodologies and Operational Tools.” *Journal of Cleaner Production* 14 (17): 1495–1501. doi:10.1016/J.JCLEPRO.2006.01.023.

Norman, Donald. 1988. *The Design of Everyday Things*. doi:10.2307/1423268.

Oliveira, Luis, Val Mitchell, and Kevin Badni. 2012. “Cooking Behaviours: A User Observation Study to Understand Energy Use and Motivate Savings.” *Work (Reading, Mass.)* 41 Suppl 1 (January): 2122–2128. doi:10.3233/WOR-2012-1016-2122.

Patrício, Lia, Raymond P. Fisk, E Falcão, and João Cunha. 2008. “Designing Multi-Interface Service Experiences: The Service Experience Blueprint.” *Journal of Service Research* 10 (4): 318–334. doi:10.1177/1094670508314264.

Pettersen, Ida, and Casper Boks. 2009. “The Future of Design for Sustainable Behaviour.” In *The EcoDesign 2009 Conference*, 1–6.

Polaine, Andrew, Lavrans Løvlie, and Ben Reason. 2013. *Service Design: From Insight to Implementation*. Edited by LLC Rosenfeld Media. New York.

PRé Consultants. 2010. *Simapro 7.3.0*. Amersfoort (Netherlands).

Radjiyev, Ayubkhon, Hai Qiu, Shuping Xiong, and KyungHyun Nam. 2015. “Ergonomics and Sustainable Development in the Past Two Decades (1992-2011): Research Trends and How Ergonomics Can Contribute to Sustainable Development.” *Applied Ergonomics* 46 Pt A (January): 67–75. doi:10.1016/j.apergo.2014.07.006.

Robert Bosch, Hausgeräte GmbH. 2013. “WAY 28740 EE. Instruction Manual and Installation Instructions.” http://www.bosch-home.es/WAY28740EE.html#tab4.

Sagot, Jean Claude, Valérie Gouin, and Samuel Gomes. 2003. “Ergonomics in Product Design: Safety Factor.” *Safety Science* 41 (2-3): 137–154. doi:10.1016/S0925-7535(02)00038-3.

Saravia-Pinilla, Martha H., Carolina Daza-Beltrán, and Gabriel García-Acosta. 2016. “A Comprehensive Approach to Environmental and Human Factors into Product/service Design and Development. A Review from an Ergoecological Perspective.” *Applied Ergonomics* 57: 62–71. doi:10.1016/J.APERGO.2015.11.007.

Shostack, Glenna. 1982. “How to Design a Service.” *European Journal of Marketing* 16 (1): 49–63. doi:10.1108/EUM0000000004799.

Shostack, Glenna. 1984. “Designing Services That Deliver.” *Harvard Business Review* 62 (1): 133–139.

Smith, Jim, and Ray Wyatt. 2006. "Project Inception: A Performance Brief Approach." In *Proceedings of CRIOCM 2006 International Research Symposium on Advancement of Construction Management and Real Estate, Vols 1 and 2*.

Stanton, Neville A., Mark S. Young, and Catherine Harvey. 2014. *Guide to Methodology in Ergonomics: Designing for Human Use*. Edited by CRC Press. Second.

Stickdorn, Marc, and Jakob Schneider. 2011. *This Is Service Design Thinking*. *BIS Publishers*. Amsterdam: BIS Publishers. doi:10.1007/BF01405730.

Tang, Tang, and Tracy Bhamra. 2012. "Putting Consumers First in Design for Sustainable Behaviour: A Case Study of Reducing Environmental Impacts of Cold Appliance Use." *International Journal of Sustainable Engineering* 5 (4): 288–303. doi:10.1080/19397038.2012.685900.

Thatcher, Andrew. 2012. "Early Variability in the Conceptualisation of 'Sustainable Development and Human Factors'." *Work (Reading, Mass.)* 41 Suppl 1 (January): 3892–3899. doi:10.3233/WOR-2012-0058-3892.

Thatcher, Andrew. 2013. "Green Ergonomics: Definition and Scope." *Ergonomics* 56 (3): 389–398. doi:10.1080/00140139.2012.718371.

Thatcher, Andrew, and A Groves. 2008. "Ecological Ergonomics: Designing Products to Encourage pro-Environmental Behaviour." In *CybErg 2008: The Fifth International Cyberspace Conference on Ergonomics*.

Thatcher, Andrew, Patrick Waterson, Andrew Todd, and Neville Moray. 2018. "State of Science: Ergonomics and Global Issues." *Ergonomics* 61 (2): 197–213. doi:10.1080/00140139.2017.1398845.

