

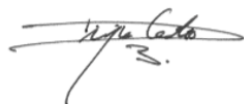
Understanding diversity when designing to promote sustainable behaviour

PhD Dissertation by ANNE MIREN IRIZAR ARRIETA

within the doctoral program ENGINEERING FOR
THE INFORMATION SOCIETY AND
SUSTAINABLE DEVELOPMENT



Candidate
Ane Irizar Arrieta



Co-Advisor
Dr. Diego Casado Mansilla



Co-Advisor
Dr. Aiur Retegi

Siempre tuya

Abstract

Due to the rise of the climate emergency, many initiatives have been implemented to reduce the environmental impact of systems and processes. From global to local projects, the challenge to address pro-environmentalism is evident at different levels and contexts. A wide range of approaches emerged from this need, addressing the development of technologies that promote sustainability and reduce environmental impact. In addition to optimising processes and developing environmentally friendly systems (e.g. the electric car or renewable energy sources), several proposals focus on the human factor and the relationship between people and technology. Raising awareness and motivating people about the importance of taking into account the impact of their actions is a key issue that is extensively addressed in the body of scientific literature. However, the vast majority of existing approaches propose static interventions and apply them in a linear fashion, i.e. without taking into account the heterogeneity of people and their flexible and changing nature.

Thus, this dissertation focuses on two main tasks: first, it aims to understand the key issues that should be taken into account when designing interactive systems that encourage sustainable behaviour, providing ideas on how to implement the theoretical findings. Second, it intends to address the diversity of people by proposing a dynamic and flexible classification model that includes the most relevant dimensions of the individual in the context of pro-environmental behaviour. This model is applied in three different cases in order to understand its implications. Other relevant issues identified when applying the model to smart contexts are also explored through a qualitative study with experts.

Therefore, this Doctoral Thesis proposes a framework that helps at promoting sustainability through technology by approaching people from a holistic point of view, in order to improve awareness and pro-environmental behaviour, reduce the negative impact of human actions, and promote a more sustainable, balanced and environmentally friendly lifestyle.

Resumen

Debido a la emergencia climática, las iniciativas para reducir el impacto medioambiental de procesos y sistemas han aumentado de manera drástica en los últimos años. Desde proyectos globales a otros muy locales y concretos, la necesidad de abordar la sostenibilidad medioambiental resulta inminente a diferentes niveles y contextos. De esta necesidad, han surgido estudios e investigaciones que abordan el desarrollo de tecnologías que fomentan la sostenibilidad y reducen el impacto medioambiental. Además de optimizar los procesos y desarrollar sistemas más eficientes y menos dañinos para el medio ambiente, numerosas iniciativas ponen el foco en el factor humano y la relación de las personas con la tecnología. Concienciar y motivar a las personas sobre la necesidad de tener en cuenta el impacto de sus acciones y mejorarlas es un tema clave que se aborda extensamente en la literatura científica, existiendo diversas maneras de aplicar esta idea. Sin embargo, gran mayoría de las aproximaciones existentes plantean intervenciones estáticas y aplicadas de manera lineal, es decir, sin tener en cuenta la heterogeneidad de las personas y su naturaleza flexible y cambiante.

Esta tesis doctoral se centra, por tanto, en dos tareas principales: primero, entender los aspectos clave a tener en cuenta en el diseño de sistemas interactivos que fomenten un comportamiento sostenible, y proporcionar ideas sobre como implementar los hallazgos teóricos. Segundo, abordar la diversidad de las personas proponiendo un modelo de clasificación dinámico y flexible que incluya las dimensiones más relevantes planteadas por la literatura relacionada. Este modelo se aplica en diferentes contextos para poder entender sus implicaciones, y además se exploran otras cuestiones relevantes a través de un estudio cualitativo con expertos.

Por tanto, esta Tesis Doctoral propone un marco teórico que ayuda a fomentar la sostenibilidad a través de la tecnología apelando a las personas de manera holística para mejorar la concienciación y las conductas pro-ambientales, reduciendo el impacto negativo de las acciones del ser humano y promoviendo un estilo de vida más sostenible, equilibrado y en concordancia con nuestro entorno.

Acknowledgements

He de reconocer que estos agradecimientos son lo último que escribo, y también que no está siendo nada fácil abordarlos: cuesta condensar tanto en tan poco espacio. Y es que esta Tesis lleva mi nombre, pero no hubiera sido posible sin mucha gente. Tanta, que no caben todos, así que, en aras de la simplicidad, tendré que sintetizar bastante. Pero gracias, de verdad, a todas las personas que han formado y forman parte de mi vida.

Esta Tesis está dedicada a ti, Amatxo. Estés donde estés, eskerrik asko. Soy consciente de lo orgullosa que estarías y lo que te hubiera gustado estar aquí conmigo. De hecho, esto es casi más tuyo que mío, así que zorionak a ti también. Cómo no, eskerrik asko también a mi Aita, a Fotxis y a Mari Cruz, por aguantarme de manera incondicional siempre, que ya sabemos que no han sido tiempos fáciles. Por todo lo bueno que está por venir.

Bihotz-bihotzez, eskerrik asko ere nere Parrus maiteari. Izugarrizko harrotasuna sentitzen dut zuek bezalako emakume indartsu zein miresgarri alboan ditudala pentsatzen dudanean. Eta bidean agertu (eta agertuko) diren mini-parrusei ere, noski. Familia handi bat bihurtzen ari gara eta ez dakizue zen poztasuna ematen didan hori. Gauza asko ospatu behar ditugu, ea laister. Urte askotarako neskak.

También tengo que mencionar una persona clave en toda esta aventura. Gracias Luis Ramón por tener aquella idea, y por tu gran apoyo durante todo este tiempo.

Y ya en el terreno académico, millones de gracias a Diego -López de Ipiña-. Recuerdo muy claramente cuando me senté en su despacho por primera vez, nerviosísima, y le conté mi película. Me sorprendió que no me mirase como si fuese un alien. Luego me presentó a Diego Casado, y comenzó la historia que se cuenta en este libro. Así que mil gracias, Diego, por todo.

Toca ahora mencionar a mis directores. Dieguich: muchísimas gracias, de corazón. Por estar ahí siempre, tanto en lo profesional como en lo personal, a las duras y a las maduras. Ha sido todo un honor haber hecho este viaje contigo. Aiur: nahiz eta tesia hasita ezagutu izana, ikerketa hau zurea egin duzu, nire burukeriak jasan dituzu eta izugarri lagundu nauzu (arlotzietan ere) asike mila-mila esker, benetan.

A todo el equipo de MORElab: gracias. Ha sido toda una suerte caer en un grupo con personas de una calidad tan alta como la vuestra: Oihane, mi compi de tesis, gracias a ti la investigación ha sido menos solitaria y mucho más llevadera. Quedarán para el recuerdo

muchos buenos momentos que han hecho esta aventura tan genial. Aritz: eskerrik asko por todo, benetan. Eres el mejor. Aldrintxu: eskerrik asko también por tu soporte incondicional y tu motivación, todo un ejemplo a seguir. Aitor: gracias por ser tan generoso a la hora de transmitir tu sabiduría de senior experimentado. Has sido un gran apoyo. Unai y Mikel, eskerrik asko también por contribuir a ese ambiente fácil y ameno en el que se trabaja tan a gusto. A los Minions, que han cogido el relevo como doctorandos, mucha suerte con lo vuestro y eskerrik asko también por contribuir a ese clima tan guay. Gracias también a Novoa, Koldo, y el resto de former members. Y a todos los doctorandos con los que he compartido camino: Irene, Ioanna, Héctor... Todas habéis contribuido de una manera u otra a esto.

Finally, I have to acknowledge my time in Siegen University. Thank you, Marc, for hosting me, it was much better than expected. I know you did an exception and I really appreciate it. Thank you, Matthias, for your support, kindness and for your brain. I miss the reflections and debates from your seminar about Behavioural Design. I hope we could continue sharing ideas. Also, thanks to the rest of the group: Alarith, Judith, Shadan... I felt part of the team when I was there so thank you so much for your warm hosting. I wish you all the best.

Bihotz-bihotzez, eskerrik asko danoi

Anne M. Irizar-Arrieta

Table of contents

List of Figures	XV
List of Tables	XVII
Acronyms	XIX
1. Introduction	I
1. 1. Context and motivation	3
1. 2. Thesis statement	4
1.3. Structure and research process	6
1.4. Thesis outline	8
2. Contributions and highlights	13
2. 1. Challenges and opportunities from the state of the art	13
2. 2. Applying an incipient theory in the design and implementation of an interactive artifact	18
2. 3. The FOX model and its application	25
3. Addressing Behavioural Technologies Through the Human Factor: A Review	41
4. User perspectives in the design of interactive everyday objects for sustainable behaviour	61
5. Exploring the Application of the FOX Model to Foster Pro-Environmental behaviours in Smart Environments	77
6. Conclusions and Future Work	107
6.1 Summary of contributions and conclusions	107
6. 2 Contributions and objective validation	110
6. 3 Publications and awards	113
6. 4. Future work	115
References	121

List of Figures

Figure 1. Stages and objectives of the research work.	7
Figure 2. Examples of different augmented objects designed to display energy consumption.	15
Figure 3. The IC shows some of the states that can display.	20
Figure 4. Participants of the Focus Group sessions.	23
Figure 5. The dimensions included in the FOX model.	26
Figure 6. The FOX model including the dimensions, categories and relations.	27
Figure 7. Jon and the main characteristics that are included in the profiling at the initial stage.	32
Figure 8. Lily and the main characteristics that are included in the profiling at the initial stage.	33
Figure 9. Sua and the main characteristics that are included in the profiling at the initial stage.	34
Figure 10. The workflow defined to identify the main stages in the application of the FOX model.	36
Figure 11. The diagram of the holistic framework created after analysing the findings of the research presented in this dissertation.	109

List of Tables

Table 1. The objectives defined in the Chapter 1 are linked to the contributions.

112

Acronyms

BT	Behavioural Technologies
DfSB	Design for Sustainable Behaviour
GT	Grounded Theory
HCI	Human-Computer Interaction
IC	Interactive Coaster
IoT	Internet of Things
SHCI	Sustainable Human–Computer Interaction
TPB	Theory of Planned Behaviour
TTM	Trans Theoretical Model
VBN	Value-Belief-Norm Theory

*Das chaos sei willkommen,
denn die ordnung hat versagt.*

Karl Kraus

CHAPTER 1

Introduction



Over the last decades, the environmental situation has become critical. Climate change threatens planet Earth, and the need for strategies to minimise its damage or find solutions to adapt to it is essential. For this purpose, a wide range of measures have been implemented at different levels so far: from policies and other initiatives created by governments and public agencies, such as Sustainable Development Goals¹ from United Nations to smaller and more localised actions implemented by companies or other private organizations, e.g. Deusto Haritza Program². Hence, the approach to this problem is being addressed in a holistic and systemic manner in most cases.

While the need for a global approach to the problem is quite obvious, the human factor [27] arises as a key point to raise the awareness of the society and reduce the negative impact of some everyday actions in which citizens neglect the cost for the environment. In order to do so, there are different ways to proceed, but there are two actions that are becoming predominant at different levels: Traditional awareness campaigns (e.g. posters, adverts and reports) and the implementation of technological solutions aiming at encouraging more sustainable habits (e.g. social media influencers, digital reminders, emails and mobile apps). Technology-based strategies can address different aspects and allow the implementation of innovative solutions; therefore, this is the main focus of this dissertation. Following the ideas of Blevis [3] and Mankoff et al. [23] sustainability can and should be a key factor in the design and development of the technological systems, overall in those that aim at interacting with end-users. Following the approach exposed by Mankoff and colleagues, sustainability can be described through two main conceptualisations.

- * Sustainability in design is related to the practical design of the products, e.g. the optimisation of the materials and processes of the associated hardware and software to reduce their environmental impact. Energy use, device-reuse, reduction of waste and enablement of shared devices or resources are the key ideas included in this approach.
- * Sustainability through design is related to the improvement of pro-environmental lifestyles and decision-making processes in favour of sustainability through the design of technology. In this approach, three different levels are devised:
1) Individual level, based on transforming abstract environmental information

1 <https://www.un.org/sustainabledevelopment/sustainable-development-goals/>

2 <https://sites.google.com/deusto.es/programa-haritza/home?authuser=0>

into concrete and useful inputs for the individuals; 2) Group level, related to the systems designed to influence groups of people (e.g. families or employees); and 3) Societal level, related to the idea of a cultural change or social movement (e.g. citizens or grassroots).

Completely technology-based approaches (e.g. fully automated thermostats or lighting systems) could be able to offer a pro-environmental solution without any human intervention, following the idea of Sustainability in design. Nevertheless, informing individuals -Sustainability through design- has beneficial consequences: people's awareness increases, and pro-environmental actions are promoted (whether directly or indirectly linked to the level of awareness). Moreover, targeting a specific strategy to people rather than to artifacts (using devices as mediator), the positive impact emerged from it could be performed and extrapolated to different contexts.

In order to apply the latter approach, there are different methodologies and initiatives for making people aware of environmental issues and helping to reduce the impact of their actions. From Persuasive Technology [18] to DfSB [22], [20], a wide range of proposals have been developed to form new individual or collective behaviour. In Michie and colleagues' work [24], for example, a taxonomy of 93 behaviour change techniques can be found.

Having explored the plethora of interventions and frameworks to nudge society to take an action towards the environment, this dissertation draws on a specific point of view emerged from this context: how the best pro-environmental strategy, tool or method can be tailored to a heterogeneous group of people?

As it will be exposed in the following pages, there are several scholars that explore diversity of people in relation to sustainability, some examples are the works developed by Lockton and colleagues [21] and by Coskun & Erburg [10], [9], among others. Nevertheless, the dynamism and heterogeneity of themselves implies a problem when implementing existing theoretical solutions making it difficult to select the best strategy for a target group, since the differences are varied and may change according to intrinsic, contextual and socio-economic factors [17]. For that, a dynamic and flexible framework of behaviour change models is required to understand the complexity of the individuals when performing sustainable behaviours.

Considering this background, this PhD dissertation aims to tackle the heterogeneity of people to be able to apply personalised strategies to foster sustainable behaviour. Thus, the group or collective strategies are beyond the scope of this research. The initial idea developed in the present thesis will help to understand the dynamism of people to facilitate the design of artifacts and the selection of the best intervention in each moment, adapting it dynamically when required.

To tackle this challenge, several actions have been made: first, after defining the problem and the scope of the research, the main gaps and challenges of the field have been

analysed. Then, an incipient theory extracted from a long-term study has been applied in the design and implementation of the IC, an everyday object intended to offer persuasive nudges to promote sustainable behaviour in work environments (specifically in office-based workspaces). This device was then tested qualitatively with a group of individuals, extracting promising insights and findings related to the interaction with the device. After analysing these results, the main insights were implemented in a novel behavioural framework. The proposed meta-model aims to address the diversity dynamically taking into account behavioural theories in a holistic and flexible way. Following this idea, in order to explore the potential applications of the model, a qualitative survey with experts in the field was developed. This survey analysed the main concerns related to the model and explores how it can be used by researchers and practitioners to implement behavioural strategies taking into account the diversity. Once the results and findings were considered, the model was applied in the development of three case studies to understand the implications of the people when using specific systems in any given context.

All this previous work has brought valuable findings about how to address the heterogeneity of individuals in the context of pro-environmental behaviour. These findings demonstrated that by taking into account the emerged key dimensions or themes, (both in relation to devices and people) and applying them dynamically, the acceptance of strategies that promote awareness and pro-environmental behaviour can be encouraged.

The remainder of the chapter is structured as follows: Section 1.1 introduces the context and the motivation of this thesis. Then, Section 1.2 exposes the thesis statements, including the objectives and scope of this research. After that, Section 1.3 explains the research structure. Finally, Section 1.4 describes the outline of this PhD dissertation.

1. 1. Context and motivation

As exposed previously, environmental impact is a relevant issue when it comes to developing new technologies. In this line, SHCI scholars [11] aim to address the impact of technologies addressing the human factor. SHCI considers the relations and interactions of the individual with digital/physical systems or technologies to improve sustainability [11]. Hence, user interactions and behaviours are analysed in the context of SHCI to 1) better understand how to tackle the challenges derived from the human factor; and 2) to enhance the management of technological devices, systems, and processes, in order to minimise their impacts on the environment. This is a relevant key point in human-centred intelligent environments [5], where actions are usually recognised to adapt interventions and to offer feedback related to the characteristics and needs of people.

Following the previous ideas, it seems necessary to assume the complexity of the individual and to understand the different issues that may influence his/her behaviours and actions [10]. Thus, the study of the diversity of individuals emerges as a relevant requirement. The fact that people are different from each other may be critical for designing behavioural interventions, however, another key factor that should be taken into account is that individuals themselves also differ, depending on the context and due to many various factors (e.g., a person with the habit of always taking the stairs, instead of the lift, may change this behaviour due to a temporary injury). Taking into account this idea, heterogeneity may be studied as a flexible and dynamic attribute to face the contextual barriers and uncertainties that could modify individual actions and behaviours.

To influence sustainability in people, behavioural theories must be taken into account [13]. He et al. [12] argued that most of the technologies designed to promote certain behaviour offer the same design solutions and provide the same feedback to every individual, neglecting that end-users may be in different stages of change, or may have different values, beliefs or motivations. Hereby, one of the directions to improve the design and implementation of behavioural interventions should be focusing on diversity to maximize their effectiveness and impact through targeting key dimensions of individuals in relation to pro-environmental behaviour.

According to Coskun and Erburg [9], existing literature on user diversity for sustainable behaviour change involves three main topics: 1) theoretical frameworks of different user characterizations; 2) recommendations and design patterns directed to each user profile; and 3) application of personalized design strategies addressing different users. Nevertheless, the flexibility and dynamism of individuals due their heterogeneity presents a gap that should be addressed in order to ensure accuracy and success when implementing mid and long-term behaviour change strategies.

Based on these challenges and opportunities, the main motivation of this research is to improve the understanding towards the interactions of individuals and technological artifacts in the context of pro-environmentalism by applying theoretical guidelines when designing systems and processes. Thus, through the design of personalised frameworks, we can reframe the everyday actions of individuals to improve their awareness and their behaviours, making sustainability interesting and positive for individuals.

1. 2. Thesis statement

Based on the current state of HCI regarding pro-environmental behaviour, a specific research opportunity has been detected. In the following lines, the hypothesis of this dissertation and the objectives to be validated are defined.

1.2.1. Hypothesis

The hypothesis of the present research work is the subsequent:

Addressing the diversity of individuals when designing behaviour change strategies in the context of pro-environmentalism improves the awareness and performance towards sustainable behaviour.

1.2.2. Main objective

To be able to validate the presented hypothesis, the main goal of this thesis is:

To define and develop procedures and frameworks to address user diversity when designing to foster pro-environmentalism.

1.2.3. Research methodology

In order to achieve the main goal, the following specific and measurable objectives are defined. These objectives will guide the research process and stages. Besides, Figure 1 shows each objective related to its corresponding stage.

- o1. To study and analyse the current state of the art.
- o2. To identify the key dimensions for designing technologies addressed to boost the pro-environmental behaviour.
- o3. To extract and define evidence-based design ideas of the most relevant dimensions for sustainable behaviour change.
- o4. To implement theoretical findings in an interactive everyday artifact conceived to stress the importance of maintaining sustainable actions.
- o5. To analyse if the proposed artifact offers positive behavioural interventions to heterogeneous individuals.
- o6. To discover qualitative insights regarding the connection between the solution and the awareness towards sustainable behaviour.
- o7. To implement findings extracted from the evaluation in a new theoretical framework.
- o8. To identify the challenges and opportunities related to the proposed framework.

- o9. To analyse and discover the potential applicability of the theoretical framework and its main requirements.
- o10. To apply the proposed framework to gain understanding on how to face individuals' heterogeneity dynamically.

1.3. Structure and research process

The subsequent procedure (see Figure 1) has been followed in order to accomplish the hypothesis and goals presented in Section 1.2.

1. *Exploratory phase.* In this initial stage, all the relevant works and related literature have been explored, in order to build a theoretical background which will support the subsequent work. Although this phase is the first step to face the research work, it is understood as an iterative phase that will be updated throughout the whole research process.
2. *Definition of the scope and theoretical approach.* After the analysis of the state-of-the-art and once all the involved factors of the research proposal were understood, the scope of the research work is identified. This includes the definition of the theoretical approach that will support the following steps. The identification of the theoretical guidelines that will encourage the design phase emerge as a paramount task to develop successful frameworks and systems that will encourage the implementation and adoption.
3. *Design of the solution.* At this stage, and taking into account the previous knowledge, the final solution will be designed. For that, by implementing specific user-research methods, a first prototype will be designed and then developed. This prototype will include the theoretical strategies and inputs designed and developed in previous steps.
4. *Implementation and insights.* After the design, the prototype is implemented and tested, analysing and extracting qualitative insights. This will verify its validity and applicability in real-world environments and contexts.
5. *Exploration of an improved theoretical framework.* After the implementation of the proposed solution, the results are analysed. The main insights are implemented in a novel meta-model that will offer a theoretical framework to address user diversity when designing technologies and systems to foster pro-environmental behaviour. In order to explore the potential of the model, a qualitative study will be conducted. Besides, the model will be applied in the development of three case studies.