Thatcher, Andrew, and Paul H.P. Yeow. 2016. "A Sustainable System of Systems Approach: A New HFE Paradigm." *Ergonomics* 59 (2): 167–178. doi:10.1080/00140139.2015.1066876.

Tosi, Francesca. 2012. "Ergonomics and Sustainability in the Design of Everyday Use Products." *Work (Reading, Mass.)* 41 Suppl 1 (January): 3878–3882. doi:10.3233/WOR-2012-0055-3878.

Umweltbundesamt. 2005. "Ökodesign von Produkten. Gestaltungsauftrag Für Mehr Umweltschutz Und Innovation." Deutschland: BMU/UBA. http://www.umweltbundesamt.de/sites/default/files/medien/publikation/long/3154.pdf.

Vredenburg, Karel, Ji-Ye Mao, Paul W. Smith, and Tom Carey. 2002. "A Survey of User-Centered Design Practice." *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems Changing Our World, Changing Ourselves - CHI '02* 56 (3). New York, New York, USA: ACM Press: 471. doi:10.1145/503376.503460.

Wordcount: 5,482 words

Wastling, Thomas, Fiona Charnley, and Mariale Moreno. 2018. "Design for Circular Behaviour: Considering Users in a Circular Economy." *Sustainability* 10 (6): 1743. doi:10.3390/su10061743.

Wever, Renee, Jasper van Kuijk, and Casper Boks. 2008. "User-centred Design for Sustainable Behaviour." *International Journal of Sustainable Engineering* 1 (1): 9–20. doi:10.1080/19397030802166205.

Wordcount: 5,482 words

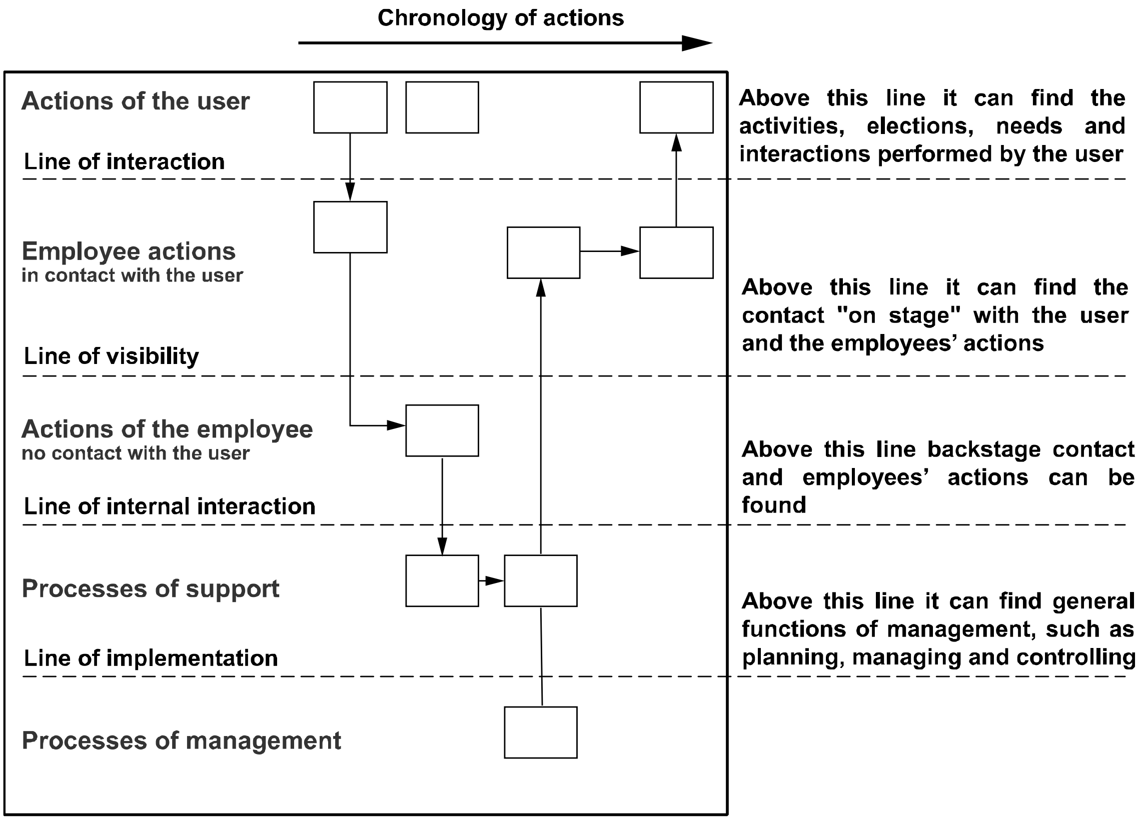

Figure 1. Traditional *Blueprinting* model suggested by Shostack (1982) and Kingman-Brundage (1989)

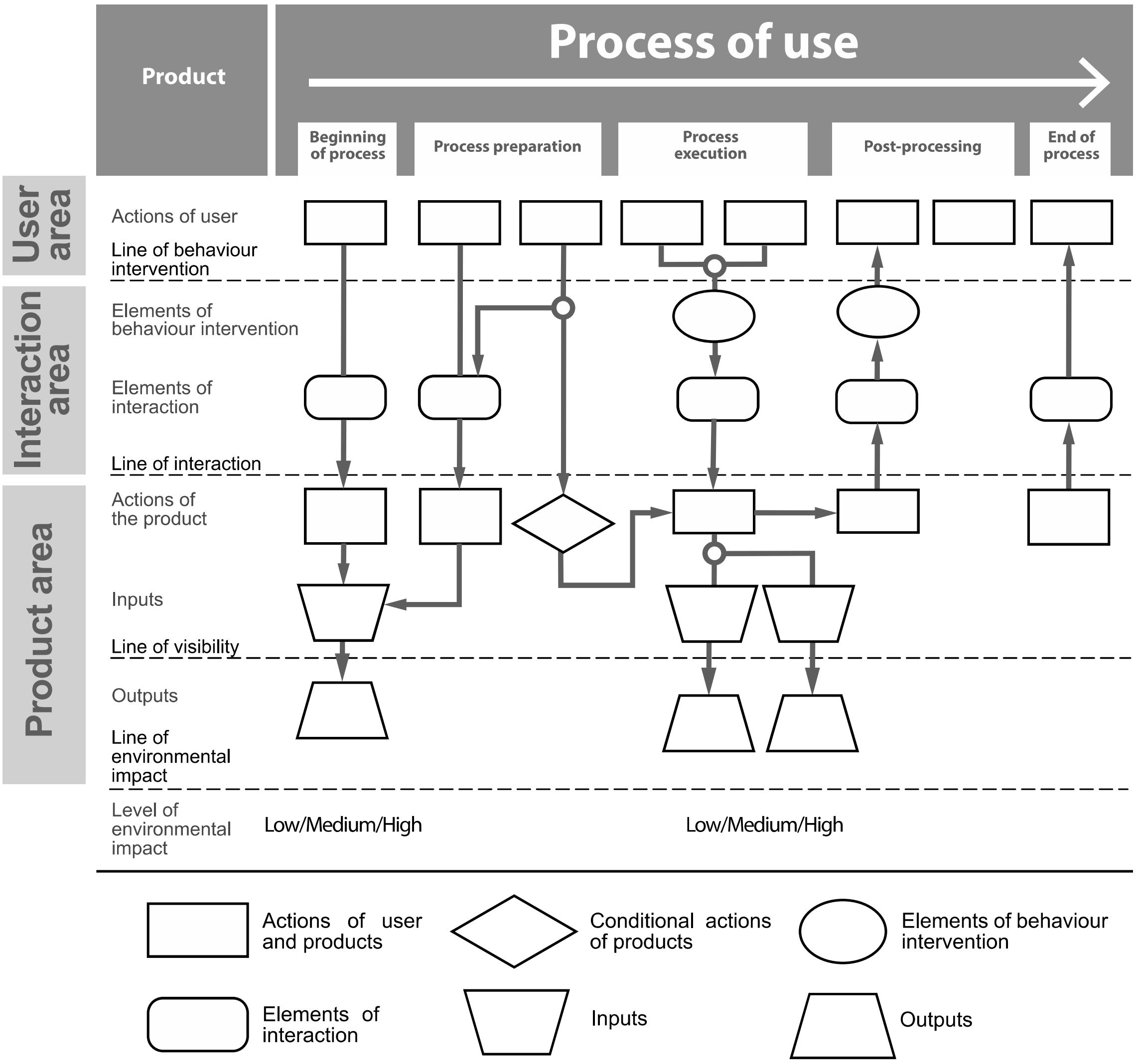

Figure 2. The proposed Eco-Ergo model scheme

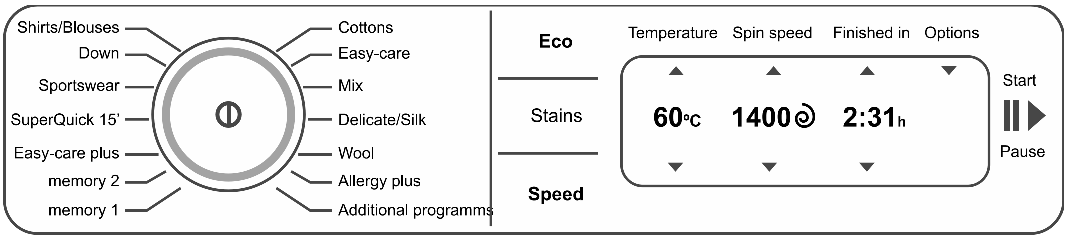

Figure 3. Scheme of interaction panel of the washing machine

Dispenser I	Detergent for prewash
Dispenser ❀	Softener
Dispenser II	Detergent for main wash
Dispenser A	for dosing liquid detergent