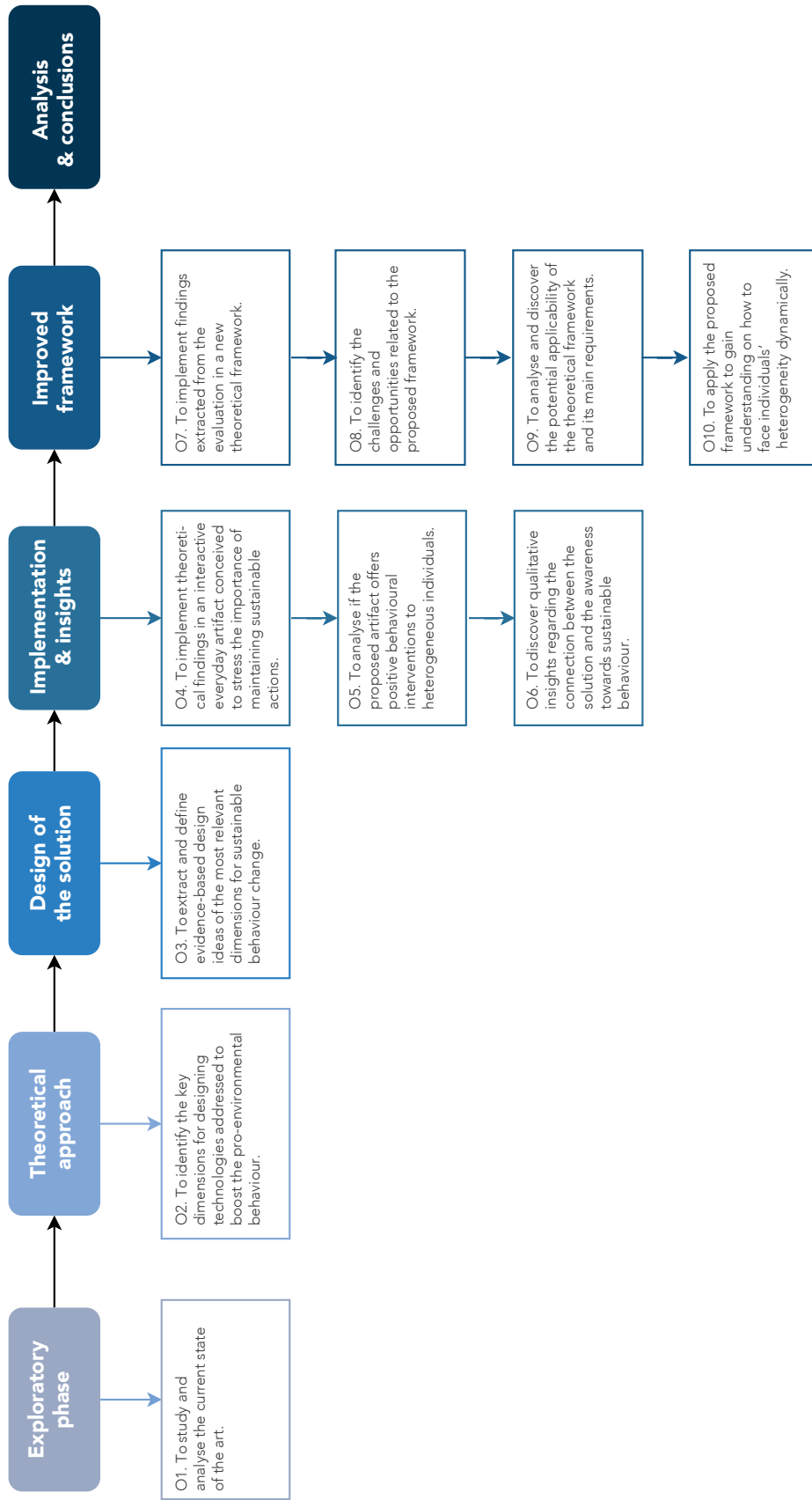


Figure 1. Stages and objectives of the research work

6. *Final conclusions, dissemination and development of the PhD dissertation.* The final step of the research process involves the definition and analysis of the main results and contributions of the previous stages. This dissemination task will involve the writing and development of the scientific publications, which are expected to be relevant for both academic and social fields. Ultimately, the research work will be finished and refined with the development of the present dissertation, and with its later submission and defence.

1.4. Thesis outline

This dissertation consists of a compilation of research articles that include all the stages, processes and steps exposed in the present research work. It is structured in 5 chapters.

The current Section, **Chapter 1**, introduces the research work exposing its context, motivation and the main statements and goals.

Chapter 2 describes the main contributions, results and highlights from the present dissertation. This chapter provides a brief summary of the publications included in this thesis and a discussion of the key ideas that link each research piece.

Chapter 3 contains the first manuscript, entitled “*Addressing Behavioural Technologies Through the Human Factor: A Review*”. In this publication a review of the state of the art is exposed, presenting the detected challenges and opportunities.

Chapter 4 includes the second manuscript, entitled “*User perspectives in the design of interactive everyday objects for sustainable behaviour*”. This publication sets the theoretical background and exposes the implementation of the results obtained from a long-term study into a novel everyday object.

Chapter 5 comprises the third manuscript, entitled “*Exploring the Application of the FOX Model to Foster Pro-Environmental behaviours in Smart Environments*”. This work presents the ideation of a meta-model to understand the diversity of individuals in a flexible and dynamic way. Besides, the application of the model is explored and implemented through three case studies.

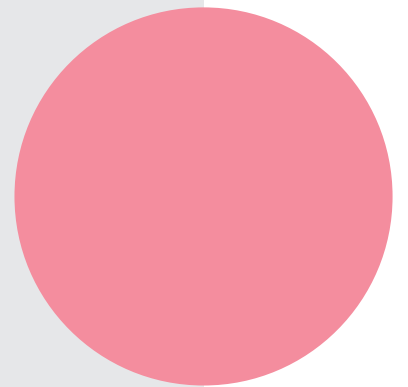
Chapter 6 summarises the main findings and conclusions of the research work, exposes the objective validation and proposes future lines and challenges.

Confetti, bonbons, artillery.

G. K. Chesterton, *The Man Who Was Thursday*

CHAPTER 2

Contributions and highlights



Along this chapter, an overview of the main contributions of the different stages of the research work is provided. Besides, in order to link the different phases, a brief discussion is offered, covering the main challenges and key ideas of each research stage.

2. 1. Challenges and opportunities from the state of the art

As exposed previously, sustainability-related research has gained a growing interest in recent years due, among other factors, to the imminent scarcity of non-renewable resources. In this initial exploratory phase, the aim is to analyse its current status and to understand the related concerns. Thus, this stage of the research process contributes with a thorough review and analysis of state-of-the-art, detecting the main challenges and opportunities.

This research piece has been compiled in a manuscript which has been published in IEEE Access Journal. This publication can be found in the Chapter 3 and includes a detailed explanation of this exploratory stage.

For selecting the pieces of research presented in this initial phase, the following selection criteria has been applied: taking into account the wide range of sustainability-related publications, mainly works related to the energy efficiency have been analysed, and the theoretical approach has been delimited to this area to avoid losing the focus from the target topic. If the amount or relevance of energy-related works was not enough, these have been complemented with other sustainability-related works e.g. regarding recycling behaviours.

The present section is structured as follows: next, the relevant insights from the analysis of most common and used theoretical approaches applied to sustainable behaviour are exposed, including works that use and implement these frameworks in technological systems or interfaces. The objective is to offer a solid theoretical background to frame and understand the technologies that address sustainability through the human factor. This section will help the research community to address the development of technological systems with the understanding of main concerns that need to be taken into

account to develop human-centric strategies and interventions. Then, the focus is located on the behaviour recognition technologies in intelligent environments (Section 2.2). Behavioural recognition involves technologies to gather and process data from the users in order to model and predict their activity. In this context, the existing approaches are analysed to offer an overview of the current state of the art in the field. After the revision of theoretical concerns and the modelling and recognition technologies, the next step in the development of BT should be to select behaviour change strategies and methods. In Section 2.3, the insights related to the review of the most relevant guidelines, tool-kits and other methods are exposed to provide an overview that aims at helping the researchers and practitioners in the strategy selection and implementation. Then, tangible and digital systems that address energy efficiency through human factors are reviewed, from energy consumption data to context-aware information and including other behaviour-related systems. Section 2.1.4 exposes the main ideas extracted from this review, providing an overview of the main concerns related to the implemented systems. Figure 2 shows a selection of augmented objects designed to display information aimed at improving sustainable behaviour. Finally, a discussion is proposed in order to include other relevant ideas and findings that may be taken into account when developing behavioural strategies.

Thus, in the following lines the main highlights and ideas emerged from the literature review are detailed, taking into account each stage of the development of behavioural strategies and systems. These are understood as the results and contributions of this first exploratory stage, determining the findings and knowledge that will set the scope of the work described in the present dissertation. The gaps, challenges and opportunities exposed in next subsections will guide the following research, providing the theoretical framework that will be exposed and applied in next chapters of this thesis.

2. 1. 1. Theoretical frameworks for sustainable behaviour change

As exposed previously, the need to rely on a theoretical background when approaching the human factor is widely recognised by the research community. Thus, the main theoretical frameworks and approaches have been reviewed and analysed. The aforementioned analysis has led to multiple insights that will be deployed in the following lines.

From this review, the first emerging idea is that although the importance of using behavioural theories as a guide is commonly accepted, the understanding of their limitations is still challenging and confusing. The difficulty of overcoming the restrictions of behavioural theories sets a relevant finding that should be carefully taken into account to avoid the shortcomings derived from implementing a framework without understanding its limitations.

Another relevant fact is that there is a wide range of valuable and diverse research works referring to behavioural theories. However, the lack of validated studies and measure-

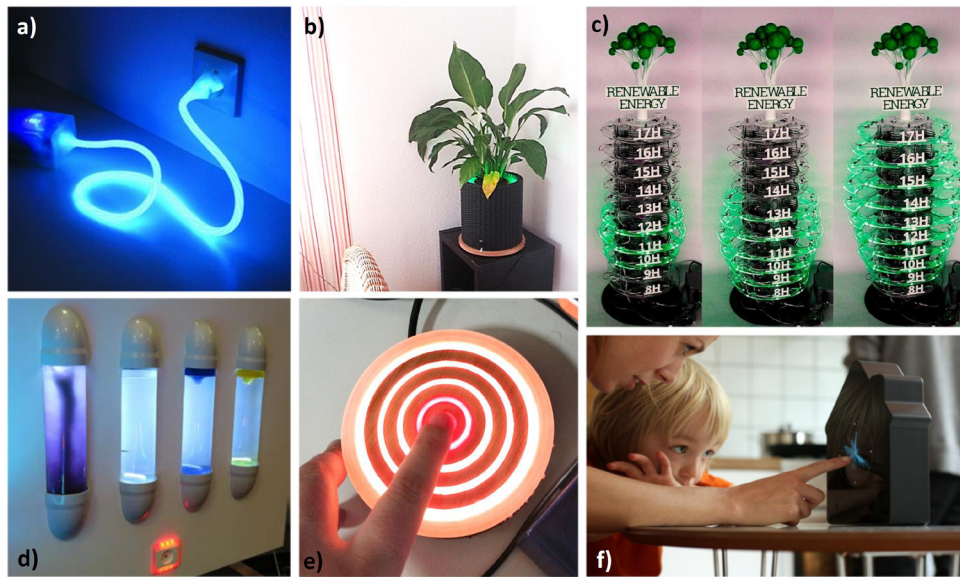


Figure 2. Examples of different augmented objects designed to display energy consumption: a) Power Aware Cord, b) InfoPlant, c) CairForm, d) Watt-i-see; e) Interactive Coaster; and f) Energy Aware Clock. All included images are property of their respective Authors.

ments makes it difficult to ensure the impact and effectiveness of the different behaviour change frameworks and approaches.

In addition to this, it is important to note that different theoretical models or frameworks should be understood as global approaches. Analysing specific theoretical dimensions or elements can be feasible when isolating the study of one factor. However, it may present shortcomings in some contexts as there are confounding and hidden factors overlooked. Having said that, addressing some parts of the behavioural theories may be adequate, while understanding and contextualising the strategy in the global context of the original theoretical approach. This way, the importance of the relations of the constructs will not be overlooked. The analysis of global approach of behavioural strategies sets a research opportunity that may fill the gap derived from the shortcomings emerged from the closed and specific perspectives.

2. 1. 2. Behaviour Recognition and modelling technologies

From the current use of behaviour modelling and recognition techniques applied to foster energy efficiency through behaviour change, the following conclusions can be drawn: modern behaviour recognition could enrich the way in which behaviour change researchers could evaluate their behaviour models and methodologies, allowing the automated detection of minor changes in user's behaviours. Even though there are several behaviour recognition approaches, it has not been made yet a deep analysis of which

approaches are better qualified for this task. Although behaviour recognition techniques' performance has drastically improved during the last years, there are a small number of research works combining advanced behaviour recognition techniques with behaviour change approaches. Moreover, the amount of work focused on behaviour change to foster energy efficiency is even lower since most of the approaches goal is to foster energy efficiency through automated processes. This sets a research gap that may be addressed to link these recognition and modelling techniques with interventions intended to boost the human behaviour.

2. 1. 3. Methods, guidelines and other findings

The wide amount and variety of guidelines and recommendations to implement BT makes it difficult to decide which strategy has a best fit in specific contexts. Thus, following a detailed selection process is important to make the task feasible. Besides, the audience should be studied carefully to adequate the strategies to the specific target users and its diversity.

Taking into account the review done in this stage, one of the main conclusions that emerged is the variety and large amount of methods, frameworks and findings that are focused on offering behaviour change interventions. Hence, researchers may find it difficult to identify all existing methodologies that can be applied. For this purpose, further research on the methodology classification can be a promising future line of work.

Other relevant insight is the lack of validated and measured frameworks, which implies uncertainty when selecting the one which may have a higher impact. To cope with this issue, future research can explore the study and make a comparison of the different strategies and methods, measuring their impact to extract validated data.

Finally, the importance of informational strategies over other types of interventions should be highlighted. Was found out that Eco-Feedback technologies have been widely implemented. Thus, there is a raising need to complement the solely information-based strategies with other techniques to target the heterogeneity of the individuals and to avoid the shortcomings derived from the "one size does fit all" approach [12].

2. 1. 4. Digital and tangible systems

Finally, the last section describes the main findings and insights emerged from the analysis of digital and tangible systems intended to boost the sustainable behaviour. These ideas are exposed below.

As the study of literature shows, completely technology-based approaches such as autonomous smart grids, demand response management systems and monitoring platforms are not enough to reduce energy consumption. Thus, an improved understanding of

how users interact with the power grid and of the influence of Eco- feedback is needed to develop successful solutions.

The interfaces of these solutions must avoid meaningless representations of the data through abstract metrics and inputs. On the contrary, information needs to be clearly presented, providing context and hierarchizing the different cognitive levels. In order to increase awareness and motivation, research should put the focus on the implications of Eco-feedback presentation methods and strategies, as well as on evaluating the usability of the interfaces.

Current trends indicate a shift from traditional feedback devices (such as in-home displays) to new innovative ones based on tangible visualization interfaces. Redesigning and augmenting everyday objects to provide a more natural interaction may be the way to increase the potential of the feedback. Above all, the design needs to overcome barriers regarding the uptake, lack of attachment or the distrust of technology to actually engage users in the long term.

2. 1. 5. Discussion of the literature review

To conclude, a few concerns extracted from the research work are discussed. Firstly, it must be highlighted that, as exposed previously, most behavioural theories and their implementations present shortcomings due to the specificity of the scope of the models. However, this presents an interesting challenge where the different theories could be analysed together, finding common determinants and relations to map and link the most common theoretical models for sustainable behaviour, and enriching the isolated approaches. In this way, the shortcomings of each model can be avoided or minimized fulfilling the gaps presented by each theory with complementary theoretical approaches.

The second key point derived from the analysis of literature is the need to implement global and cross-cutting strategies beyond a specific approach, since all the reviewed approaches tackle sustainable behaviour through mostly rigid or static strategies. Besides, most of the reviewed works implemented their strategies through technological devices without complementing or reinforcing these approaches through other channels. Due to this, the responsibility is, in most cases, relegated to the autonomous piece of technology, so that capacity for sustainability falls on it and the user tends to be left apart. Both physical and digital devices, as well as recognition and modelling tools, should be part of a global and flexible strategy and should not be dependent on the device. In addition, people's needs, and the emotional/psychological aspect of behaviour change (e.g. motivations) must be taken into account in order to develop effective strategies that truly improve the awareness, attachment and the acquisition of the responsibility

2. 2. Applying an incipient theory in the design and implementation of an everyday interactive artifact

Taking into account the findings emerged in the previous chapter, we can state that despite the increasing interest in strategies for enhancing pro-environmental behaviour it appears to be hard to find a set of comprehensive guidelines addressed to the application and/or implementation of theoretical frameworks. This may be, among other reasons, due to the variety of possible sustainable actions, the desire or undesired willingness to make them, and the diversity of users (profiles, traits, interests, beliefs, etc.). In conclusion, the majority of the reviewed literature includes short studies. Following this idea, the main objective of this stage of the research process is based on the analysis of qualitative findings from a long-term study to identify emerging themes and to extract and apply a set of design-hypotheses that researchers and practitioners might implement when approaching the design of behavioural technologies and interventions. In the following lines, the main ideas and insights appeared in the mentioned phase are exposed in order to offer a summary as an overview of this research stage.

This section is structured as follows: Section 2.2.1. summarises the key insights from the definition of theoretical background. Next, specific design insights for each theme are introduced. Then, in Section 2.2.3 the implementation of the design insights into a novel device is briefly explained. The following section summarises the evaluation of the Interactive Coaster, and after that, a brief discussion is offered to explain the most controversial ideas.

2. 2. 1. Theoretical background

Aiming at better understanding the relevant insights to apply successful behavioural interventions, an experimental intervention of one year designed to test the effectiveness of persuasive techniques in office environments was implemented. This study was developed by instrumenting with sensing technology several capsule-based coffee machines in different work environments for more than one year. Three experimental conditions were evaluated which entailed leveraging various features on the appliances: 1) persuasive feedback; 2) energy monitoring through a dashboard; and 3) automated operation to avoid forgetfulness.

At the end of the study, it was demonstrated quantitatively that the IoT-based Persuasive treatment helped to save more energy than the other two treatments [6]. Specifically, it was found that the IoT-based Persuasive treatment helped to save more energy than the other two treatments reducing the energy waste by 44.53%.

GT methodology [8], was applied to analyse the qualitative data extracted from the long-term study to produce design insights for creating augmented behavioural devices. In the Open coding phase, 132 unitary codes were extracted. Attributes such as frequency, target, intensity or duration were annotated together with each of the emerging codes. At this stage, five categories emerged from the initial codes: 1) interaction, 2) mediator | emotion, 3) attachment | confidence, 4) context, and 5) behaviour. Following the ideas of GT methodology, the resulting diagram is devised to organise the nascent theory and to see the relative power, scope, and direction of the categories in the analysis as well as the connections among them for linear narrative purposes.

2. 2. 2. Design insights

As mentioned before, GT was applied to the data obtained from groups to extract ideas and suggestions that help to inform the design for similar everyday smart devices. In the following lines, these categories are exposed, summarising the emerging design insights that may help targeting these categories when developing BT.

Interaction. This category covered one of the most recurrent and it captured the majority of unitary codes in the GT analysis. According to the qualitative analysis, to improve the intuitiveness in the different users, the designers should be aware that the 'one-size fits all' approach will not cover all user needs. Further, in the qualitative phase, it is more than probable that some of the interviewees will miss features that the literature reckons that do not work for changing the intended behaviour in the mid and long term (e.g. provide kWh without comparisons or provide financial incentives). Thus, these opinions should be taken with extra care in the design phase because they may blur the goal of changing the behaviour.

Mediator/emotion. Sometimes, individuals considered the device as a new ally to cope with energy inefficiency, and they responded to smart object personalities the same way they responded to human personalities. These emotions are important because they are predictive factors for technology adoption and technology appropriation.

Attachment/confidence. As qualitative findings show, to strengthen these two themes, the augmented everyday objects should be designed to remain close to the people to keep the positive influence on the users throughout time. For that, it is important to provide dynamic feedback that maintains the engagement. Moreover, the information provided by the devices has to be clear and transparent and efforts should be put on making them to become a relevant authority in the field of application.

Use context. Designers should take into account the spillover effects [25] derived from the change of context. The spillover effect proposes that engaging in one behaviour affects the probability of engagement or disengaging in a second behaviour (consciously or unconsciously). Therefore, the formed behaviours may be beneficial at one use-context (e.g.

workplace) but are offering detrimental consequences in other contexts (e.g. at home when no intelligent devices are there to remind the user to do sustainable actions).

Behaviour. One of the problems that designers may find in successful studies is to witness a relapse effect when the researcher completely removes the experimental conditions. The designer of augmented everyday objects should carefully plan the longitudinal extent of the system and reflect upon foreseeable consequences of feedback removal. A proposal would be to taper the feedback off during intervals instead of doing it abruptly or creating context-aware gradually adaptive systems based on the most up-to-date user status.

2. 2. 3. Interactive Coaster

Aiming at deepening in the research and at understanding the practical issues that emerged in the theoretical approach, a novel artifact was designed and developed, implementing the emerging design insights. This device, intended to promote awareness towards sustainable behaviour, include specific strategies based on previous theoretical findings.

The IC is a coaster (see Figure 3), and its lights show a different colour depending on the average energy expenditure. Besides, the IC features different modes and visualisations to enhance user awareness and motivation about energy efficiency. 1) A historical energy consumption visualisation (when the user pushes the central button of the IC the four different circles of the coaster show a different colour depending on the energy expenditure of each time unit - previous day, current week, current month, current year); 2) an automatic visualisation alerts about the energy consumption consumed during the work-day; 3) a vibration alarm buzzes when different energy expenditure levels are exceeded (the colour coding remains the same as current consumption or historical information); 4) “party mode” lights a visualisation with random colour coding, aiming at offering playful value through colourful and animated visual effects; and 5) a “snooze mode” is activated when the user flips over the IC switching off all the lights until it is flipped over again. The IC is able to connect to the Internet extracting all the information about en-

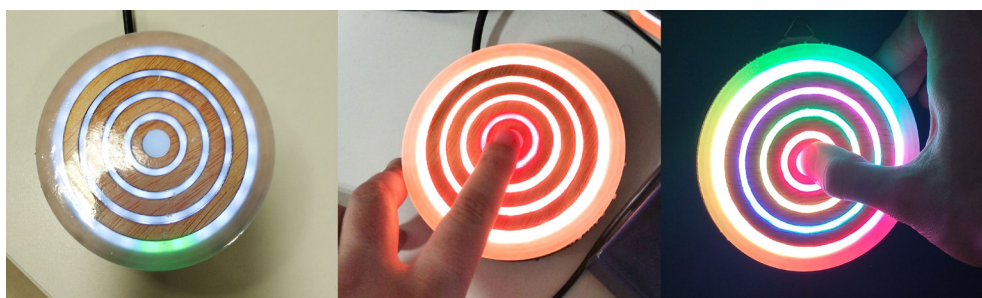


Figure 3. The IC shows some of the states that can display.

ergy consumption through a Wi-Fi module built-in the System on Chip, which controls the whole operation of the IoT device.

The coaster has been designed following a user-centric approach [15]. During the design process, seven end-users were involved following a semi-structured interview approach after letting them interact with the early versions of the IC. They were asked about their opinion of the IC, which metrics were preferred to understand their energy consumption, the colour-coding preferred, which kind of feedback was more understandable for them, where they would place the coaster within their workstation, etc. With this information and the qualitative insights from the GT approach, the design of the new IoT object was finalised. The five/seven design-hypotheses of the emerging themes (interaction, mediator/emotion, attachment/confidence, use context, and behaviour) are used as drivers to face the design phase in the ideation and development of the IC. In the following lines, how the theory and its design-hypotheses were implemented in the IC is summarised.

Interaction. The heterogeneity of the individuals and their different needs, emotions or perspectives were specially addressed in the evaluation sessions to extract design features to implement in the IC. Hence, different features were implemented, aiming at offering diverse and complementary strategies to cover the needs of the existing segments of people. These design strategies were developed taking into account the research developed by Lockton et al. [21] and Petkov et al. [26] where they offer specific design solutions addressed to the diversity based in the behavioural models of the human system [21], and the personal norms, values and beliefs [26]. Obviously, we cannot ensure that with this, we have covered all relevant dimensions of individuals, but we believe that this approach will reduce the end-user expectations considerably on missed features. Further explanation about how the IC addresses the user diversity can be found in a previous work [15].

Emotion/mediator. The emotions were another factor that emerged from the relationship between the device and the individuals. The IC implements the emotional factors through product design. The top side of the IC has been designed taking into account the idea of the tree trunk and its rings. This strategy offers a visual metaphor that is intended to impact the emotional side of the individual. In order to strengthen this metaphor, the material selected for the case was wood. Besides, the visual design of the RGB lights and the appealing party mode are features intended to enhance the emotional properties of the device through design patterns.

Attachment/confidence. A variety of strategies can be followed to improve the level of attachment of the user towards the IC and to gain confidence in the long term. In this regard, the device has been designed to be small and easy to be moved to one place or another within the desktop in order to not be obtrusive. The confidence theme is implemented by offering consistency over the visual information provided and openness. On the one side, the users are explained that what they observe with colours in the IC is an analogy of the real energy consumption being monitored by a smart plug connected to

their workstation. On the other side, it was offered to them the option of visualising the energy consumed in a digital time-series graph to corroborate that the visual cues built-in the device correspond to the power being drawn.

Use context. The IC is intended to promote energy efficiency in an office-based work environment and therefore, the limitation of this narrow context should be taken into account. To minimise the potential negative spill over effects related to a cause-effect design (e.g. forgot to switch off the monitor at home because the user does not have a blinking coaster in its private setting), the IC is designed to provide overall awareness about energy-efficiency. Therefore, the IC's objective is to enhance understanding and eventually energy savings rather than recall a specific undesired action continuously. We believe that this design is prone to provide positive spill over effects in other contexts.

Behaviour. The IC has been primarily designed to enhance awareness and to serve as an energy ally to the user rather than focusing on the improvement of a single behaviour. Therefore, and taking into account the design-hypothesis of this theme, the potential relapse effect derived from the elimination of the artifact should be less unfavourable. Besides, the own energy usage patterns learned by users after having interacted with the coaster for a short period could drive to more sustainable actions. Moreover, these might be more likely to stick because the behaviour change is not linked to the device but to the motivation and new energy-related knowledge of the individual.

2. 2. 4. Evaluation and findings

In the following, the main outcomes and insights from the evaluation of the IC are reported. Then, the results are summarised including an outlook to the impact. This evaluation and other related insights of the study have been published in a previous work [7].

In December 2018, 10 volunteers who had the IC in their workstation (see Figure 4) were recruited. The initial findings from this session were the following: First, the functioning of the IC was found ambiguous by session's participants. Some of them did not know what to expect from the IC in terms of energy efficiency, others were expecting an alarm-based system whenever non-sustainable behaviours were detected, and others reported effects on obtrusive feedback (overall vibration and light intensity). Besides, we observed that people used and reflected on the IC. Specifically, some participants commented that they usually compare their current consumption with the previous days. Finally, we found that the IC provoked discussion among peers in the vicinity. The main purpose of the discussion was to find an agreement of the use and functioning of the IC. People were curious about the colours of close neighbours as these were used for comparative purposes.

After two months, they were recruited again to evaluate the interaction in a follow up session. It was found that people started to not use the devices for different reasons.



Figure 4. Participants of the Focus Group sessions.

Some people thought that it occupies precious space in the workstation, others did not want to see a light always on continuously and others argued that it was useless for them. Besides, the conversations among neighbours about the IC diminished accordingly. In addition, there was an overall perception that the device was very simple on its own and more (digital) information was necessary to understand the benefits of it in the daily routine. After these two months, the general feeling was that people did not notice changes in their behaviour. However, some people reported to regularly switch off the monitors during breaks, switching the computer off when they go home or even switch the lights of the bathroom. Thus, the IC can be understood as a subtle reminder of eco-practices that are quickly integrated in the ecosystem, reducing their energy impact in the short-term.

To sum up, the perception of people was that the IC was too simple and that more enhanced information was needed. They missed triggers to alert them when a wasteful energy practice is recognised (e.g. consume energy when the employee is not sat in its workstation). However, the value offered by the IC remained on its ambient interaction to make people aware that they should continue to do actions in favour of the environment.

In the third session, a meeting was done again with most of the volunteers. The results from the general discussion confirmed the highlights of the second session: People do not use the IC for its purpose. Still, people insisted on using the IC as a real coaster for placing the mug over, and as a subtle reminder for doing sustainable actions at the

workplace. Another interesting finding is related to the idea that people wonder whether the small pro-environmental actions do really have an impact on the overall energy consumption, taking into account that they usually use energy-intensive devices for computing. Besides, participants missed explicit anchors to know if their behaviour was enhancing or worsening during the time. In the same vein, there was an agreement that the IC energy performance would have been ameliorated with periodic performance digest through e-mail or other e-channels. Whereas volunteers rated the IC positively in the workplace, the majority thought that this could be also effective in a household context where families would be able to collectively reflect on energy consumption.

After the development of the first focus group, a Slack³ group was created with the participants to open a direct communication channel with the recruited users. This platform had two main purposes: 1) create a direct way to gather the spontaneous feedback of the participants and 2) ask some open questions regarding the IC to track the performance of the device. These questions were provided in the first weeks, aiming at opening a discussion about the IC. After this time, the platform was maintained open until the end of the experimentation phase to let the participants a direct channel to communicate incidences and other related issues.

The open questions led to some answers that covered a variety of topics such as the conversations about the energy efficiency, the use-context of the device, the awareness about energy waste and effects of technology removal. From the feedback of participants, a variety of insights were extracted. An interesting finding was that people considered that the IC makes more sense in a collective environment than for individual use. It was also discovered that the IC was well accepted and easily adopted by the participants of the experiment. Nevertheless, the initial attention decreased after the first weeks. The awareness and adoption were different for each participant: while some of them seemed to be happy to have a device to help them, others felt it forced and unnecessary.

As the results of the qualitative studies show, the IC helped to enhance the awareness about energy efficiency in the participants. Besides, it reminded them to adopt and maintain sustainable and green easy actions. Nevertheless, maybe due to its (intended) simplicity, after the initial weeks the usage of the device decreased dramatically. Therefore, although the positive insights and conclusions, still there is a gap to improve and motivate individuals towards the need to adopt and maintain energy efficient practices and actions.

2. 2. 5. Discussion

From the research presented in this stage, the key themes that must guide the design and implementation of behavioural interventions can be extracted. Besides, the discovered design insights related to each theme facilitate the implementation of successful

3 <https://slack.com/>

strategies, improving the overall performance. As exposed previously, the IC promotes awareness and encourages the importance of pro-environmental behaviour. Nevertheless, after a while the effect of the strategies decreases and finally it becomes mainly a personal reminder. Since the research findings show that there were differences between individuals' preferences and opinions, we conclude that the adopted strategies to face the diversity were not enough to maintain their effect after the first weeks of novelty due to the lack of dynamic and adaptable strategies. This idea sets a key finding that must be further researched and developed.

In line with the aforementioned idea, the main conclusion of this stage is the need of deepening into the diversity of individuals in order to improve the understanding of the main elements of behaviour change. Thus, it seems necessary to improve the theoretical approach to address diversity. The emerging theory from the GT analysis, which involves the relevant elements to face the design of interactive devices, maintains its validity. The need appeared from these findings is to propose a scheme focused on individuals, including their relevant attributes or categories, and thus be able to offer more concrete and effective interventions. This way, a guide to design better devices will be provided, and on the other hand, a framework to improve the understanding of individuals.

2. 3. The FOX model and its application

Driven by the knowledge emerged in previous stages, in the following lines the FOX model is presented: a novel meta-model that sets a holistic framework to address the diversity of individuals dynamically. Besides, a qualitative survey has been conducted to understand the main insights and potential application of the proposed framework. Section 2.3.2. exposes the main ideas from this mentioned survey, including the findings and results. Finally, in order to provide an example of application and the model has been applied into three case studies (Section 2.3.3.).

2. 3. 1. The FOX model

Two of the key findings of the previous stage were that the simplicity of the solution proposed through the IC was not enough to cover the needs of the different individuals, and that dynamic and personalised feedback was a main need for them. Thus, the need for a more complex and flexible framework to understand and classify individuals emerged as a requirement to implement behavioural strategies successfully. Following this idea, a novel and revised approach was ideated to address the diversity of people dynamically.

The FOX model [16] is a framework where the most relevant approaches to change behaviour are included (i.e. TTM [28], TPB [2], VBN [31] and Lockton's classification [21]),

maintaining the original relations and meanings of different constructs and dimensions. This model offers a general perspective on the relevant elements to cope with diversity in the context of pro-environmental behaviour. This early model has been understood as dynamic; that is, the categorisation should be updated throughout time when changes in the individuals are detected. Furthermore, the model is also flexible. Thus, the dimensions of behaviour can be complemented with others (e.g., demographics) and can be prioritised, structured, and organised depending on the requirements of the application context. Nevertheless, the relations of the different dimensions and the overall structure of these models should be taken into account, in order to avoid shortcomings. Following the findings discovered in the literature review, the frameworks were selected in relation to their complementary nature, selecting those that could be complemented with others. Another key factor to define the elements of the FOX model is related to its context. All selected theoretical frameworks have been previously applied in the context of sustainable behaviour. Thus, the suitability and relevance of the selected dimensions is ensured (see Figure 5 for an overview of the key dimensions and their connections).

By adapting the original structure of the included approaches, each dimension complements and reinforces the others. Therefore, mixing and linking the most common theoretical models and classifications may help to avoid a narrow perspective of each single proposal by offering a more complex and holistic way to understand the behaviour. To better connect different items and understand their relations, Figure 6 illustrates the dimensions and categories.

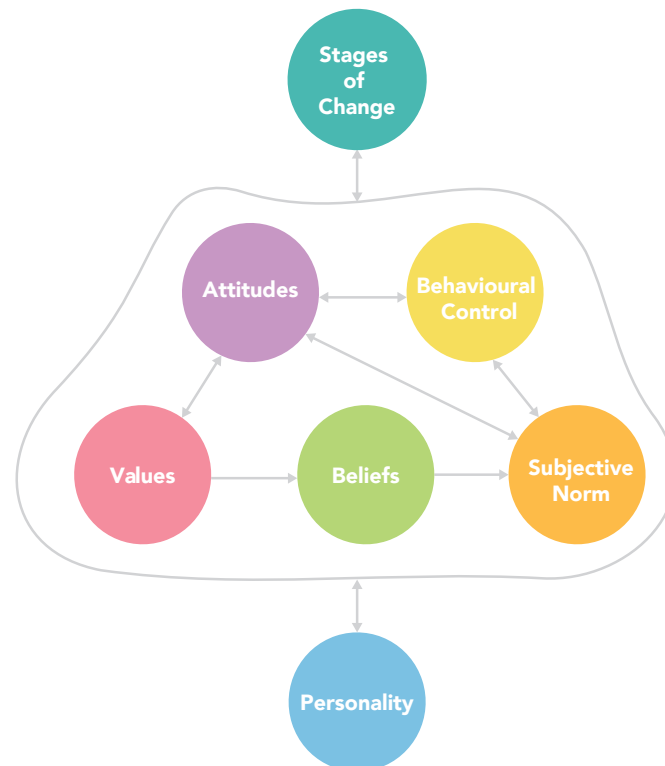


Figure 5. The dimensions included in the FOX model.

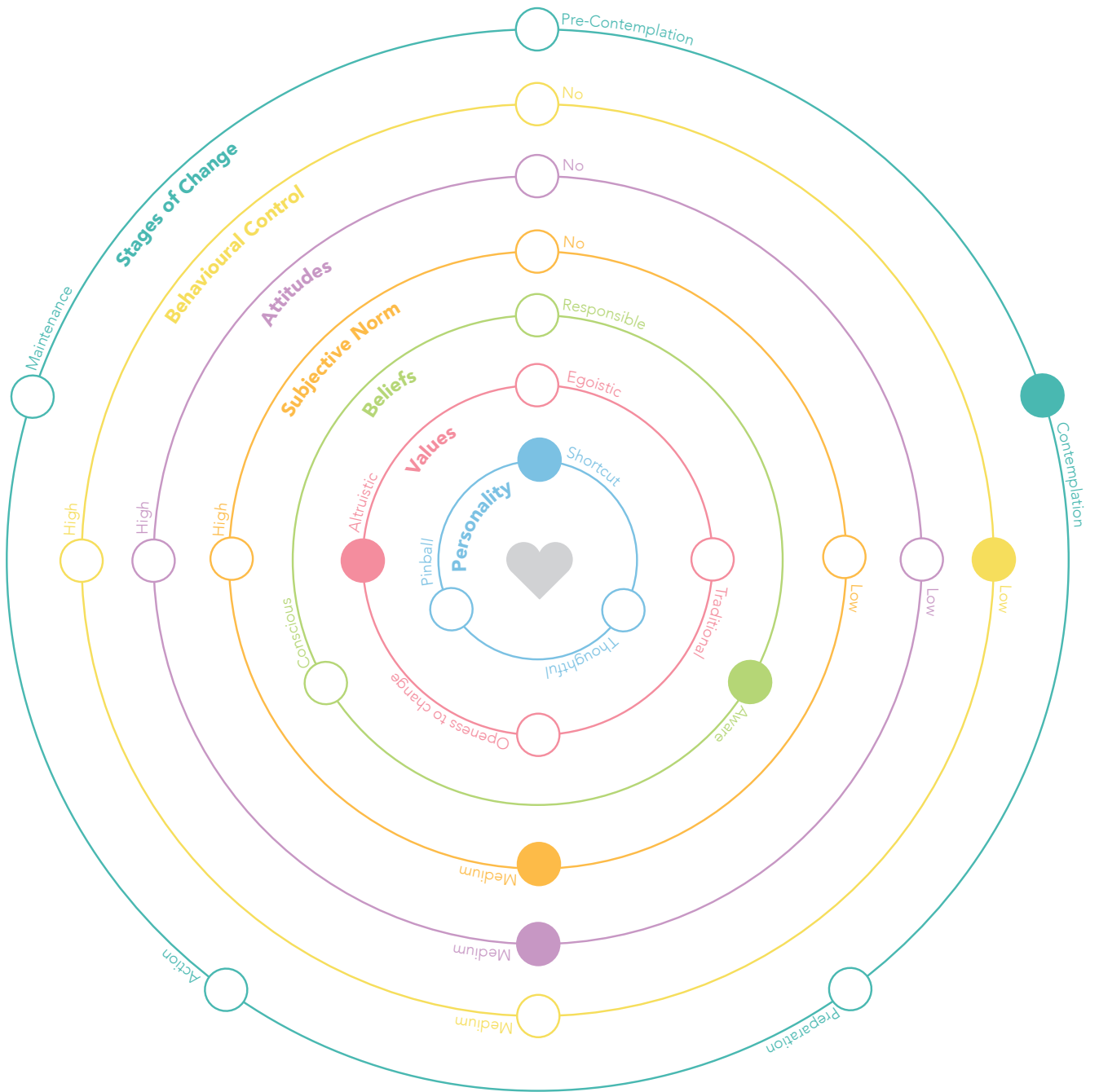


Figure 6. The FOX model, including the dimensions and categories. Filled circles indicate where the individual is classified according to the model.

Stages of Change. The TTM frames the behavioural process by addressing the stages of change over time [28]. Thus, Stages of Change are included in the model as a whole dimension, where the phases are defined as the elements or categories of this dimension. Stages of change are classified as: 1) Pre-contemplation: the individual has no intention to take action in the next six months; 2) Contemplation: the individual intends to take action in the next six months. 3) Preparation: the individual intends to take action within the next month and has taken behavioural steps to face it; 4) Action: significant changes in behaviour within the past six months; and 5) Maintenance and relapse: besides significant changes in the behaviour for more than six months, the person tries to sustain the acquired actions and to prevent relapse.

Personality. When developing behavioural technologies, the diversity among individuals with similar contexts, values, and habits (e.g., siblings or friends) implies a differential factor. Thus, diverse personalities can be determined by the acceptance and adoption of inputs. In this context, the taxonomy proposed by Lockton et al. [21] fits due to its nature. This author identified three profiles: 1) Shortcut are human models that regulate their behaviour and are understood as narrowly rational users, making choices to minimise energy or cognitive expenditure; 2) Pinball are linear human systems, implying a user who only reacts simply to inputs and does not think about any decisions; and 3) Thoughtful individuals are learning human systems: people who analytically think about what they are doing and why, being able to set and modify their own goals.

Attitudes. Following the TPB, behavioural beliefs produce a favourable or unfavourable attitude toward behaviour, which changes dynamically [2]. Attitudes are incremental and are defined as follows: 1) No Environmental Attitude—the individual does not see benefits or immediate positive impact; 2) Low Environmental Attitude—the individual thinks that a pro-environmental attitude may be positive but does not see its benefits or its immediate positive impact. Besides, he/she may perceive several barriers; 3) Medium Environmental Attitude—the individual thinks that a pro-environmental attitude is positive but perceives several barriers that obscure fully positive beliefs towards his/her behaviour change; and 4) High Environmental Attitude—the individual's beliefs towards sustainable behaviour are at the maximum level, believing that a pro-environmental attitude is very positive.

Behavioural Control. This is another construct proposed by the TPB, which is linked with the control beliefs of the individual towards the specific target behaviour [2]. The classification proposed for this dimension is: 1) No Behavioural Control: people perceive that they have no control over a specific behaviour; 2) Low Behavioural Control: people think that the desired behaviour is difficult and that there are many barriers to carrying out the desired action or behaviour; 3) Medium Behavioural Control: people think that it is not difficult, nor easy to achieve the target behaviour and that some barriers make the change difficult; and 4) High Behavioural Control: the individual perceives that the target behaviour is easy and affordable.

Subjective Norm. The subjective norm is based on how sustainable behaviour is perceived by the individual and its context. Following Ajzen's idea, normative beliefs result in perceived social pressure or Subjective Norm [1]. It is related to the internal rules of the individual and its own environment. This dimension is categorised as: 1) No Subjective Norm: the individual does not have subjective rules about pro-environmental behaviour and has neither internal, nor external pressure to adopt it; 2) Low Subjective Norm: the individual feels that pro-environmental behaviour is not a bad idea, but it does not feel important in his/her own life, due to the absence of a personal or social norm; 3) Medium Subjective Norm: the individual feels that pro-environmental behaviour is a positive idea, but is not fully convinced and feels relaxed about the need to adopt the behaviour; and 4) High Subjective Norm: the individual feels that pro-environmental behaviour is an obligation, due to social and personal rules.

Values. Values are a dimension extracted from the VBN theory, which involves a people's personal concerns related to sustainability. According to Petkov et al., values alone are not enough to boost behaviour change [26], thus, this dimension should be complemented with others. Stern's paradigm proposes four types of values [32]. Thus, the classification for this dimension is: 1) Altruistic: these values are focused on avoiding threats for other people; thus, altruistic individuals are those who care about others and equality; 2) Egoistic: these values are related to the needs and wants of the individual (e.g., their gains and losses); 3) Traditional: values related to security and to maintaining the current status to preserve habits and traditions; and 4) Openness to change: values related to curiosity, involving individuals who are interested in different problems such as sustainability.

Beliefs. Beliefs are the last dimension extracted from the VBN, which involve the concerns related to the effects of human activity on the environment [32]. These are derived from values, following the idea that things relevant to those values are under threat. The categories are: 1) Conscious: involves the beliefs of the individuals who accept a new ecological paradigm; 2) Aware: classifies individuals who are aware of the adverse consequences for valued objects due to environmental problems; and 3) Responsible: involves individuals that perceive their ability to reduce the threat and, therefore, are more willing to take action and adopt sustainable behaviours.