Figure 4. Symbols in washing machine drawer

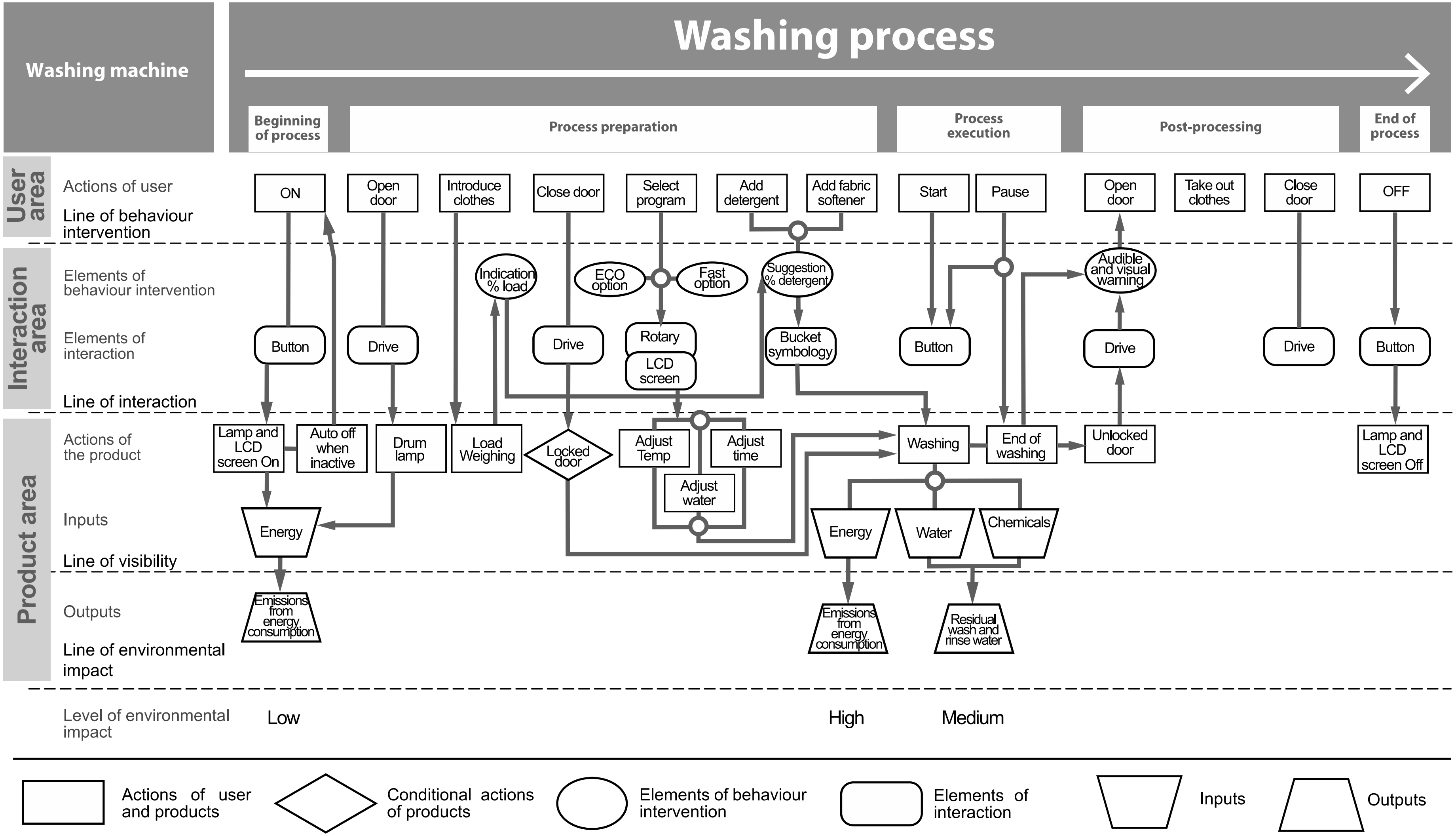

Figure 5. Eco-Ergo model