The classification of the FOX model includes different categories depending on the dimension. There are quantitative categorisations e.g., Attitudes, where indifference can be 0 value and the most positive attitude 10. On the other hand, qualitative dimensions such as Personality or Values are divided by qualities and specifications but cannot be understood in an incremental measurement context. This way, categories such as Beliefs dimension may involve both approaches: consciousness, awareness, and responsibilities are qualitative but also quantitative if they are understood as chained, being the consciousness the first state and the responsibility the last one.

The dimension Stages of Change has a longitudinal approach, and it is understood

through phases, where the individual is placed in any specific stage. Due to this, the FOX model includes all other dimensions along with the different phases, covering heterogeneity through all the stages of the change process. Personality is another dimension that is placed according to its specific nature. Taking into account that the “models of the human system” proposed by Lockton et al. [21] involve a broad contextualisation of the individual in regard to sustainable behaviour, this dimension is placed in the bottom of the model and linked with the other elements of the model. The remaining dimensions of the meta-model are linked following the relations proposed by each behavioural model: 1) the dimensions extracted from constructs of the VBN are chained, being the Values the starting point, the Beliefs based on the values the next item, and last dimension is related to the Subjective Norm that user develops based on two previous factors. 2) Attitudes, Behavioural Control and Subjective Norm are part of the TPB and therefore, these are linked to map the impact that each dimension has in others. Hence, the dimensions preserve their placement and context proposed in their own behavioural framework and should be understood with their links and relations to do not miss the influences that each dimension can imply in others. Subjective Norm is included in the VBN and TPB, and therefore, is located as a single dimension related to both models and maintaining their original connections.

2. 3. 2. Qualitative survey

In order to discover the main concerns and insights related to the proposed model, a qualitative survey was developed. After the implementation of the questionnaire, the responses were analysed and reviewed.

The main finding of the study is related to the fact that all of the respondents confirmed the model was applicable in their field of work (e.g., Internet of Things, Energy Demand Response, Blockchain, or Ambient Assisted Living). In the following lines, the relevant insights are exposed.

The importance of personalised interventions. As exposed previously, all of the respondents agreed on the applicability of the model in their own fields. Furthermore, they also agreed on the potential of the FOX model to implement personalised interventions. Thus, in this preliminary study, the model appears to be interesting and valuable for the research community in different contexts. Besides, the coverage of the different theoretical frameworks was valuable for the participants, reinforcing the idea about the importance of the different perspectives.

Specific and complementary dimensions to foster the inclusion of individuals. In line with the previous idea, another relevant conclusion extracted was the need of complementing behaviour-related dimensions exposed in the FOX model with non-behavioural dimensions. These must be specific to each context and may include social and demographic data.

Flexible and updated model to accompany the individual. As an interviewee exposed, one of the shortcomings of traditional user modelling is static characterisation. For that, the flexibility of the model is a relevant key point that should be addressed in any of its applications; that is, the system should be able to detect any change in its categorisation, update the status of the user profile, and offer inputs related to it.

Diverse context of application. Another insight extracted from the qualitative study was the applicability of the FOX model in different contexts. Although this framework was created to foster pro-environmental behaviour, three respondents explicitly exposed its possible application to their own fields, such as education and health. Nevertheless, in order to apply the framework to any given context, it seems crucial to study the relevant dimensions and/or variables for each context, adapting the model according to them.

Rules and measures to categorise individuals. As this preliminary model proposes a novel classification mechanism, some participants questioned the idea of how to distribute people. Thus, specific rules and measures are needed to organise individuals, according to the dimensions, and to define specific interventions for each of them.

Neither intrusion nor tedious systems for data gathering. Following with the previous idea, the data gathered for the modelling should be done with non-intrusive systems that provide a good experience. Thus, the relevance of the design-specific and non-intrusive data gathering tools emerges as a need to further develop the FOX model. Nevertheless, how the data can be gathered depends on the technological capability and the context. Although gathering the data through questionnaires and other traditional tools can be very tedious, in most cases, data collection can be done through smart devices and specific sensors located to capture information with no intrusion, while taking into account the privacy of the individual.

Avoid biases to foster diversity. As a final conclusion, a relevant insight should be taken into account: it is highly important to be careful with the fact that the inclusion of some characteristics (e.g., demographics such as gender, race and/or country) may bias the model. Thus, the inclusion of complementary dimensions and the definition of the specific rules for each dimension should be studied and analysed in detail, in order to ensure that the model does not include any bias.

2. 3. 3. Case studies

Aiming at exploring how the FOX model can be applied and to better understand the target individuals in their context, three qualitative case studies were developed. Following the approach of Schwandt and Gates, there is no single definition of “case study” when trying to understand the behavioural implications of people [30]. Besides, the authors ensured that there were considerable variations across disciplines. Taking this into account, in the present dissertation the definition of Schwandt and Gates is used; that is,

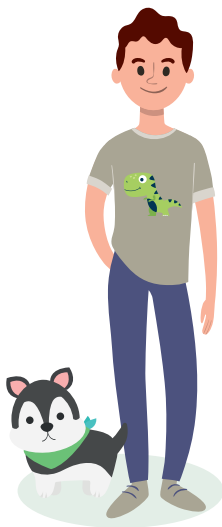
understanding a case study as a detailed description and analysis of any specific issue, being a method widely used to perform qualitative research [30].

For the development, the Persona-Scenario method [14] was applied. This procedure integrates the Persona method with scenario building. Persona [4] is a common methodology in the field of HCI, which is intended to define user archetypes. It aims at envisaging a real individual, in order to gain an understanding of target groups. It provides an idealisation of a specific user profile, including all the relevant elements to understand the main attributes, lifestyle, emotions, feelings, and other relevant information. This tool is useful to define and visualise individuals in relation to any given context.

Hence, by developing Personas, the profile of an individual can be understood and envisaged in more depth. This is in line with the approach followed by He et al. [12] when describing the application of the TTM. In addition, the description of the preferences

JON ZABALA

" I know the environmental problem is serious and I do my best to try to be sustainable. However, I'm very busy and I can not think too much on it."



Jon lives in Berlin with Peter and Zero (their dog). He is a 34-year-old architect who recently started a new job in a very prestigious architecture studio. He is a hard-working person who is always worried about being efficient and productive in his life. He is very familiar with technological devices and gadgets and he has been a fan of the Apple brand for a long time. At present, he owns two Macs, an iPhone, an Apple Watch, AirPods, and an iPad. He likes rock music and going to music concerts.

Jon is not a sporty person, but he tries to stay active in his everyday life. Therefore, he goes walking whenever possible and goes hiking on the weekends. Since he was a child, he has loved dinosaurs. He has a great collection of books and other related stuff. His perfect weekend is a concert with friends on Saturday and watching Netflix and relaxing on Sunday.

Jon is conscious of the environmental situation and its importance. He cares about the situation of people in danger, and most of his friends are very active in this field. Indeed, pro-environmentalism is a common topic in his everyday life. Due to this, Jon somehow aspires to improve his lifestyle according to his concerns. For example, he eats less meat, and he tries to reduce his waste output. Nevertheless, as he has many things on his mind, he does not make any relevant effort to improve the impact of his actions. He often thinks about it and feels guilty, but due to the fact that he finds it complicated to make any meaningful impact on the environment, he does not behave fully responsible in terms of sustainability.

AGE 34
LOCATION Berlin, Germany
OCCUPATION Architect
STATUS Lives with his boyfriend
ARCHETYPE Busy & lazy

PAINS Sometimes Jon feels that he does not do enough for the environment. He thinks it is difficult to be sustainable.
GAINS Jon is happy when he does his best. If the choice is affordable, he always chooses the most sustainable option.



Figure 7. Jon and the main characteristics that are included in the profiling at the initial stage.

and other relevant insights helps researchers and practitioners to understand better how an intervention would be received by the potential users. The creation of scenarios is the next step of the Persona-Scenario method, which involves the exploration of the performance of the Personas in any specific context and/or system. This tool helps to envisage how a system or framework, in the context of the Personas, would work and to identify potential design problems in early stages.

Personas. For this research work, three individuals have been devised: Jon, Lily and Sua. These profiles were developed taking into account the different personalities proposed in the FOX model. Thus, Jon is a Shortcut user, Lily is a Thoughtful user; and Sua is a Pinball user. Figure 7 shows the main attributes and description of Jon, Figure 8 of Lily and finally, Figure 9 shows the information related to Sua.

Scenarios. Once user profiles are defined, the next step is to underpin how these arche-

LILY RICCI

"It is our problem, our home is in a big danger. We must do whatever we can to solve it."



Lily lives in Catania, Italy. She is a 43-year-old woman who lives in a small flat in the city centre together with her two cats, Milos and Alfred. She loves her small flower shop and works hard on it. She is an open-minded person who is calm, optimistic, and polite. She enjoys everyday contact with people and loves working with flowers and plants and being in natural environments. She uses social media in her daily life, mostly to promote her business and to deal with customers. Indeed, she prefers personal relationships. She practices yoga and Tai-Chi once a week. She reads a lot; most of the books are historic and noir novels, and as she is a dreamer, she enjoys visualising herself in these adventures. Lily is a convinced vegan, although she does not like persuading others about it. Her perfect weekend is travelling outdoors to discover landscapes by walking in the middle of nature, followed by having a coffee and cake in a nice place.

Lily is very aware of the environmental situation. She feels responsible for it, and she is very active in doing her best to reduce her environmental impact. For Lily and her friends, being environmentally conscious is very important; therefore, they always make the most environmentally friendly choices when eating, travelling, buying groceries, and so on. She always reflects on her actions and tries to improve her behaviour. Nevertheless, she feels that some environmental issues are out of her control, and she feels frustrated about it.

AGE 43
LOCATION Catania, Italy
OCCUPATION Flower Shop owner
STATUS Single, lives alone
ARCHETYPE Responsible & proactive

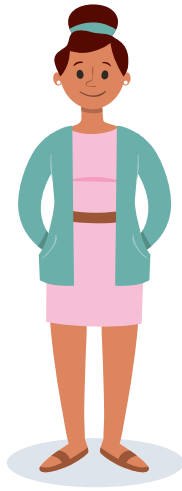
PAINS Lily wants to do more for the environment but she feels she can not.
GAINS Lily is excited about learning new pro-environmental things. Besides, she is very proud of her process and improvements in relation to sustainability.



Figure 8. Lily and the main characteristics that are included in the profiling at the initial stage.

SUA BOIX

"I have a lot of problems in my everyday life and I can not think on this right now. Besides, it is the responsibility of the politicians."



Sua (58) lives in Barcelona with her husband Josu. They have two sons, Mikel (29) and Aitor (33), who moved out a few years ago, but live near them, at their own places in Barcelona. Sua is a teacher at a high school with 15–16-year-old students. She has worked there for more than 20 years, and she is happy there, although she thinks very often about retirement. Although Sua and her family do not have big problems, Sua is always worried and concerned about her husband and her sons.

Sua and Josu love going to the beach. They own a house in a small village near the sea, and they go there very often. Sua likes cooking and gardening, growing vegetables in the small garden they have in their country house. Her perfect weekend is going to the beach early in the morning, then preparing and enjoying a big lunch for all of her family with her own raised vegetables.

Sua is not really concerned about the environmental situation. She recognises that it is a problem, but she does not feel it is her problem. She believes that this situation is a direct consequence of the poor management of politicians, and she does not feel responsible for it. As she is constantly worried about her family's economics, she is worried about the specific behaviours that have a direct impact on them, such as the monthly bills. Nevertheless, as she does not think about her actions, she has made some improvements (due to her sons) without noticing them.

AGE	58	PAINS	GAINS
LOCATION	Barcelona, Spain	Sua believes that politicians and companies are ruining the environment.	Sua is happy because she made some sustainable improvements that also were good for her (e.g. saving energy).
OCCUPATION	Teacher	She feels she can do nothing about it.	
STATUS	Married with 2 sons		
ARCHETYPE	Detached		

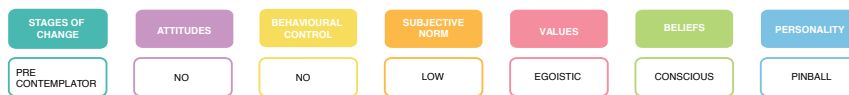


Figure 9. Sua and the main characteristics that are included in the profiling at the initial stage.

types perform their sustainable behaviour by applying the FOX model in the context of smart environments. For that, the first step is to set the main stages and actions of the implementation process to identify the critical areas Figure 10 shows the workflow defined to apply the FOX model. This tool will help to detail the specific tasks and stages of the process to gain knowledge on how the system will work. Based on the workflow, three specific scenarios are developed, one for each user model: 1) The scenario of Jon is contextualised in his workplace. In this open space, the main devices are shared with other colleagues, but they have a smart system that can detect individual actions and give personalised inputs according to them. The main device involved in this context is an app that offers information and other features. As Jon's workplace is a smart office, this app is connected to the different sensors of the office. 2) The context of Lily involves her home. She has just one smart device, a smart meter, which can learn from Lily's behaviour and predict her actions, reinforce her behaviour, offer recommendations, and suggest automation strategies. 3) The last scenario involves Sua and her family. Their

context involves a smart home (an individual space with a smart system installed), where the key factor is the inclusion of different user profiles, offering common interventions to reinforce the group, as well as personalised inputs, according to the different user profiles. In this way, all the individuals have a common goal while preserving their personal preferences.

Thus, they will feel a part of the group while maintaining their individuality. The devices involved in this scenario are mainly the app and other home appliances connected to the Internet, such as the vacuum cleaner, the lights, and the thermostat.

A detailed explanation of these scenarios can be found in the manuscript included in Chapter 5.

2. 3. 4. Discussion of the FOX model

The exposed Personas explored an individual's universe and his/her complexity, while the use cases explored how these archetypes perform their behaviours and interact with the system in any given context. In this way, the development of Personas may help to better understand individuals, while the development of the case studies may help to comprehend how these user archetypes interact with the system in their everyday life. Furthermore, although more research is needed to validate the findings, the possibilities the FOX model offers can be envisaged through these scenarios. Besides, using these methods the implementation of the strategies can be conceptualised in an early stage of the process, in order to test whether an idea or intervention works in a given context, before investing resources into it. To provide an overview of the performance of the model, Figure 10 shows the workflow where the main stages of the performance of the FOX model are detailed.

Another critical factor that should be considered is the importance of complementing the dimensions of the model with other specific data. From the results of the survey, we conclude that the dimensions should vary depending on the context of the application, complementing the core elements of the model with other information such as demographic variables. Besides, the proposed case studies show also how the usage of non-behavioural dimensions is a paramount issue.

Additional relevant topics that should be further investigated relates to the way that rules and measures for classifying individuals should be set up. As the results of the qualitative study show, in order to implement the FOX model in the user modelling process, specific measures are needed to include the individual in each category, depending on their characteristics.

Finally, from the qualitative study, we also extracted how the FOX model can be applied to different contexts. From health to education, the model may be implemented to cover the diversity of individuals when developing interventions in any target population.

Nevertheless, as previously indicated, the selection of the dimensions, the development of specific rules and measures, and the implementation of data gathering tools must be carefully considered, in order to adapt and apply the model successfully.

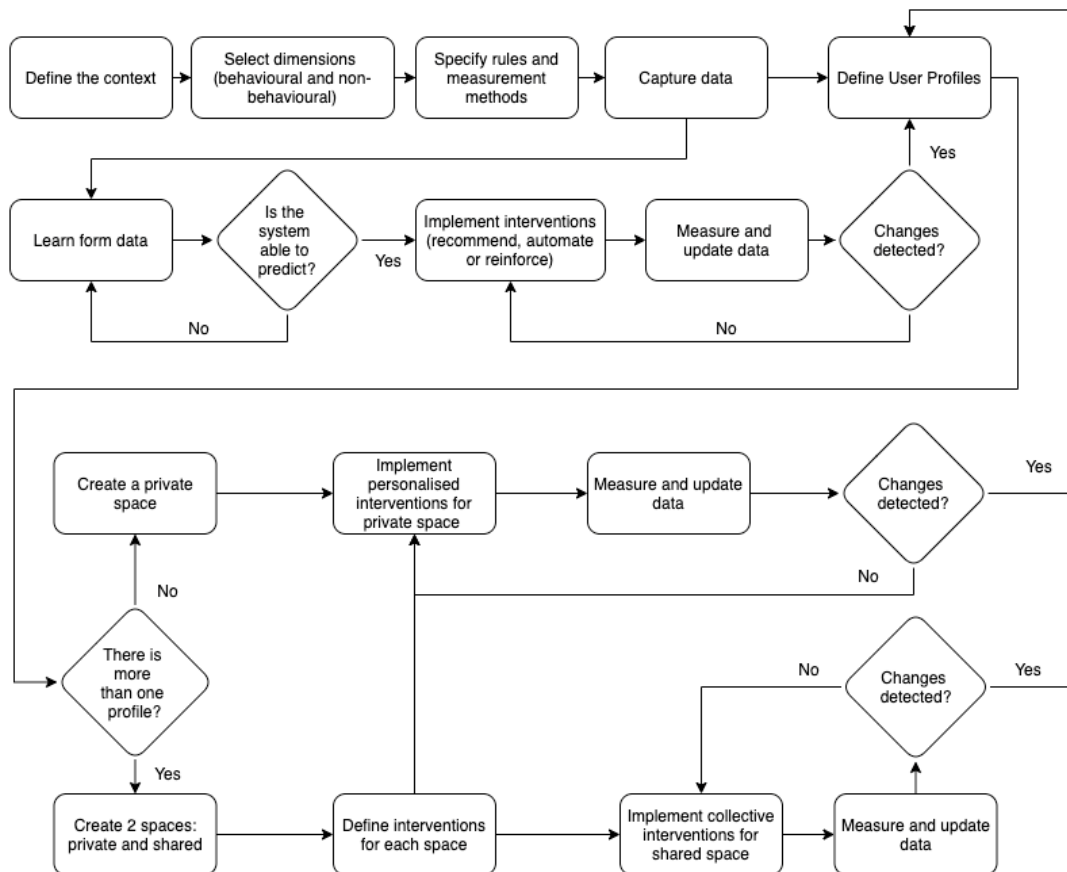


Figure 10. The workflow related to the performance of the FOX model.

"I confess that I should feel a bit afraid of asking Sunday who he really is."

"Why," asked the Secretary, "for fear of bombs?"

"No," said the Professor, "for fear he might tell me."

G. K. Chesterton, *The Man Who Was Thursday*

CHAPTER 3

Addressing Behavioural
Technologies Through the
Human Factor: A Review



Addressing Behavioural Technologies Through the Human Factor: A Review

ANE IRIZAR-ARRIETA¹, OIHANE GÓMEZ-CARMONA, ARITZ BILBAO-JAYO,
DIEGO CASADO-MANSILLA¹, DIEGO LÓPEZ-DE-IPÍÑA¹,
AND AITOR ALMEIDA¹

DeustoTech, University of Deusto, 48007 Bilbao, Spain

Corresponding author: Ane Irizar-Arrieta (ane.irizar@deusto.es)

This work was supported in part by the FuturAAL under Grant RTI2018-101045-A-C22 and in part by the Sensitive Things under Project TIN2017-90042-R. Besides, we gratefully acknowledge the support of the Basque Government's Department of Education for the Deustek Research 1174 Group - IT 1078-16 D and the pre-doctoral funding of some of the authors.

ABSTRACT Energy-efficiency related research has reached a growing interest in recent years due to the imminent scarcity of non-renewable resources in our environment and the impending impacts their usage have on our environment. Thus, facing the reduction of energy waste and management has become a pivotal issue in our society. To cope with energy inefficiency, the scientific research community has identified the promotion of people's behaviour change as a critical field to foster environmental sustainability. However, the body of literature shows a lack of systematic methods and processes to reach a common ground when designing technology for promoting sustainable behaviour change. Therefore, this paper contributes with a thorough review and analysis of state of the art. Firstly, theoretical works related to behaviour change are collected and studied to clarify their main concepts and theories. Secondly, the different technologies, processes, methods and techniques applied in the field are reviewed to find diverse strategies in the application of the previously explained theoretical domains. Moreover, a wide range of systems developed to improve energy efficiency through human behaviour change is analysed (from augmented objects to the Internet of Things, digital applications or websites). Finally, the detected research gaps are listed to guide future research when aiming to raise the awareness of individuals through Information and Communication Technologies.

INDEX TERMS Behaviour change, Internet of Things, sustainability, sustainable behaviour change, ICT.

I. INTRODUCTION

The industrial development and the fast proliferation of Information and Communication Technologies (ICT) and electronic devices are some of the wide amount of factors that have increased energy usage in the current years [1]. To avoid massive exploitation and waste of natural resources, a sustainable approach must be implemented in all the stages of the value-support chain. There are 2 common approaches to tackle energy efficiency through technological systems, which can be used in an isolated or complementary way: 1) *With Technology*: this approach involves technology-based solutions, like automation or Artificial Intelligence. This idea puts the focus on the devices or systems themselves. Thus, the responsibility of being efficient lies in the technology.

The associate editor coordinating the review of this manuscript and approving it for publication was Yi Zhang.

Although this can be a powerful strategy, it presents some negative effects when individuals are involved: the automated processes may cause distrust, and a rebound effect may appear when the technological aspect is removed due to the disassociation of the user [2]. 2) *Through Technology*: This approach uses technology as a way to influence on the individual. For that, the Human-Computer Interaction relies on the user side to improve awareness about energy efficiency and sustainable behaviour through methods and techniques that focus on the human factor.

To understand human behaviour towards waste of energy, the context is a key factor that presents specific challenges. In scenarios where the individual is not involved (like in some industrial processes) "*With tech*" approach can be feasible. However, the individuals behave differently depending on the context and therefore, the context-related factors must be taken into account when the user is involved in a specific

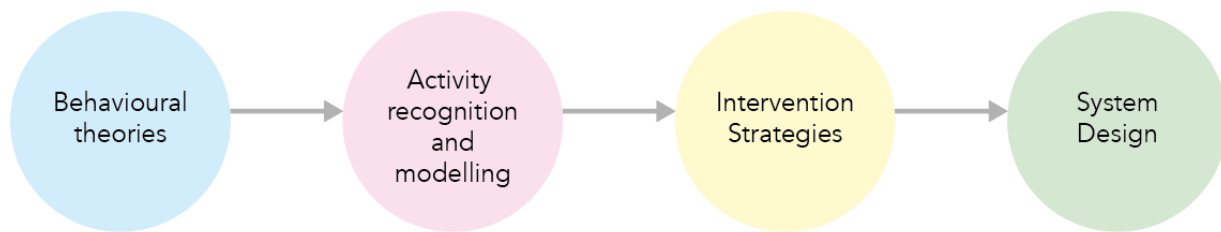


FIGURE 1. The basic workflow of the development of Behavioural Technologies is followed in this work to review the different works in the field.

strategy or interaction. The physical environment where sustainable behaviour is performed is directly related to this context [3]. At private spaces, like home, the individual is more aware of their own energy consumption since they are the one in charge of managing the energy-related issues and paying the fees. In shared or public spaces, like the workplace, the responsibilities are diluted and the behaviour is less strict as a consequence. Thus, the awareness about energy consumption in workplaces is poorer than in private spaces due to the third party management and payment, and therefore, energy waste is higher in this type of contexts. Although the awareness of the individuals through sustainable behaviours and efficient energy management should be improved and fostered in every context and moment, the gap to improvements is higher in contexts managed by third parties.

While awareness is always linked with consciousness, the behaviour change can be performed avoiding the conscious actions and decision-making processes. Some strategies and tools to foster the change can not influence the individual, but most of them address the rational side, improving the awareness to raise the change subsequently. Therefore, both “awareness” and “behaviour change” concepts are closely related, but it is important to recognise the differences. In fact, they should be taken into account to understand the implications and correlations between both concepts in order to target each strategy.

Following the lines proposed by a previous works in the field [4], this paper offers an overview of the different concerns related to energy-efficient behaviour. Furthermore, it covers a significant number of relevant pieces of research from different scholars, ranging from the theoretical issues to the final applications and systems. Hence, the main contributions are, i) to collect relevant works from the body of literature; ii) to analyse the current status of the research topic; iii) to find gaps and the uncovered issues in the literature; and iv) to set future research lines and shed light on how the research field may evolve. To address these objectives, we provide a structured analysis to offer researchers and practitioners a guide of the different concerns related to the development of technologies to foster the energy-efficiency addressing the human factor. The structure of this paper follows the work-flow of the ideation and development of Behavioural Technologies (BT) (see Figure 1). For additional clarification, BT are understood as technological strategies and systems addressed to target the behaviour change.

For selecting the works presented in this article, we applied the following methodology: mainly works related to the energy efficiency have been analysed, and the theoretical approach has been delimited to this area to avoid losing the focus from the target topic. From this selection criteria, the most recent works have been prioritised. The included information has been extracted from the main scholarly research databases, including Google Scholar, Scopus or IEEE Xplorer. These databases were queried using a combination of keywords such as “Behavioural Technologies”, “Sustainable Behaviour Change”, “Eco-feedback” or “Activity Recognition Model”.

From the large number of works included in those categories (e.g. 2750 results for “Eco-feedback”, 1270 for “Sustainable Behaviour Change” or 1160 for “Activity Recognition Model” in Google Scholar), every search was redefined using secondary keywords such as “sustainability” or “energy-efficiency” to find the best combination. Those with the main keyword in the title or the abstract and containing the secondary ones in the rest of the paper were pre-selected and categorised according to the different topics they were related to. However, in section III some other works non-related to the energy have been added in order to show examples of works using advanced behaviour recognition techniques for behaviour change in other fields.

The most relevant papers were then carefully reviewed to determine the final eligibility, and its bibliography was also analysed in order to extract relevant references which could enrich our study. As a result of this process, this work includes a selection of almost 150 papers, most of them recently published, on a wide variety of topics around energy-efficiency and behaviour change.

The rest of the paper is structured as follows: Section II reviews the most common and used theoretical approaches applied to energy efficiency, highlighting works that use and implement these frameworks in technological systems or interfaces. The objective is to offer a solid theoretical background to contextualise the technologies that address energy efficiency through the human factor. This section will help the research community to face the development of technological systems with the understanding of theoretical concerns that needs be taken into account to develop human-centric technologies and systems. Next, we put the focus on the behaviour recognition technologies in intelligent

environments (Section III). Behavioural recognition involves technologies to gather and process data from the users in order to model and predict their activity. In this context, the existing approaches are reviewed to offer an overview of the current state of the art in the field: data-driven approaches, knowledge-driven approaches, and hybrid approaches. This section offers a summary of the current state of the art in behaviour modelling and recognition and may be helpful to the practitioners due to the review of the available approaches and technologies provided, which can guide the selection of technologies and the development of new ones. After the revision of theoretical concerns and the modelling and recognition technologies, the next step in the development of BT should be to select behaviour change strategies and methods. In Section IV, we offer a review of the most relevant guidelines, toolkits and empirical findings to provide an overview that aims at helping the researchers and practitioners in the strategy selection and implementation. Once covered the theoretical frameworks, behaviour recognition/modelling technologies and strategy selection, we put the focus in the technological systems intended to change the human behaviour to face energy efficiency. Therefore, Section V, tangible and digital systems that address the energy efficiency through human factor are reviewed, from energy consumption data to context-aware information and including other behaviour-related systems. Next, we propose a discussion to analyse the most controversial findings and different or complementary approaches that can be complex and diffuse. And finally, with the intention of offering valuable knowledge, we highlight the findings of the research work, providing a summary of the main conclusions. Besides, we summarise the main findings of the current state of the art, the main gaps that are uncovered and the future research lines that should guide the research work.

II. THEORETICAL APPROACHES FOR BEHAVIOUR CHANGE

As Hekler *et al.* [5] stated, BTs are gaining importance in the research community. Therefore, to develop successful systems and strategies it is crucial to understand human behaviour in its different phases. In fact, most of the behaviour change systems set their work upon theoretical models to sustain their research in a psychological background that contextualises the behavioural action and process. Nevertheless, the behavioural theories are not universal and they can present shortcomings. The researchers and practitioners should take this into account in the selection and analysis of the behavioural theoretical background.

In this section, we describe the most relevant theoretical approaches that have been implemented in BT addressed to promote energy efficiency. Firstly, we introduce the most used behaviour change theories and models. Secondly, we introduce Behavioural Economics, a field that emerged from economists that have been applied to improve energy-efficient behaviours. Finally, we summarise the main theoretical framework used for activity modelling and recognition.

The explained theoretical models have significant differences taking into account the constructs used to frame the behavioural process. These differences can be used to choose the appropriate framework for each case. Besides, these can be combined and complemented to avoid the potential shortcomings derived from the static of the use of a single framework.

A. THEORETICAL MODELS FOR BEHAVIOUR CHANGE

In this review, we only put the focus on theoretical approaches and/or conceptual frameworks that are used to foster energy efficiency. This is important, as we only focus on these available theories that are being taken into account to develop BT. Hence, the main models of behaviour change applicable in the field of environmental sustainability are the following:

- 1) The Trans-Theoretical Model (TTM) [6] takes into account the different phases that occur in the behaviour change process: pre-contemplation, contemplation, preparation, action, maintenance and termination. Certain principles and processes to generate the desired behaviour change work best in each of the different stages mentioned. Based on this framework He *et al.* [7] implement different strategies based on the diversity of the individuals. In addition, Wising, Chirez and Adams [8] develop a proposal based on an adaptation of the Trans-Theoretical model to improve the industrial energy efficiency by changing the energy culture.
- 2) The theory of Values Beliefs Norms (VBN) [9], applies a value-based theory to a wide range of factors influencing the individual. Subjective norm is activated when individuals become aware that certain behaviour that they perform have adverse effects on issues they believe, and that behavioural action will have a positive and significant impact on the aspects the individual values. This approach is proposed by Stern *et al.* [9] and refined later [10], developing a framework of pro-environmental behaviour following the value-beliefs norms. Besides, [11] Petkov *et al.* proposed an interface offering feedback to different user types depending on the different values outlined by Stern's theory.
- 3) The Theory of Planned Behaviour (TPB) [12], is a conceptual framework that links beliefs, attitudes and behaviours with the intentions, which helps to understand how people's behaviour can be changed or directed with a series of predictable aspects that can influence the intended behaviour. This theory is based on the decision-making process (intentions) and the execution of the activity, and is conditioned by three factors: the personal evaluation of the behaviour (positive or negative), subjective norms and perceived behavioural control over the behaviour you want to change. In the same way as Petkov *et al.* applied the VBN, Coskun and Erburg [13] defined hypothetical user types for pro-environmental behaviour based on the variables defined by the Theory of

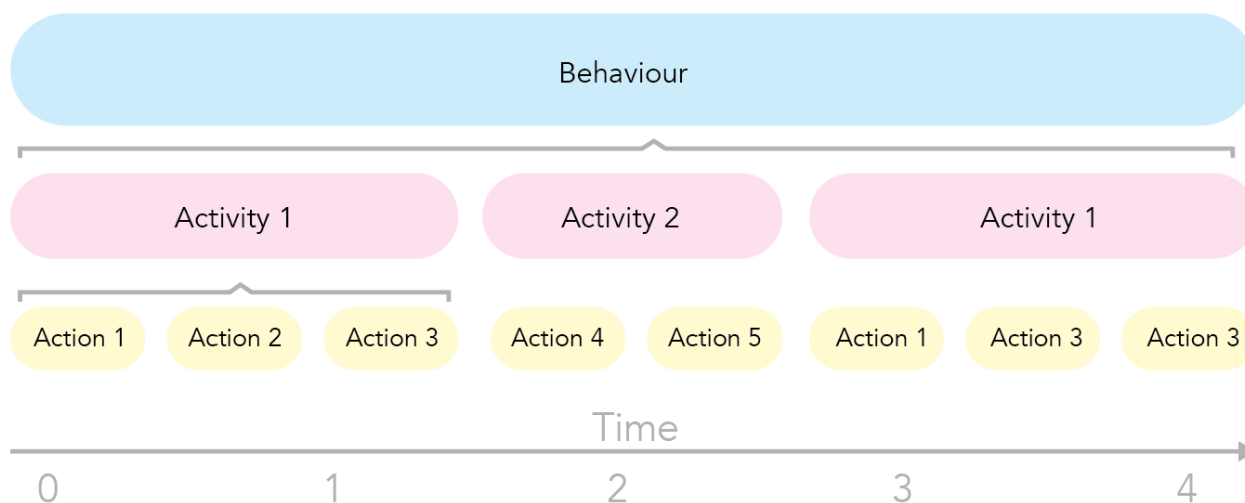


FIGURE 2. Activity recognition hierarchy model.

Planned Behaviour. In addition, Greaves, Zibarras and Stride explored the environmental behavioural intentions in the workplace using the TPB theory [14].

- 4) The Self-Concordance Model [15] is based on the idea that it is possible to improve the (sustainable) behaviour connecting specific behaviours with goals which are important to the individual. Although this model has been applied in another context, to the best of our knowledge there is only one related to energy efficiency: a recent study developed by Unsworth and McNeil [16] where an intervention is tested, validating the idea that connecting the goals and pro-environmental behaviour, the latter can be improved.

B. BEHAVIOURAL ECONOMICS

Behavioural Economics is a field that analyses the effects of psychological and cognitive factors in the decision-making process of individuals [17]. It aims at guiding the conduct of the individuals covering the discrepancies among the perceived behaviour and the real conducts and actions. Behavioural economics is based on the limitations and barriers that influence the decision-making process and consequently in the behaviour. For that, this approach is focused on the heuristics and biases that influence the individual's choices. In recent work, Sorrell exposes a review of issues, challenges and approaches to address the energy efficiency, including behavioural economics as a field that provides a more robust understanding of economic decision-making [18]. Besides, Frederiks, Stenner and Hobman apply the behavioural economics to understand the consumer decision-making and behaviour in the household energy-use [17]. The role of Behavioural economics in Energy and Climate Policy has been explored by Pollit and Shaorshadze [19]. They analyse the three areas of impact: consumption and habits, investment in energy efficiency and

provision of public goods and support for pro-environmental behaviour. Nevertheless, they conclude that behavioural economics seem unlikely to provide the solution to massive energy consumption problematic.

C. BEHAVIOURAL THEORIES FOR ACTIVITY RECOGNITION

From the point of view of the activity recognition, the behavioural theories are understood as conscious movements developed in a determinate frequency. Multiple authors have introduced several definitions for human conduct in intelligent environments, conditioned by the complexity and granularity of the modelled conduct. Chaaraoui *et al.* [20] propose a model with three levels of conduct: actions, activities and behaviours. In this model, each of the levels is composed by conduct instances of the previous level, i.e. activities are composed by actions and behaviours are composed by activities. Almeida & Azkune [21] extended and formalised this model, providing definitions of each level and distinguishing two types of behaviours, intra-activity behaviours and inter-activity behaviours (Figure 2). Authors propose the following definitions:

- Actions are temporally short and conscious muscular movements made by the users (e.g., taking a cup, opening the fridge, etc.).
- Activities are temporally longer but finite and are composed of several actions (e.g., preparing dinner, taking a shower, watching a movie, etc.).
- Behaviours describe how the user performs these activities at different times. They have identified two types of behaviours. The intra-activity behaviours describe how a single activity is performed by a user at different times (e.g., while the user is preparing dinner, sometimes they may gather all the ingredients before starting, while on other occasions, the user may take them as they are needed). The inter-activity behaviours describe how the user chains different activities (e.g., on Mondays after

having breakfast, the user leaves the house to go to work, but in the weekends, they go to the main room).

III. BEHAVIOUR MODELLING AND RECOGNITION IN INTELLIGENT ENVIRONMENTS

Human behaviour modelling and recognition is an active area of research for promoting behaviour change in intelligent environments. To do so, several behaviour modelling approaches have been employed. For instance, Carulla *et al.* [22] proposed the modelling of higher-level conducts, starting from the behaviour. The authors proposed a hierarchical structure that includes behaviours, habits (repeated behaviours that have been internalized) and lifestyles (groups of habits). They model a taxonomy of six higher level habit categories (diet/exercise, vitality/stress, sleep, cognition, substance use and other risks).

In this direction, other authors have also created several ontologies to describe human behaviour. Chen & Nugent [23] propose an ontology modelling the Activities of Daily Living [24] to be used for activity recognition. Similarly, Nevatia *et al.* [25] created an ontology to model actions in videos. While Latfi *et al.* [26] propose an ontological architecture of a telehealth-based smart home aiming at high-level intelligent applications for elderly persons suffering from loss of cognitive autonomy. Azkune *et al.* [27] propose an ontology to model actions and activities based on their type and the sensors used for their detection. Riboni *et al.* [28] use a detailed ontology of possible behaviours to recognize them. Finally, Almeida & López-de-Ipiña [29] propose a model that considers uncertainty and fuzziness when modelling intelligent environments.

Behaviour recognition in intelligent environments is divided into two significant approaches, data-driven and knowledge-driven approaches, with the hybrid approaches that combine both of them gaining popularity in the last years. Data-driven approaches use annotated datasets to apply machine learning and data mining algorithms to learn models able to recognize the target behaviours. Several examples of the data-driven approaches exist in the literature. Brand *et al.* [30] present a Hidden Markov Model based system to recognize the activities that the users are performing. Hayashi *et al.* [31] use deep neural networks for activity recognition based on accelerometer data and environmental sounds. Moreover, Almeida *et al.* [32] represent user actions using Word2Vec embeddings and then apply multi-scale convolutional neural networks (CNN) to predict the user behaviour based on the previously executed actions. To conclude, Guan & Plötz [33] use ensembles of LSTMs to recognize activities of daily living in smart-homes, based on sensor data.

In the case of the knowledge-driven approaches for behaviour recognition, prior domain-specific knowledge is used to create behaviour models that are compared with the captured data. To do that, Chen *et al.* [34] propose a logical framework for cognitive behavioural modelling, reasoning and assistance based on a logical theory of

actions, which they refer to as Event Calculus. In COSAR, Riboni & Bettini [35] use ontologies and ontological reasoning combined with statistical inference. The authors use structured symbolic knowledge about the environment to infer which activities among the candidates identified by statistical methods are more likely being executed. Chen & Nugent [36] also propose another different system, based on multi-sensor data streams in smart homes, which exploits semantic reasoning and classification for activity recognition, enabling both coarse-grained and fine-grained activity recognition. Finally, Noor *et al.* [37] present an algorithm that integrates OWL ontological reasoning mechanism with Dempster-Shafer theory of evidence to provide support for handling uncertainty in ontology-based activity recognition.

Hybrid approaches combine both data- and knowledge-driven solutions for behaviour recognition. For example, Ye *et al.* [38] present a hybrid activity recognition system named USMART, where ontologic models define the sensors measures that compose an activity. In order to detect the sensor patterns that need to be mapped, they propose a semantic similarity metric. Azkune & Almeida [39] propose an easily scalable activity recognition systems named HARS, which uses an unsupervised pattern recognition algorithm to detect possible activities and using minimal activity models to recognize them. Riboni *et al.* [28] first model the behaviour knowledge using an ontology which later is mapped to a Markov Logic Network, an approach that requires very detailed models of the users' behaviour.

A more in-depth analysis of behavior recognition can be found in the surveys by Lara & Labrador [40], Shoaib *et al.* [41], Chen *et al.* [42] and Wang *et al.* [43].

Following this trend, different works have applied behaviour recognition and modelling techniques to improve energy efficiency through behaviour change. Casado-Mansilla *et al.* [44] model and predict specific energy-related behaviours (i.e. usage of specific devices) using ARIMA to foster more sustainable behaviours. Fabi *et al.* [45] modelled human window opening behaviour in residential buildings in order to reduce levels of buildings energy consumptions. Nguyen *et al.* [46] present an ontology-based activity recognition system in office environments in order to serve as input for building energy and comfort management systems. The proposed system handles multiple-user, multiple-area situations, rapidly recognizing office activities. Cottone *et al.* [47] propose a hybrid activity recognition model based on the SAIL [48] and MDL [49] algorithms in order to predict energy consumption.

IV. METHODOLOGIES TO DEVELOP BEHAVIOUR CHANGE TECHNOLOGIES

Behavioural theories and frameworks may be abstract and complex to be implemented when developing BT to improve energy-efficiency. To address this challenge, several pieces of research offer different proposals. Empirical findings and the design hypotheses are the typical starting point to guide

the design of strategies. Many different approaches and works can be found in the literature that offer guidelines to address the energy waste through behaviour change: 1) Persuasive Technology, 2) Design for Sustainable Behaviour (DfSB) and 3) Nudging are some of the fields that focus on the improvement of the energy-efficient behaviour. Besides, there are other tool-kits and proposals that offer guidelines and methods to face energy efficiency through the human factor. In the following lines, we highlight the most relevant proposals in this field according to the authors' criteria.

- 1) Fogg [50] defines Persuasive Technology as “the class of technologies or interactive computing systems that are intentionally designed to change a person’s attitude or behaviour”. There is a wide amount of literature on persuasive technology and its review is out of the scope of this paper. Therefore, we highlight some of the most significant proposals to better contextualise the field. According to Fogg, the functional triad is a framework that illustrates the three roles computing technology can play: tools, media and social actor. As tools, persuasive technologies make users’ activities easier or more efficient to do, e.g. by performing calculations or providing guidance that leads users through processes in a step-by-step manner. As media, persuasive technologies provide interactive and engaging experiences. Finally, as social actors, persuasive technologies attempt to mimic a living entity, e.g. by providing feedback or social support. The Persuasive Systems Design (PSD) [51] discusses the process of designing and evaluating persuasive systems and describes which kind of content and software functionality may be found in the final product. Persuasive systems are defined as “computerised software or information systems designed to reinforce, change or shape attitudes or behaviours or both without using coercion or deception”.
- 2) Design for Sustainable Behaviour (DfSB) [52] is a field that aims at reducing the environmental impact intervening people’s everyday activities through the design of interfaces and systems. It takes into account the different impact-types throughout the product (or system) lifecycle [53]. This field focuses on the system-design to influence the improvement of human behaviour. The DfSB covers the main areas of influence on user decision-making: eco-feedback, which guides change, behaviour steering, which maintains change and Persuasive Technology, which ensures change. DfSB, therefore, provides a framework for acting in all areas of influence when designing products and systems that promote energy efficiency. Michie proposes specific strategies and techniques for this task, offering a taxonomy of techniques applicable to the process outlined in the DfSB [54]. Besides, in other relevant work, the author proposes a mapping of behaviour change techniques to behaviour determinants [55].
- 3) Following the behavioural economics’ theoretical approach, a relevant part of the literature has

emphasised Nudging as a method to guide energy-efficient behaviour [56]. Nudges are strategies to steer individuals while preserving freedom of choice. The key concept is to facilitate the most sustainable decision and make the unwanted choice more difficult, without cutting options and offering choices. Newell and Siikamäki applied nudges to evaluate the impact of energy-efficient labelling in the user-decision making process, finding that economic-related simple information was the main element that guided the decision [57]. Ölander and Tøgersen analysed the impact of both informational and nudging strategies, concluding that only educational approaches had limited success at changing behaviour. Besides, the environment-related choices include some conditions (as the delayed effect of the choices, the difficulty of these, the poor feedback...) that obstructs the decision-making at the cognitive level being necessary behaviour steering tools and techniques. Therefore, following the authors’ conclusion, the researchers and practitioners should ensure that informing and nudging strategies are applied in a simultaneous and complementary way [58]. Nudging has become a key term to encompass techniques that work through the automatic decision-making system (for example the setting of defaults as pre-set flows of an action). Therefore, it should be understood as an empirical application of behavioural theory, and more research is needed to define a more elaborated and solid framework, offering defined and validated guidelines.