for a washing machine

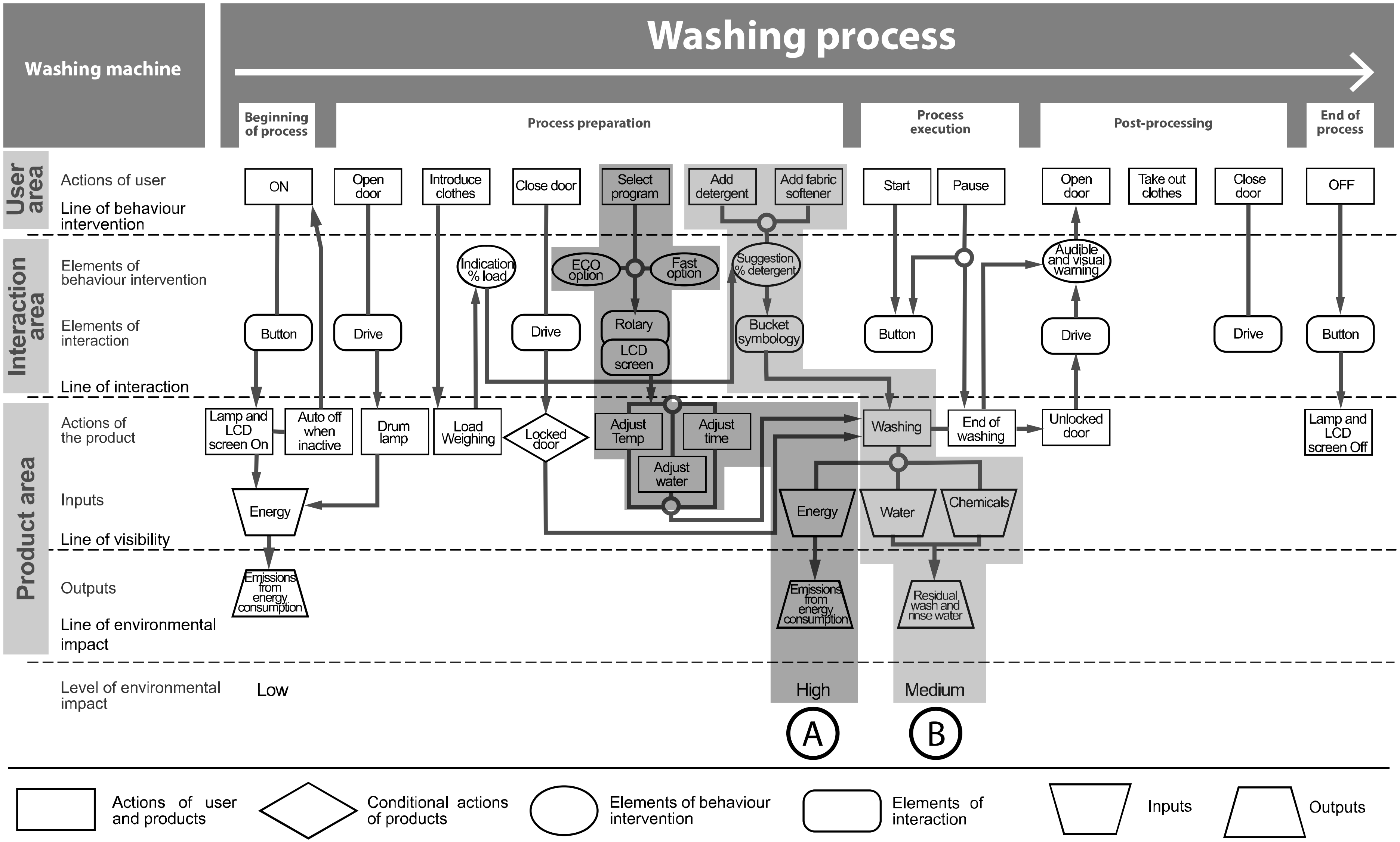

Figure 6. Improvement areas for washing machine