Once reviewed the most relevant research fields that tackle the implementation of the theoretical background presented above, there are some other relevant works that should be included. These studies present empirical findings that guide the design phase and offer complimentary strategies to develop systems, technologies and interfaces that address energy efficiency through the human factor. Besides, other specific tool-kits and frameworks are reviewed to offer a summary of the most relevant methods and tools. Finally, other relevant empirical insights are exposed to offer an overview of papers that cover other types of research work, aiming to address the plurality of the available methods and points of view.

- The Behaviour Change Wheel (BWC) [59] is a methodology that includes a synthesis of 19 frameworks of behaviour change. It includes 3 main dimensions of behaviour, providing a simple framework to contextualise the behaviour. Capability, opportunity and motivation are presented as 3 key conditions for behavioural activity. Moreover, sources of behaviours, intervention functions and policy categories are included to facilitate the application across levels from individuals to groups. This framework has been used to design energy interventions [60] and as a methodology to guide the systematic review of the available evidence on interventions to change behaviour and save energy in the workplace [61].

- The Theoretical Domain Framework (TDF) [62] provides a method for conducting a more elaborate behavioural analysis. The 14 domains of the TDF can be mapped onto the Capability, Opportunity and Motivation components of BCW. Although this framework seems very relevant to develop a structured implementation of behavioural strategies to foster sustainable behaviour, to the best of our knowledge, it only has been applied to foster the recycling behaviours [63].
- The Design with Intent method proposes a tool for influencing user behaviour through different perspectives [64]. This approach is contextualised within the concept of Persuasive Technology and offers complementary and specific interventions to this field [65]. The Design with Intent method includes a tool-kit composed by a card deck to facilitate the design and implementation of behaviour change strategies [64]. This method has been applied to energy efficiency [66] and offers practical guidance, based on the theoretical background, that can enhance the design of Behavioural Technologies. In this context, Morgan *et al.* [67] used this tool in their studies to face energy efficiency in a large organisation.

Finally, to cover the different areas and other research works in the field, we review the studies that provide empirical findings on how to address the design and development of Behavioural Technologies.

Lockton *et al.* exposed the relevance of the DfBS and User-Centered design as a methodology to allow to develop energy-efficient systems and products [53]. Kuijter and Jong [68] and Wever, van Kuijk and Boks also worked in this idea [69]. In a later work, Lockton *et al.* [70] delve deeply into the study of the user diversity, proposing three different user profiles according to the behavioural traits of the individuals. For each profile, the authors suggest strategies and ideas to develop sustainable behavioural systems, technologies and products. In this line, Coskun explores user diversity analysing the dimensions of the users according to the Theory of Planned Behaviour [13], [71]. The authors also offer design ideas, guidelines and recommendations to address the heterogeneity of human behaviour. Besides, Petkov *et al.* [11] and He *et al.* [7] face user diversity purposing a user differentiation based on the constructs extracted from different Theoretical Frameworks, as exposed previously, offering suggestions and recommendations for each user type.

Morgan *et al.* explore the role of co-design in a large organisation through a Living Lab [67]. The authors extract insights and findings from workshops and develop an initial prototype to foster energy efficiency in the workplace. Yun, Aziz and Lasternas [72] explore the online feedback and control strategies for sustainability in the work environment and Bao *et al.* [73], [74], explore the impact of the quantitative and emotional feedback in the displays, finding that both aspects were relevant to improve the awareness in the individuals.

Cor and Zwolinski [75] exposed a procedure to select the intervention strategy on a product or system, offering a model that can guide the researchers and practitioners in the development of Behavioural Technologies.

V. TANGIBLE AND DIGITAL SYSTEMS

In a society where the proliferation of electronic devices leads the rising demand for energy, it seems paradoxical that the same cause of the problem, that is using even more electronic devices, could be part of the solution [76]. However, technological advances are enablers to contribute to a more environmental-friendly energy management [77] and to optimize the performance of electricity distribution and consumption [78]. Additionally, they can also to cover the lack of awareness of the individual about energy-related matters and its influence on the ecological footprint [79]. Under this context, technology can play an essential role in the reinforcement of energy efficiency relevance while increasing awareness through sustainable behaviours (i.e. monitoring which habits need to be changed and providing information about the consequences of the energy use). In this regard Pierce *et al.* [80] stated that technology based-solutions should undertake an optimal combination of measurement systems, a timely delivery of relevant information for personal control and the right design of interfaces to interact with the users.

In this particular, the Internet of Things (IoT) is emerging as a new paradigm in the ICT sector that aims to build up a dynamic worldwide infrastructure by connecting a variety of physical and virtual things [81]. The potential of IoT to provide appropriate solutions for energy awareness resides on its ubiquitous services. These services seek to convert the world in a global network of connected people and devices, enabling them to interact, collect and exchange data, make measurements and perform automatic analysis of the obtained data. Therefore, the pervasive nature of the Internet of Things can be considered a suitable tool to mediate the relationship between humans and their motivation towards energy-efficiency.

In essence, technology for energy-efficiency needs to put the focus on how data is obtained and how this data can be analyzed to extract relevant information in order to infer peoples' behaviours. These objectives range from the design of appropriate instruments and electronic devices for energy measurements (Smart Metering) to the use of advanced techniques for data processing and representation (Data analytics and Eco-feedback). Furthermore, this process should not oversee the promotion of technology adoption while achieving an appropriate user experience at the same time [82].

A. FROM ENERGY CONSUMPTION DATA TO CONTEXT-AWARE INFORMATION

One of the main requirements to foster energy efficiency through behaviour change is to initially collect data about the energy consumption of the users in different contexts. Data is usually obtained through smart gadgets such as wearables,

and in particular to the case of energy with smart meters. This equipment facilitates the communication and data exchange among the users and the energy supply chain. For this reason, it provides additional capabilities for demand response techniques, managing the load shifting of the power grid [83]. As a consequence, the deployment of smart meters allows to monitor consumer usage, adjust prices according to the hour and season and provide detailed information that helps users to identify power-saving opportunities.

Regarding the user, the primary purpose of smart metering techniques is to obtain enough data to illustrate energy habits in different everyday live contexts, particularly in contexts where individuals' choices and behaviours have a more significant impact on the energy consumption [84]. Different research works have approached smart metering technologies to monitor electricity usage, presenting architectures for data acquisition through IoT objects, a combination of these devices with big data analytic, or ubiquitous sensor-based systems. In 2016, Spanò *et al.* [85], presented a customer-centric architecture for the smart grid infrastructure, embedding smart home applications for energy monitoring in an IoT platform. Other works combine big data analytics with intelligent systems designed to provide information to the utility and the customers [86]. Other approaches allow to remotely monitor and control devices to better manage energy consumption according to user demands [87]. On the basis that sensorization is not enough to properly develop final energy-aware services, Terroso-Saen *et al.* [88] presented an accurate monitoring and control system for a large variety of energy-related agents, dealing with energy quality insurance and support for data analytic. Other approaches address the challenges for near real-time energy-related data processing towards developing energy management strategies [89]. In this direction, a ubiquitous sensor-based platform for tracking user's relevant actions was introduced by Jahn *et al.* [90]. Moreover, Al-Turjman *et al.* reviewed advanced metering infrastructures for power quality and reliability monitoring, highlighting IoT-related challenges for providing efficient control of the current power grids [91].

However, data itself is not enough in order to change the energy consumption patterns. Additionally, information needs to be clearly presented in a contextualized way that helps to associate this information to everyday practices [92]. This involves interacting with the users to show them data about their energy-related performance and corresponds to the concept of Eco-feedback [93], [94]. Eco-feedback has the potential to transform users' decision-making style from a habit-driven mode to a deliberate thinking mode [95]. To that end, two main aspects need to be taken into consideration to increase the feedback effect: which information is given to the user and how it is presented.

In this regard, in 2016 an analysis of energy consumption saving through real-time in-home displays feedback compared two approaches, one in which users learn about the energy consumption versus a one having a constant nudge or reminder of energy use [96]. In this work, real-time

information was found more effective in the long term when introducing the learning factor. Other strategies focus on the nature of the information, where electricity consumption can be associated with other factors, such as price visualization. In this sense, a pricing-based interactive control strategy was designed [97]. The idea behind this work was to remove the peak loads on the smart grids and match the energy supply with demand. By the same token, Nilsson *et al.* [98] analyzes the effect of real-time price visualization in overall household electricity consumption level. The results showed a load shifting of approximately 5% of the total daily electricity consumption from peak hours to off-peak hours. Other visualization strategies rely on showing the consequences of the energy-related behaviours on the environment [99] and appealing to the attitudes and determinants of more environmentally friendly behaviour [100].

The way in which feedback is framed must also be carefully considered. This corresponds to the visual methods employed to display energy-related information and feedback. In this category, ambient displays and other digital approaches such as web user interfaces are common visualization interfaces [101]. The visual delivering of energy-related information has been the subject of study from a design point of view in which the visual forms that are used in current research are reviewed [102]. In this work, Castelly *et al.* pointed to the adoption of more advanced visualization and analytic techniques to identify strategic goals. Another study addressed the key design components of eco-feedback interfaces and showed that historical comparison and incentives-based information worked as engagement tools for these platforms [103]. Visualization interfaces have also been harnessed to work as a tool to implement web-based intervention programs [104] and real-time monitoring [105]. Mobile phone applications also stand out as a suitable medium to provide behaviour-influencing feedback [106]. PowerPedia is an illustrative example of an application designed to better understand the energy usage metrics and to identify the energy consumption of different domestic appliances [107]. Peer-to-peer comparative approach and the social dimension is another strategy that directly correlates with existing social media initiatives [108]. In this regard, Petkov *et al.* presented EnergyWiz [109], a mobile application that enables comparative feedback supported by a community where participants can compare themselves with the rest of the users. More innovative approaches include enhanced variations, such as an interactive agent to operate the washing machine by booking time slots in order to minimize the cost of a wash by charging a battery at times when electricity demand is low [110] and a conversational agent for energy feedback [111].

Although previous works offer promising insights for encouraging energy conservation, new visualization platforms need to be studied [112]. For this reason, a wide range of augmented devices seeks to directly interact with the user and offer new ways to deliver information [113]. Tangible visualization through augmented everyday objects emerge

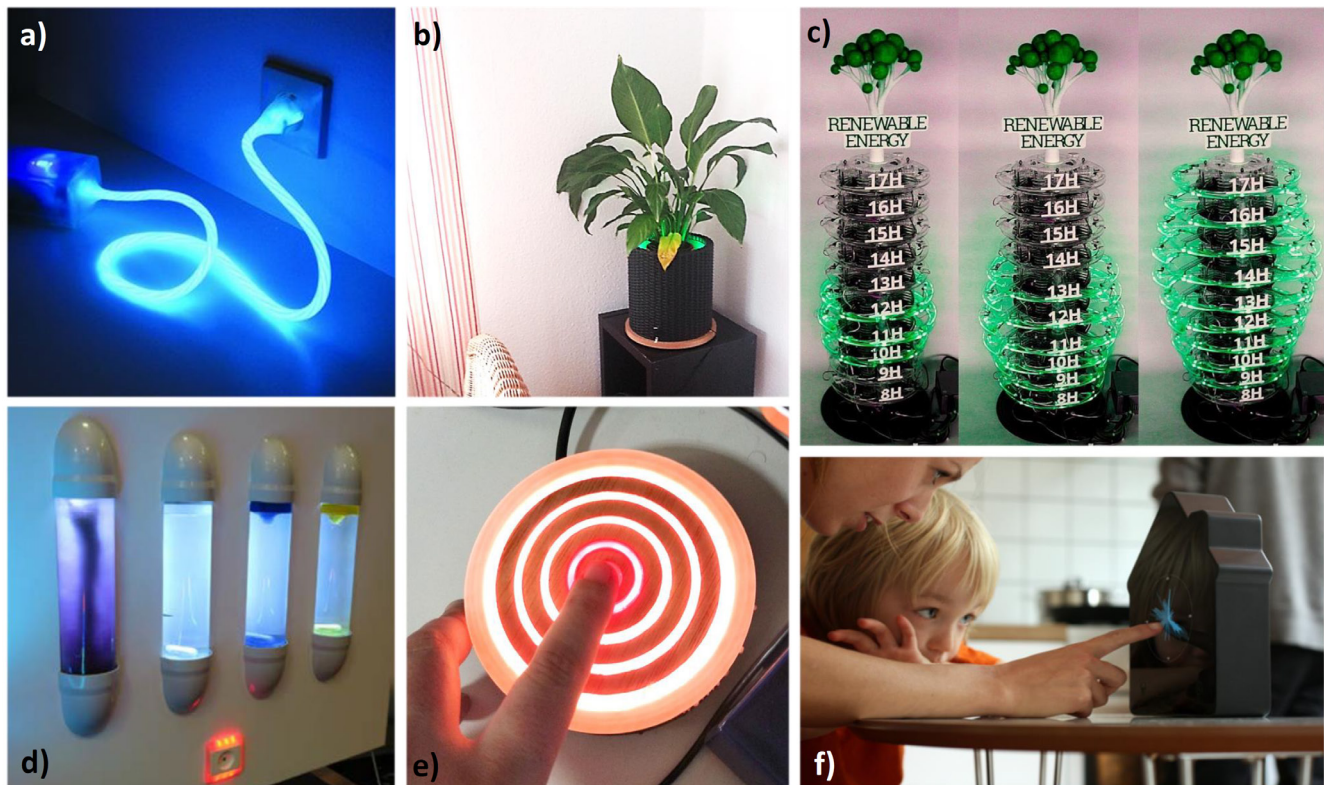


FIGURE 3. Examples of different augmented objects designed to display energy consumption: a) PowerCord b) InfoPlant c) CairForm d) Watt-i-see e) The Interactive coaster and f) The energy aware clock. Images ow of their corresponding authors. All images included are the property of their respective Authors.

as a very illustrative and innovative option to perform this user-level interaction by reinterpreting the functionality of a common object. In 2005, Gustafsson *et al.* presented the ‘Power-Aware Cord’ [114], a re-design of a common electrical power strip modified to displays the amount of energy passing through it at any moment. The main purpose of this strategy was to resemble the energy flow and make people aware of the level of energy needed at a given time. The idea behind this concept was studied by Backlund *et al.* [115], who analyzed how energy-related issues could be made tangible through form and the different aspects of energy feedback in objects. Following this path, other works have explored the possibilities of different attention-catching devices for energy awareness. Daniel *et al.* [116] presented a shape-changing interface using illuminated disks for representing physical histograms. Likewise, Heller *et al.* designed a power socket that visualizes the power consumption directly on the outlet [117]. In 2010, Broms *et al.* presented an approach to display the history of electric consumption through different patterns [118]. Furthermore, Schrammel *et al.* introduced a watch that provides the current status of the power supply grid [119]. The idea behind this work is to align users’ behaviour with the dynamics of the energy generation and promoting the time slots where green electricity is available. Other tangible visualization interfaces can serve to display which ratio of available energy comes from a green source,

as Quintal *et al.* illustrated using four glass pipes containing a coloured vortex and coloured power sockets [120].

Other approaches go even further and use different metaphors that resemble the environment and increase energy awareness. This is the case of InfoPlant, a living plant augmented through technology. This plant was designed to provide unobtrusive feedback and make users aware of their electricity usage [121]. Moreover, Hammerschmidt *et al.* propose using waterdrops falling sounds to inform about resources consumption while taking a shower [122]. Common shared places have also been the subject of attention for this kind of interaction. The workplace stands out as appropriate places to increase energy awareness and to guide workers in their routine. With this in mind, Irizar-Arrieta and Casado-Mansilla proposed a digital interface [123], and in the context of H2020-GreenSoul project [124] an Interactive Coaster was designed for office environments. The idea of this device is to persuade workers to be more aware of their energy consumption related to the electrical devices surrounding them in their desktop. Besides of this individual approach, improving energy efficiency from a general perspective via behaviour change in a large organization has also been addressed. Tho that end several strategies have been implemented, from measuring shared lab equipment usage [67] to projecting real-time energy statistics of a factory in the physical environments [125] and convert work

equipment into persuasive devices to motivate green behaviours and raise eco-awareness [126].

To illustrate how everyday objects can be augmented and enhanced with new functionalities to foster energy awareness, figure 3 shows some of the examples mentioned above.

VI. DISCUSSION

As has been observed in this manuscript, there is a common agreement on the need for taking into account the behavioural theories when designing energy-related interventions. However, this presents several shortcomings that deserve discussion. Firstly, the wide range of models and theories covers different aspects of the individual (as norms or attitudes). These aspects can be useful depending on the context, the target behaviour or the user dimension. Nevertheless, the selection of what theoretical frame to apply in each occasion can be difficult and complicated. Besides, there are existing research that only address some constructs of a model instead of applying the whole framework. This presents some problems since the omission of the global framework can involve a misusing and understanding of the whole model and causal factors. Secondly, the behavioural models are theoretically validated, yet they should not be assumed as an “universal truth”. Thus, the contextual factors and barriers should be studied carefully in order to avoid shortcomings when bring them to the field environments. Finally, due to the limited amount of research methods and the difficulty of implement and measure the behaviour change, there is a lack of solid and triangulated data that supports the effectiveness of the implementation of behavioural theories.

Another key point that emerges from the development of this work is the involvement of the ethics in BT. Whereas the existing research in the field seemed to be ethically adequate, the usage of behaviour change strategies often involves a more thorough review of the ethics of each developed system. The freedom of choice should be allowed, informing the user and avoiding coercive strategies. This idea is in line with the difference between behaviour change and awareness. While behaviour can be a consequence of the high awareness of the individual, the behaviour change may be generated through other strategies that might not involve a conscious decisions-making. This can be achieved through coercive strategies or not, but the framing of the behaviour should be placed in second place and always having ethics in mind. The priority should be to raise the awareness of the individual informing and motivating about the decision-making process, and to support this with other complementary strategies to facilitate the most sustainable choice. Besides, the lack of informational strategies can involve negative effects and other context-related implications.

The complexity of the individuals is another relevant factor when implementing BT. The literature agrees on the fact that users have different needs and motivations and on the importance to face this heterogeneity. Although there are some studies covering this topic, to the best of our knowledge, there are no gold standards to address the heterogeneity of

the individuals. There is neither a flexible nor a multi-dimensional user taxonomy applied to the sustainable behaviour change. The reviewed works present specific classifications and design recommendations based on their empirical findings, which presents valuable knowledge. However, the idea about how to address the user heterogeneity is still controversial and faced in different ways.

The need for a global approach when addressing sustainable behaviour change is another relevant idea. A wide range of the corpus reviewed present isolated findings, being difficult to locate them in the real world, where are a lot of contextual factors that have an impact on the final result. The implication of different factors in the behavioural process presents a hard challenge, and the study of them involves a difficult work. Nevertheless, more multidisciplinary experiments and studies are needed to find the relation between the theoretical approaches and the final systems and to find how they work in the real world.

Even though modern behaviour modelling and recognition approaches offer powerful analysis techniques to automatically model people’s behaviour and detect potential behaviour changes, it is a research field that has not been deeply explored. Most of the behaviour recognition approaches used to foster energy efficiency has been focused on applying learned behaviour models to later build energy-efficient machines which use previous knowledge to adapt their behaviour to users habits. However, there is still a lot of work to do on using behaviour modelling and recognition techniques in the promotion of human behaviour change to foster energy efficiency.

Moreover, behaviour recognition approaches could offer a new method for evaluating behaviour change methodologies to foster energy efficiency using other metrics than the amount of saved energy, comparing the initial behaviour of the users with their behaviour after applying behaviour change methodologies. In some cases, improved action or behaviour may generate little energy savings over the previous behaviour. While this may be a limitation, it is important to bear in mind that these residual savings can be extrapolated to other contexts, settings and behaviours. This is why it is essential to maintain the consistency of the strategy/intervention, even if the quantifiable results are apparently small, given that the impact of energy-saving can grow exponentially. Besides, although the quantitative data can be an indicator of the energy savings, other qualitative information about the impact on the awareness and behaviour change can be relevant to find the effectiveness of the decide.

The technology and in particular ubiquitous devices are the tools in charge of interacting with the user and guiding their behaviours to more sustainable ones. Therefore, particular emphasis should be given to increase the attachment to this new landscape of devices. Ensuring its efficacy may depend on different factors that focus on user engagement, technology acceptance, and adoption [127], [128]. Furthermore, the main challenge is to motivate end-users to feel willing to invest time in the technology upkeep through

technology appropriation and ownership while creating an emotional bond [129], [130]. These aspects become crucial when technology guide users behaviours through the process of bringing energy awareness of their own everyday habits. In this sense, Eco-feedback and Smart metering allows receiving (and sharing) information related to energy use. These techniques require users to interact with the energy providers, something that may create more psychological connections between the utility and the users [131]. However, this connection depends on perceived technology attributes such as usefulness, cost, privacy risks or the emotional response [132]. Perceived usefulness of technology is a strong predictor of the adoption intention of technology for energy usage measurement [133], where the factors influencing users' intentions can be measured applying the Theory of Planned Behavior (TPB) and the Technology Acceptance Model (TAM) [134]. Moreover, cost becomes an important variable when expensive devices are needed to obtain real-time information regarding the quantity and the quality of the power supply [135]. Privacy concerns arise as a consequence of the growing awareness about the amount of data collected by the ubiquitous devices and the treatment that is made of this information. As a consequence, monitoring technology needs to overcome additional barriers regarding perceived privacy concerns about the potentially sensitive personal information [136], [137]. Finally, to boost the efficacy of energy-related interventions, an emotional response is particularly important to engage users in the long term and to increase the links between emotions, motivations and users' sustainable behaviours [73].

The potential of the feedback provided through technology is another essential factor to consider. In a conducted study to measure the potential for demand-side management to reduce peak load, Laicane *et al.* [138] concluded that the household consumption level decrease only was able to occur by changing user behaviour. In this case, the feedback and the information provided in the context of smart metering was found mainly effective as far as it acts as a reminder and motivator. For this reason, the authors put the focus on how to get users' attention and educate them to increase customer awareness and participation in demand management. Accordingly, Bastida *et al.* [139] analyses the role of the consumers' behaviour with respect to the potential of ICT-based interventions to decrease electricity usage in households. In this work, they addressed motivating, reinforcing and enabling factors to encourage lasting behaviours and analysed their impact on the efficacy of ICT approaches to mitigate CO₂ emissions. By the same token, Buchanan *et al.* [140] presents a critical analysis of the effectiveness of the energy-feedback through smart meter devices and in-home-displays. These findings sustained the statement that existing display interfaces may not induce the desired energy-reduction response if new feedback devices are not designed with user engagement in mind. Three main problems were addressed: i) the limited evidence of efficacy in the reviewed works and the difficulty of validating this

results, ii) the need for user engagement to avoid technology uptake and iii) the potential for unintended consequences due to a meaningless presentation of the data. These results reinforce one of the cornerstone ideas that articulate this article: innovative feedback mechanisms are needed to actually engage users taking into account the individual differences and giving importance to "the human factor" [141], [142].

VII. CONCLUSION

In this section, the most relevant findings are summarised. In Table 1, we analyse the extracted insights and we propose future research gaps and lines aiming at offering some guidance in the development of this research area.

A. THEORETICAL FRAMEWORKS FOR SUSTAINABLE BEHAVIOUR CHANGE

The need to rely on theoretical foundations approaching the human factor is widely recognised by the research community. The most relevant findings obtained throughout this manuscript are exposed below:

- The **importance** of using **behavioural theories** as a guide when developing technologies is **commonly accepted**. However, **understanding** their **limitations** is a key point that the researchers and practitioners should take into account, being contextual factors carefully analysed. These shortcomings or limitations can be further investigated to extract valuable insights to apply to the upcoming works and studies.
- There is a wide range of valuable and diverse studies referring to behavioural theories. However, the **lack of validated studies and measurements** makes it difficult to ensure the impact and effectiveness of the different behaviour change frameworks. Besides, it is difficult to replicate the specific studies due to the lack of systematisation and scalability. Thus, it can be difficult to find validated data and extrapolate those findings. Taking this into account, future research lines should work in this line to ensure replicability.
- The different **theoretical models** or frameworks **should be understood as a global** approach. There are some works that breakdown the frameworks in different parts. This practise seems to be right isolating the study of one factor. However, it may present shortcomings in some contexts as there are confounding and hidden factors overlooked. Having said that, we argue that isolated determinants or constructs can be addressed in a specific way, yet understanding the main framework is a must in order to contextualise the determinants that are in relation to others. Therefore, addressing some parts of the behavioural theories can be adequate, while understanding and contextualising the strategy in the global context of the theory. In this way, the importance of the relations of the constructs will not be overlooked. The global approach of the behavioural strategies can be a future line of research to fill the shortcomings emerged from the closed and specific perspectives.

TABLE 1. Summary of the insights obtained from the conducted review containing the current status, found gaps and guidelines for the future lines of work.

Summary and Finding Insights			
	Current Status	Gaps	Future Lines
Theoretical models and frameworks	Theories are widely used with the understanding that they have limitations and ambiguous aspects.	The shortcomings of the theories are not properly analysed and measured.	More research is needed to find knowledge and understand the limitations and shortcomings of theoretical models and frameworks.
	There is a variety of different and diverse studies involving a wide range of theories and approaches.	Lack of validated, systematic and scalable studies.	An effort should be made to systematise, validate and measure the impact of behavioural theories.
	The theories are applied in a diverse way.	The use of certain parts of the theories can be a limited approach if it is not understood in a global and contextualised manner.	Global approach is needed to contextualise a specific strategy avoiding the shortcomings deriving from excessively specific interventions.
Behaviour recognition and modelling	There is a wide range of applicable behaviour modelling and recognition techniques.	Lack of behaviour change works using behaviour recognition techniques for its evaluation.	It should be concisely analysed how behaviour recognition techniques could help in the evaluation of behaviour change techniques.
	Most of the works are focused on using behaviour modelling and recognition techniques to create automated processes to foster energy efficiency.	Lack of behaviour modelling and recognition techniques to foster energy efficiency through behaviour change	It should be analysed if behaviour modelling and recognition techniques could be used to cause a behaviour change on people
	Very few works use behaviour modelling approaches to address or evaluate their behaviour change methodologies.	It is not clear yet which are the best behaviour modelling and recognition techniques for the promotion of behaviour change.	An analysis of which behaviour modelling and recognition are the most appropriate for the promotion of behaviour change.
Methods, guidelines and toolkits	There is a wide range of techniques and methods to develop behavioural interventions.	Lack of studies that bring together the variety of methodologies available.	Classify, analyse and measure the different methods and guidelines to find which can be more adequate in each case.
	Some recent works offer guidelines and ideas on how to develop the strategy selection.	The intervention selection remains being complicated as the impact is neither fully measured nor validated.	Develop intervention selection guidelines taking into account the wide range of them.
	There is an excessive focus on informational strategies, forgetting other kinds of strategies and techniques.	Lack of interventions applied in a global and complementary manner and addressing the heterogeneity of people.	Implement strategies and interventions addressing the heterogeneity of the individuals' behaviour and providing different and complementary strategies to avoid the "One size does not fit all" issue.
Tangible and digital systems	Ubiquitous computing, together with visualization interfaces, represent the core of energy-related information channels	Limited evidence of Eco-feedback efficacy in the reviewed works and the difficulty of validating its results	Increase the attachment to the intelligent system and engage users in the long term through a sense of perceived usefulness of technology
	Smart Grinds and Demand-side management have the potential to make more efficient usage of the resources, aligning users' behaviour with the dynamics of the energy generation.	Technology-based behaviour change interventions suffer from a recurrent problem of lack of continuity and follow-up where the devices employed end up being forgotten and unnoticeable elements	Designing easy to use, secure and trusted systems to boost the motivating, reinforcing and enabling factors that lead to technology upkeep and acceptance.
	Existing approaches tend to move this core to innovative feedback mechanisms, re-designing and augmenting everyday objects.	Representation methods and strategies can lead to unintended consequences and low income due to a meaningless presentation of the data.	Investigate in in-depth how eco-feedback information should be presented to increase the efficiency of energy-monitoring applications

B. BEHAVIOUR RECOGNITION AND MODELLING TECHNOLOGIES

The following conclusions can be drawn from the current use of behaviour modelling and recognition techniques applied to foster energy efficiency through behaviour change:

- Modern behaviour recognition could enrich the way in which behaviour change researchers could evaluate their behaviour models and methodologies, allowing the **automated detection of minor changes in user's behaviours**.
- Even though there are several behaviour recognition approaches, **it has not been made yet a deep analysis of which approaches are better qualified for this task.**

- Although behaviour recognition techniques' performance has drastically improved during the last years, there are **a small number of research works combining advanced behaviour recognition techniques with behaviour change approaches**. Moreover, the amount of work focused on behaviour change to foster energy efficiency is even lower since most of the approaches goal is to foster energy efficiency through automated processes.

C. METHODS AND GUIDELINES AND OTHER FINDINGS

The amount of different guidelines and recommendations makes difficult to decide which strategy has a best fit in

specific contexts. Thus, following a specific selection criteria is important to make feasible the process. Besides, the audience should be studied carefully to adequate the strategies to the specific target users. Other relevant conclusions are presented hereafter:

- Taking into account the review done in this work, one of the main conclusions that emerged is the **variety** and large amount of **methods, frameworks and findings** that are focused on offering Behaviour Change interventions. These isolated works are usually implemented independently and, to the best of our knowledge, **is hard to find studies grouping these works**. Hence, researchers may find it difficult to identify all existing methodologies that can be applied. For this purpose, further research on the **methodology classification** can be a promising future line of work.
- It remains to be difficult to select the best intervention strategy to each context albeit we have performed a thorough review of the body of literature in behaviour change techniques. One reason (in addition to the many strategies available) may be **the lack of validated and measured frameworks** which implies uncertainly when selecting the one which may have a higher impact. To cope with this issue, future research can explore the study and comparison of the different strategies and methods, **measuring their impact to extract validated data**.
- Finally, once reviewed the core corpus of the literature we highlight the **importance of the informational strategies** over another type of interventions. Eco-feedback technologies have been widely implemented with interesting results, but as a conclusion we can argue that there is a raising **need to complement the only informational strategies with other complementary techniques** to target the heterogeneity of the individuals and to avoid the shortcomings derived from the “one size does not fit all” approach [7]. Besides, there is a lack of interventions applied in a global and complementary manner and addressing the heterogeneity of people. Future research lines can study the implementation of interventions addressing the heterogeneity of the individuals and providing different and complementary strategies.

D. DIGITAL AND TANGIBLE SYSTEMS

The conclusions that can be derived from the process of acquiring the data to displaying the information to the user are provided next:

- Smart grids, demand response management systems and monitoring platforms **are not enough to reduce energy consumption** or to change load shifting if a proper analysis the energy consumption patterns is not made beforehand. An **improved understanding of how users interact with the power grid and the influence of Eco-feedback** is needed to develop energy-aware services to pursue the energy efficiency goal.

- System interfaces need to **avoid meaningless representations of the data** through energy metrics. On the contrary, **information needs to be clearly presented** in a contextualized manner. To increase energy-awareness more effectively, research should put the focus on the implications of **Eco-feedback presentation methods and strategies**, as long as evaluating the usability of the interfaces.
- Current trends indicate a shift from traditional feedback devices (such as in-home displays) to new innovative ones based on **tangible visualization interfaces**. Redesigning and **augmenting everyday objects** to provide a more natural interaction may be the way to increase the potential of the feedback. Above all, the design need to **overcome barriers regarding the uptake, lack of attachment or the distrust of technology** to actually engage users in the long term.

To conclude, a few concerns extracted from the research work are exposed as a final remarks. Whereas there is a wide amount of literature facing the behavioural aspects of technologies to raise the energy efficiency, across the present work we discovered the main shortcomings and gaps that should be targeted to improve the accuracy and the impact of them. In addition to the stated specific findings and conclusions, there are two main key points that the research community should take into account. Firstly, the diversity of behavioural theories and their implementations present shortcomings due to the specificity of the implementation of a given model based on a single theory and approach. However, this presents an interesting research line where the different theories can be analysed in conjunction, finding common determinants and relations to map and link the most common behaviour change theoretical models for sustainable behaviour, and enriching the isolated approaches. In this way, the shortcomings of each model can be avoided or minimized fulfilling the gaps presented by each theory with complementary theoretical approaches.

The second key point derived from the conclusions is the need to implement global and cross-cutting strategies beyond a specific approach. All the reviewed approaches tackle sustainable behaviour through a mostly rigid or static strategies. Besides, most of the reviewed works implemented their strategies through technological devices without complementing or reinforcing these approaches through other channels. Due to this, the responsibility is, in most cases, relegated to the autonomous piece of technology, so that capacity for sustainability falls on it and the user tends to become left apart. Both physical and digital devices, as well as recognition and modelling tools, should be part of a global strategy and should not be dependent on the device. In addition, people’s needs and the emotional/psychological aspect of behaviour change must be implemented in technological systems to develop effective strategies that truly improves the awareness, attachment and the acquisition of the responsibility.

ACKNOWLEDGMENT

We gratefully acknowledge the support of the Basque Government's Department of Education for the Deustek Research Group - IT 1078-16 D and the pre-doctoral funding of some of the authors.

REFERENCES

- [1] B. Aebischer and L. M. Hilty, "The energy demand of ICT: A historical perspective and current methodological challenges," in *ICT Innovations for Sustainability*, L. M. Hilty and B. Aebischer, Eds. Cham, Switzerland: Springer, 2015, pp. 71–103.
- [2] L. A. Greening, D. L. Greene, and C. D'figlio, "Energy efficiency and consumption—The rebound effect—A survey," *Energy policy*, vol. 28, nos. 6–7, pp. 389–401, 2000.
- [3] J. Pierce, W. Odom, and E. Blevis, "Energy aware dwelling," in *Proc. 20th Australas. Conf. Comput.-Hum. Interact. Designing Habitus Habitat (OZCHI)*, 2008, pp. 1–8. [Online]. Available: <http://dl.acm.org/citation.cfm?id=1517744.1517746>
- [4] A. Coskun, J. Zimmerman, and C. Erbug, "Promoting sustainability through behavior change: A review," *Design Stud.*, vol. 41, pp. 183–204, Nov. 2015.
- [5] E. B. Hekler, P. Klasnja, J. E. Froehlich, and M. P. Buman, "Mind the theoretical gap: Interpreting, using, and developing behavioral theory in HCI research," in *Proc. Conf. Hum. Factors Comput. Syst. (SIGCHI)*, 2013, pp. 3307–3316.
- [6] J. O. Prochaska, C. A. Redding, and K. E. Evers, "The transtheoretical model and stages of change," in *Health Behavior, Theory, Research, and Practice*. San Francisco, CA, USA: Wiley, 2015, pp. 125–148.
- [7] H. A. He, S. Greenberg, and E. M. Huang, "One size does not fit all: Applying the transtheoretical model to energy feedback technology design," in *Proc. Conf. Hum. Factors Comput. Syst. (SIGCHI)*, 2010, pp. 927–936.
- [8] U. Wising, S. Chirez, and B. Adams, "Improving industrial energy efficiency by changing the energy culture," in *Proc. ECEEE Ind. Summer Study*, vol. 8, 2014, pp. 659–666.
- [9] P. C. Stern, T. Dietz, T. Abel, G. A. Guagnano, and L. Kalof, "A value-belief-norm theory of support for social movements: The case of environmentalism," *Hum. ecology Rev.*, vol. 6, no. 2, pp. 81–97, 1999.
- [10] P. C. Stern, "New environmental theories: Toward a coherent theory of environmentally significant behavior," *J. Social Issues*, vol. 56, no. 3, pp. 407–424, Jan. 2000.
- [11] P. Petkov, S. Goswami, F. Köbler, and H. Krmar, "Personalised eco-feedback as a design technique for motivating energy saving behaviour at home," in *Proc. 7th Nordic Conf. Hum.-Comput. Interact. Making Sense Through Design (NordCHI)*, 2012, pp. 587–596.
- [12] I. Ajzen, "The theory of planned behavior," *Org. Behav. Hum. Decis. Process.*, vol. 50, no. 2, pp. 179–211, 1991.
- [13] A. Coskun and C. Erbug, "User diversity in design for behavior change," in *Proc. DRS*, 2014, pp. 546–559.
- [14] M. Greaves, L. D. Zibarras, and C. Stride, "Using the theory of planned behavior to explore environmental behavioral intentions in the workplace," *J. Environ. Psychol.*, vol. 34, pp. 109–120, Jun. 2013.
- [15] K. M. Sheldon and A. J. Elliot, "Goal striving, need satisfaction, and longitudinal well-being: The self-concordance model," *J. Personality Social Psychol.*, vol. 76, no. 3, pp. 482–497, 1999.
- [16] K. L. Unsworth and I. M. McNeill, "Increasing pro-environmental behaviors by increasing self-concordance: Testing an intervention," *J. Appl. Psychol.*, vol. 102, no. 1, pp. 88–103, 2017.
- [17] E. R. Frederiks, K. Stenner, and E. V. Hobman, "Household energy use: Applying behavioural economics to understand consumer decision-making and behaviour," *Renew. Sustain. Energy Rev.*, vol. 41, pp. 1385–1394, Jan. 2015.
- [18] S. Sorrell, "Reducing energy demand: A review of issues, challenges and approaches," *Renew. Sustain. Energy Rev.*, vol. 47, pp. 74–82, Jul. 2015.
- [19] M. G. Pollitt and I. Shaorshadze, "The role of behavioural economics in energy and climate policy," in *Handbook on Energy and Climate Change*. Edward Elgar Publishing, 2013, ch. 24, pp. 523–546.
- [20] A. A. Chaaoui, P. Climent-Pérez, and F. Flórez-Revuelta, "A review on vision techniques applied to human behaviour analysis for ambient-assisted living," *Expert Syst. Appl.*, vol. 39, no. 12, pp. 10873–10888, Sep. 2012.
- [21] A. Almeida and G. Azkune, "Predicting human behaviour with recurrent neural networks," *Appl. Sci.*, vol. 8, no. 2, p. 305, 2018.
- [22] L. Salvador-Carulla, F. Alonso, R. Gomez, C. Walsh, J. Almenara, M. Ruiz, M. Abellán, and E. Group, "Basic concepts in the taxonomy of health-related behaviors, habits and lifestyle," *Int. J. Environ. Res. Public Health*, vol. 10, no. 5, pp. 1963–1976, 2013.
- [23] L. Chen and C. Nugent, "Ontology-based activity recognition in intelligent pervasive environments," *Int. J. Web Inf. Syst.*, vol. 5, no. 4, pp. 410–430, Nov. 2009.
- [24] M. P. Lawton and E. M. Brody, "Assessment of older people: Self-maintaining and instrumental activities of daily living," *Gerontologist*, vol. 9, no. 3, pp. 179–186, Sep. 1969.
- [25] R. Nevatia, J. Hobbs, and B. Bolles, "An ontology for video event representation," in *Proc. Conf. Comput. Vis. Pattern Recognit. Workshop*, 2004, p. 119.
- [26] F. Latfi, B. Lefebvre, and C. Descheneaux, "Ontology-based management of the telehealth smart home, dedicated to elderly in loss of cognitive autonomy," in *Proc. OWLED*, vol. 258, Jun. 2007, pp. 1–10.
- [27] G. Azkune, A. Almeida, D. López-de-Ipiña, and L. Chen, "Extending knowledge-driven activity models through data-driven learning techniques," *Expert Syst. Appl.*, vol. 42, no. 6, pp. 3115–3128, Apr. 2015.
- [28] D. Riboni, T. Sztylek, G. Civitarese, and H. Stuckenschmidt, "Unsupervised recognition of interleaved activities of daily living through ontological and probabilistic reasoning," in *Proc. ACM Int. Joint Conf. Pervas. Ubiquitous Comput. (UbiComp)*, 2016, pp. 1–12.
- [29] A. Almeida and D. López-de-Ipiña, "Assessing ambiguity of context data in intelligent environments: Towards a more reliable context managing system," *Sensors*, vol. 12, no. 4, pp. 4934–4951, 2012.
- [30] M. Brand, N. Oliver, and A. Pentland, "Coupled hidden Markov models for complex action recognition," in *Proc. IEEE Comput. Soc. Conf. Comput. Vis. Pattern Recognit.*, vol. 97, 1997, p. 994.
- [31] T. Hayashi, M. Nishida, N. Kitaoka, and K. Takeda, "Daily activity recognition based on DNN using environmental sound and acceleration signals," in *Proc. 23rd Eur. Signal Process. Conf. (EUSIPCO)*, Aug. 2015, pp. 2306–2310.
- [32] A. Almeida, G. Azkune, and A. Bilbao, "Embedding-level attention and multi-scale convolutional neural networks for behaviour modelling," in *Proc. IEEE SmartWorld, Ubiquitous Intell. Comput., Adv. Trusted Comput., Scalable Comput. Commun., Cloud Big Data Comput., Internet People Smart City Innov. (SmartWorld/SCALCOM/UIC/ATC/CBDCOM/IOP/SCI)*, Oct. 2018, pp. 439–445.
- [33] Y. Guan and T. Plötz, "Ensembles of deep LSTM learners for activity recognition using wearables," *Proc. ACM Interact., Mobile, Wearable Ubiquitous Technol.*, vol. 1, no. 2, pp. 1–28, Jun. 2017.
- [34] L. Chen, C. D. Nugent, M. Mulvenna, D. Finlay, X. Hong, and M. Poland, "A logical framework for behaviour reasoning and assistance in a smart home," *Int. J. Assistive Robot. Mechatron.*, vol. 9, no. 4, pp. 20–34, 2008.
- [35] D. Riboni and C. Bettini, "COSAR: Hybrid reasoning for context-aware activity recognition," *Pers. Ubiquitous Comput.*, vol. 15, no. 3, pp. 271–289, Mar. 2011.
- [36] L. Chen, C. D. Nugent, and H. Wang, "A knowledge-driven approach to activity recognition in smart homes," *IEEE Trans. Knowl. Data Eng.*, vol. 24, no. 6, pp. 961–974, Jun. 2012.
- [37] M. H. M. Noor, Z. Salcic, and K. I.-K. Wang, "Enhancing ontological reasoning with uncertainty handling for activity recognition," *Knowl.-Based Syst.*, vol. 114, pp. 47–60, Dec. 2016.
- [38] J. Ye, G. Stevenson, and S. Dobson, "USMART: An unsupervised semantic mining activity recognition technique," *ACM Trans. Interact. Intell. Syst.*, vol. 4, no. 4, pp. 1–27, 2015.
- [39] G. Azkune and A. Almeida, "A scalable hybrid activity recognition approach for intelligent environments," *IEEE Access*, vol. 6, pp. 41745–41759, 2018.
- [40] O. D. Lara and M. A. Labrador, "A survey on human activity recognition using wearable sensors," *IEEE Commun. Surveys Tuts.*, vol. 15, no. 3, pp. 1192–1209, 3rd Quart., 2013.
- [41] M. Shoaib, S. Bosch, O. Incel, H. Scholten, and P. Havinga, "A survey of online activity recognition using mobile phones," *Sensors*, vol. 15, no. 1, pp. 2059–2085, 2015.
- [42] L. Chen, J. Hoey, C. D. Nugent, D. J. Cook, and Z. Yu, "Sensor-based activity recognition," *IEEE Trans. Syst., Man, Cybern. C, Appl. Rev.*, vol. 42, no. 6, pp. 790–808, Nov. 2012.
- [43] J. Wang, Y. Chen, S. Hao, X. Peng, and L. Hu, "Deep learning for sensor-based activity recognition: A survey," *Pattern Recognit. Lett.*, vol. 119, pp. 3–11, Mar. 2019.

- [44] D. Casado-Mansilla, J. López-de-Armentia, D. Ventura, P. Garaizar, and D. López-de-Ipiña, "Embedding intelligent eco-aware systems within everyday things to increase people's energy awareness," *Soft Comput.*, vol. 20, no. 5, pp. 1695–1711, May 2016.
- [45] V. Fabi, R. V. Andersen, S. P. Cognati, and B. W. Olesen, "A methodology for modelling energy-related human behaviour: Application to window opening behaviour in residential buildings," *Building Simul.*, vol. 6, no. 4, pp. 415–427, Dec. 2013.
- [46] T. A. Nguyen, A. Raspitzu, and M. Aiello, "Ontology-based office activity recognition with applications for energy savings," *J. Ambient Intell. Humanized Comput.*, vol. 5, no. 5, pp. 667–681, Oct. 2014.
- [47] P. Cottone, S. Gaglio, G. Lo Re, and M. Ortolani, "User activity recognition for energy saving in smart homes," *Pervas. Mobile Comput.*, vol. 16, pp. 156–170, Jan. 2015.
- [48] G. Chen, X. Wu, X. Zhu, A. N. Arslan, and Y. He, "Efficient string matching with wildcards and length constraints," *Knowl. Inf. Syst.*, vol. 10, no. 4, pp. 399–419, Oct. 2006.
- [49] J. Rissanen, "Minimum-description length principle," in *Encyclopedia of Statistic Science*. New York, NY, USA: Wiley, 1987.
- [50] B. J. Fogg, "Persuasive technology: Using computers to change what we think and do," *Ubiquity*, vol. 2002, p. 5, Dec. 2002.
- [51] K. Törning and H. Oinas-Kukkonen, "Persuasive system design: State of the art and future directions," in *Proc. 4th Int. Conf. Persuasive Technol.*, 2009, p. 30.
- [52] D. Lilley, "Design for sustainable behaviour: Strategies and perceptions," *Design Stud.*, vol. 30, no. 6, pp. 704–720, Nov. 2009.
- [53] D. Lockton, D. Harrison, and N. Stanton, "Making the user more efficient: Design for sustainable behaviour," *Int. J. Sustain. Eng.*, vol. 1, no. 1, pp. 3–8, Mar. 2008.
- [54] S. Michie, S. Ashford, F. F. Sniehotta, S. U. Dombrowski, A. Bishop, and D. P. French, "A refined taxonomy of behaviour change techniques to help people change their physical activity and healthy eating behaviours: The CALO-RE taxonomy," *Psychol. Health*, vol. 26, no. 11, pp. 1479–1498, Nov. 2011.
- [55] S. Michie, M. Johnston, J. Francis, W. Hardeman, and M. Eccles, "From theory to intervention: Mapping theoretically derived behavioural determinants to behaviour change techniques," *Appl. Psychol.*, vol. 57, no. 4, pp. 660–680, Oct. 2008.
- [56] R. Hertwig and T. Grüne-Yanoff, "Nudging and boosting: Steering or empowering good decisions," *Perspect. Psychol. Sci.*, vol. 12, no. 6, pp. 973–986, Nov. 2017, doi: [10.1177/1745691617702496](https://doi.org/10.1177/1745691617702496).
- [57] R. G. Newell and J. Siikamäki, "Nudging energy efficiency behavior: The role of information labels," *J. Assoc. Environ. Resource Economists*, vol. 1, no. 4, pp. 555–598, Dec. 2014.
- [58] F. Ölander and J. Thøgersen, "Informing versus nudging in environmental policy," *J. Consum. Policy*, vol. 37, no. 3, pp. 341–356, Sep. 2014.
- [59] S. Michie, M. M. van Stralen, and R. West, "The behaviour change wheel: A new method for characterising and designing behaviour change interventions," *Implement. Sci.*, vol. 6, no. 1, p. 42, Dec. 2011.
- [60] C. Wilson and M. R. Marselle, "Insights from psychology about the design and implementation of energy interventions using the behaviour change wheel," *Energy Res. Social Sci.*, vol. 19, pp. 177–191, Sep. 2016.
- [61] S. C. Staddon, C. Cyclic, M. Goulden, C. Leygue, and A. Spence, "Intervening to change behaviour and save energy in the workplace: A systematic review of available evidence," *Energy Res. Social Sci.*, vol. 17, pp. 30–51, Jul. 2016.
- [62] L. Atkins, J. Francis, R. Islam, D. O'Connor, A. Patey, N. Ivers, R. Foy, E. M. Duncan, H. Colquhoun, J. M. Grimshaw, R. Lawton, and S. Michie, "A guide to using the theoretical domains framework of behaviour change to investigate implementation problems," *Implement. Sci.*, vol. 12, no. 1, p. 77, Dec. 2017.
- [63] H. L. Gainforth, K. Sheals, L. Atkins, R. Jackson, and S. Michie, "Developing interventions to change recycling behaviors: A case study of applying behavioral science," *Appl. Environ. Edu. Commun.*, vol. 15, no. 4, pp. 325–339, Oct. 2016.
- [64] D. Lockton, D. Harrison, and N. A. Stanton, "The design with intent method: A design tool for influencing user behaviour," *Appl. Ergonom.*, vol. 41, no. 3, pp. 382–392, May 2010.
- [65] D. Lockton, D. Harrison, and N. Stanton, "Design with intent: Persuasive technology in a wider context," in *Persuasive Technology*, H. Oinas-Kukkonen, P. Hasle, M. Harjumaa, K. Segerstahl, and P. Øhrstrøm, Eds. Berlin, Germany: Springer, 2008, pp. 274–278.
- [66] D. Lockton, D. Harrison, T. Holley, and N. A. Stanton, "Influencing interaction: Development of the design with intent method," in *Proc. 4th Int. Conf. Persuasive Technol.*, 2009, pp. 1–8.
- [67] E. Morgan, L. Webb, K. Carter, and N. Goddard, "Co-designing a device for behaviour-based energy reduction in a large organisation," *Proc. ACM Hum.-Comput. Interact.*, vol. 2, pp. 1–23, Nov. 2018.
- [68] L. Kuijter and A. D. Jong, "A practice oriented approach to user centered sustainable design," in *Proc. 6th Int. Symp. Environmentally Conscious Design Inverse Manuf.*, 2009, pp. 1–6.
- [69] R. Wever, J. van Kuijk, and C. Boks, "User-centred design for sustainable behaviour," *Int. J. Sustain. Eng.*, vol. 1, pp. 9–20, Sep. 2008. [Online]. Available: <http://architectures.danlockton.co.uk>
- [70] D. Lockton, D. Harrison, and N. A. Stanton, "Models of the user: Designers' perspectives on influencing sustainable behaviour," *J. Des. Res.*, vol. 10, nos. 1–2, pp. 7–27, 2012. [Online]. Available: <http://www.inderscience.com/link.php?id=46137>
- [71] A. Coskun and C. Erbug, "Exploring and communicating user diversity for behavioural change," in *Proc. 50th Anniversary Conf. Design Res. Soc.*, vol. 4, 2016, pp. 1357–1374.
- [72] R. Yun, A. Aziz, B. Lasternas, V. Loftness, P. Scupelli, and C. Zhang, "The persistent effectiveness of online feedback and controls for sustainability in the workplace," *Energy Efficiency*, vol. 10, no. 5, pp. 1143–1153, Oct. 2017. [Online]. Available: <http://link.springer.com/10.1007/s12053-017-9509-4>
- [73] Q. Bao, E. Burnell, A. M. Hughes, and M. C. Yang, "Investigating user emotional responses to eco-feedback designs," *J. Mech. Design*, vol. 141, no. 2, 2019, Art. no. 021103.
- [74] Q. Bao, M. M. Shaukat, A. Elantary, and M. C. Yang, "Eco-feedback designs: A balance between the quantitative and the emotional," in *Proc. Int. Design Eng. Tech. Conf. Comput. Inf. Eng. Conf. (ASME)*, 2016, Art. no. V007T06A022.
- [75] E. Cor and P. Zwolinski, "A procedure to define the best design intervention strategy on a product for a sustainable behavior of the user," *Procedia CIRP*, vol. 15, pp. 425–430, Jan. 2014.
- [76] C. Fry, "The contribution of ICT to energy efficiency: Local and regional initiatives," SQW: Econ. Develop. Social Develop., U.K., Tech. Rep., 2011.
- [77] F. Karim Shaikh, S. Zeadally, and E. Exposito, "Enabling technologies for green Internet of Things," *IEEE Syst. J.*, vol. 11, no. 2, pp. 983–994, Jun. 2017.
- [78] G. Lobaccaro, S. Carlucci, and E. Löfström, "A review of systems and technologies for smart homes and smart grids," *Energies*, vol. 9, no. 5, p. 348, 2016.
- [79] J. Froehlich, "Promoting energy efficient behaviors in the home through feedback: The role of human-computer interaction," in *Proc. HCIC Workshop*, vol. 9, 2009, pp. 1–11.
- [80] J. Pierce and E. Paulos, "Beyond energy monitors: Interaction, energy, and emerging energy systems," in *Proc. Conf. Hum. Factors Comput. Syst. (SIGCHI)*, 2012, pp. 665–674.
- [81] K. Ashton, "That 'Internet of Things' thing," *RFID J.*, vol. 22, no. 7, pp. 97–114, 2009.
- [82] V. Venkatesh, J. Y. Thong, and X. Xu, "Unified theory of acceptance and use of technology: A synthesis and the road ahead," *J. Assoc. Inf. Syst.*, vol. 17, no. 5, pp. 328–376, 2016.
- [83] S. S. S. R. Depuru, L. Wang, V. Devabhaktuni, and N. Gudi, "Smart meters for power grid—Challenges, issues, advantages and status," in *Proc. IEEE/PES Power Syst. Conf. Exposit.*, 2011, pp. 1–7.
- [84] V. Tiefenbeck, A. Wörner, S. Schöb, E. Fleisch, and T. Staake, "Real-time feedback promotes energy conservation in the absence of volunteer selection bias and monetary incentives," *Nature Energy*, vol. 4, no. 1, pp. 35–41, Jan. 2019.
- [85] E. Spano, L. Niccolini, S. D. Pascoli, and G. Iannaccone, "Last-meter smart grid embedded in an Internet-of-Things platform," *IEEE Trans. Smart Grid*, vol. 6, no. 1, pp. 468–476, Jan. 2015.
- [86] J. Lloret, J. Tomas, A. Canovas, and L. Parra, "An integrated IoT architecture for smart metering," *IEEE Commun. Mag.*, vol. 54, no. 12, pp. 50–57, Dec. 2016.
- [87] A. R. Al-Ali, I. A. Zualkerman, M. Rashid, R. Gupta, and M. Alikarar, "A smart home energy management system using IoT and big data analytics approach," *IEEE Trans. Consum. Electron.*, vol. 63, no. 4, pp. 426–434, Nov. 2017.
- [88] F. Terroso-Saenz, A. González-Vidal, A. P. Ramallo-González, and A. F. Skarmeta, "An open IoT platform for the management and analysis of energy data," *Future Gener. Comput. Syst.*, vol. 92, pp. 1066–1079, Mar. 2019.

- [89] S. Singh and A. Yassine, "IoT big data analytics with fog computing for household energy management in smart grids," in *Smart Grid and Internet of Things*, A.-S. K. Pathan, Z. M. Fadlullah, and M. Guerroumi, Eds. Cham, Switzerland: Springer, 2019, pp. 13–22.
- [90] M. Jahn, T. Schwartz, J. Simon, and M. Jentsch, "EnergyPULSE: Tracking sustainable behavior in office environments," in *Proc. 2nd Int. Conf. Energy-Efficient Comput. Netw. e-Energy*, 2011, pp. 87–96.
- [91] F. Al-Turjman and M. Abujubbeh, "IoT-enabled smart grid via SM: An overview," *Future Gener. Comput. Syst.*, vol. 96, pp. 579–590, Jul. 2019.
- [92] T. Hargreaves, M. Nye, and J. Burgess, "Making energy visible: A qualitative field study of how householders interact with feedback from smart energy monitors," *Energy Policy*, vol. 38, no. 10, pp. 6111–6119, Oct. 2010.
- [93] S. Darby, "The effectiveness of feedback on energy consumption," *A Rev. DEFRA Literature Metering, Billing Direct Displays*, vol. 486, no. 2006, p. 26, 2006.
- [94] Y. A. A. Strengers, "Designing eco-feedback systems for everyday life," in *Proc. Annu. Conf. Hum. Factors Comput. Syst. (CHI)*, 2011, pp. 2135–2144.
- [95] X. Zhuang and C. Wu, "The effect of interactive feedback on attitude and behavior change in setting air conditioners in the workplace," *Energy Buildings*, vol. 183, pp. 739–748, Jan. 2019.
- [96] J. Lynham, K. Nitta, T. Saijo, and N. Tarui, "Why does real-time information reduce energy consumption?" *Energy Econ.*, vol. 54, pp. 173–181, Feb. 2016.
- [97] K. Ma, G. Hu, and C. J. Spanos, "Distributed energy consumption control via real-time pricing feedback in smart grid," *IEEE Trans. Control Syst. Technol.*, vol. 22, no. 5, pp. 1907–1914, Sep. 2014.
- [98] A. Nilsson, P. Stoll, and N. Brandt, "Assessing the impact of real-time price visualization on residential electricity consumption, costs, and carbon emissions," *Resour., Conservation Recycling*, vol. 124, pp. 152–161, Sep. 2017.
- [99] C. A. Björkskog, G. Jacucci, L. Gamberini, T. Nieminen, T. Mikkola, C. Torstensson, and M. Bertocini, "EnergyLife: Pervasive energy awareness for households," in *Proc. 12th ACM Int. Conf. Adjunct Papers Ubiquitous Comput. (Ubicomp)*, 2010, pp. 361–362.
- [100] E. K. Nisbet, J. M. Zelenski, and S. A. Murphy, "The nature relatedness scale: Linking Individuals' connection with nature to environmental concern and behavior," *Environ. Behav.*, vol. 41, no. 5, pp. 715–740, Sep. 2009.
- [101] M. A. Alahmad, P. G. Wheeler, A. Schwer, J. Eiden, and A. Brumbaugh, "A comparative study of three feedback devices for residential real-time energy monitoring," *IEEE Trans. Ind. Electron.*, vol. 59, no. 4, pp. 2002–2013, Apr. 2012.
- [102] N. Castelli, G. Stevens, and T. Jakobi, *Information Visualization at Home: A Literature Survey of Consumption Feedback Design* (International Reports on Socio-Informatics), vol. 16, no. 1, V. Pipek and M. Rohde, Eds. Bonn, Germany: International Institute for Socio-Informatics (IISI), 2019, p. 31.
- [103] R. K. Jain, J. E. Taylor, and G. Peschiera, "Assessing eco-feedback interface usage and design to drive energy efficiency in buildings," *Energy Buildings*, vol. 48, pp. 8–17, May 2012.
- [104] I. Kastner and E. Matthies, "Implementing Web-based interventions to promote energy efficient behavior at organizations—a multi-level challenge," *J. Cleaner Prod.*, vol. 62, pp. 89–97, Jan. 2014.
- [105] M. Weiss and D. Guinard, "Increasing energy awareness through Web-enabled power outlets," in *Proc. 9th Int. Conf. Mobile Ubiquitous Multimedia (MUM)*, 2010, p. 20.
- [106] V. Sumio and J.-D. Schmöcker, "Can we promote sustainable travel behavior through mobile apps? Evaluation and review of evidence," *Int. J. Sustain. Transp.*, vol. 11, no. 8, pp. 553–566, Sep. 2017.
- [107] M. Weiss, T. Staake, F. Mattern, and E. Fleisch, "PowerPedia: Changing energy usage with the help of a community-based smartphone application," *Pers. Ubiquitous Comput.*, vol. 16, no. 6, pp. 655–664, Aug. 2012.
- [108] R. Castri, V. De Luca, E. Lobsiger-Kägi, C. Moser, and V. Carabias, "Favouring behavioural change of household's energy consumption through social media and cooperative play," in *Proc. Behave Conf.*, Oxford, U.K., Sep. 2014, pp. 1–6.
- [109] P. Petkov, F. Köbler, M. Foth, and H. Krcmar, "Motivating domestic energy conservation through comparative, community-based feedback in mobile and social media," in *Proc. 5th Int. Conf. Communities Technol. (CT)*, 2011, pp. 21–30.
- [110] E. Costanza, J. E. Fischer, J. A. Colley, T. Rodden, S. D. Ramchurn, and N. R. Jennings, "Doing the laundry with agents: A field trial of a future smart energy system in the home," in *Proc. Conf. Hum. Factors Comput. Syst. (SIGCHI)*, 2014, pp. 813–822.
- [111] U. Gnewuch, S. Morana, C. Heckmann, and A. Maedche, "Designing conversational agents for energy feedback," in *Designing for a Digital and Globalized World*, S. Chatterjee, K. Dutta, and R. P. Sundarraj, Eds. Cham, Switzerland: Springer, 2018, pp. 18–33.
- [112] P. W. Schultz, M. Estrada, J. Schmitt, R. Sokoloski, and N. Silva-Send, "Using in-home displays to provide smart meter feedback about household electricity consumption: A randomized control trial comparing kilowatts, cost, and social norms," *Energy*, vol. 90, pp. 351–358, Oct. 2015.
- [113] R. Gupta, L. Barnfield, and M. Gregg, "Exploring innovative community and household energy feedback approaches," *Building Res. Inf.*, vol. 46, no. 3, pp. 284–299, Apr. 2018.
- [114] A. Gustafsson and M. Gyllenswärd, "The power-aware cord: Energy awareness through ambient information display," in *Proc. Extended Abstr. Hum. Factors Comput. Syst. (CHI)*, 2005, pp. 1423–1426.
- [115] S. Backlund, M. Gyllenswärd, A. Gustafsson, S. Ilstedt Hjelm, R. Mazé, and J. Redström, "Static! The aesthetics of energy in everyday things," in *Proc. Design Res. Soc. Wonderground Int. Conf.*, vol. 115, 2007, pp. 109–123.
- [116] M. Daniel, G. Riviere, and N. Couture, "Cairnform: A shape-changing ring chart notifying renewable energy availability in peripheral locations," in *Proc. 13th ACM Int. Conf. Tangible, Embedded Embodied Interact.*, 2019, pp. 275–286.
- [117] F. Heller and J. Borchers, "PowerSocket: Towards on-outlet power consumption visualization," in *Proc. Extended Abstr. Hum. Factors Comput. Syst. (CHI)*, 2011, pp. 1981–1986.
- [118] L. Broms, C. Katzeff, M. Bång, Å. Nyblom, S. I. Hjelm, and K. Ehrmberger, "Coffee maker patterns and the design of energy feedback artefacts," in *Proc. 8th ACM Conf. Designing Interact. Syst. (DIS)*, 2010, pp. 93–102.
- [119] P. Petkov, F. Köbler, M. Foth, and H. Krcmar, "Motivating domestic energy conservation through comparative, community-based feedback in mobile and social media," in *Proc. 5th Int. Conf. Communities Technol. (C&T)*, Brisbane, QLD, Australia. New York, NY, USA: Association for Computing Machinery, 2011, pp. 21–30, doi: 10.1145/2103354.2103358.
- [120] F. Quintal, C. Jorge, V. Nisi, and N. Nunes, "Watt-I-see: A tangible visualization of energy," in *Proc. Int. Work. Conf. Adv. Vis. Inter.*, 2016, pp. 120–127.
- [121] J. Hammerschmidt, T. Hermann, A. Walender, and N. Kromker, "InfoPlant: Multimodal augmentation of plants for enhanced human-computer interaction," in *Proc. 6th IEEE Int. Conf. Cognit. Infocommun. (CogInfoCom)*, Oct. 2015, pp. 511–516.
- [122] J. Hammerschmidt, R. Tunnermann, and T. Hermann, "Infodrops: Sonification for enhanced awareness of resource consumption in the shower," in *Proc. Int. Conf. Auditory Display*, 2013, pp. 1–8.
- [123] A. Irizar-Arrieta and D. Casado-Mansilla, "Coping with user diversity: UX informs the design of a digital interface that encourages sustainable behaviour," in *Proc. Int. Conf. Interfaces Hum. Comput. Interact.*, 2017, pp. 1–8.
- [124] A. Irizar-Arrieta, D. Casado-Mansilla, and A. Retegi, "Accounting for user diversity in the design for sustainable behaviour in smart offices," in *Proc. 3rd Int. Conf. Smart Sustain. Technol. (SpliTech)*, 2018, pp. 1–6.
- [125] L. Jönsson, L. Broms, and C. Katzeff, "Watt-Lite: Energy statistics made tangible," in *Proc. 8th ACM Conf. Designing Interact. Syst.*, 2010, pp. 240–243.
- [126] D. Casado-Mansilla, A. M. Irizar, P. Garaizar, and D. Lopez-de-Ipina, "Design-insights for devising persuasive IoT devices for sustainability in the workplace," in *Proc. Global Internet Things Summit (GIoTS)*, Jun. 2018, pp. 1–6.
- [127] D. Pasini, F. Reda, and T. Häkkinen, "User engaging practices for energy saving in buildings: Critical review and new enhanced procedure," *Energy Buildings*, vol. 148, pp. 74–88, Aug. 2017.
- [128] A. Fensel, D. K. Tomic, and A. Koller, "Contributing to appliances' energy efficiency with Internet of Things, smart data and user engagement," *Future Gener. Comput. Syst.*, vol. 76, pp. 329–338, Nov. 2017.
- [129] C. P. Kirk, S. D. Swain, and J. E. Gaskin, "I'm proud of it: Consumer technology appropriation and psychological ownership," *J. Marketing Theory Pract.*, vol. 23, no. 2, pp. 166–184, 2015.
- [130] J. Chapman, "Design for (emotional) durability," *Design Issues*, vol. 25, no. 4, pp. 29–35, Oct. 2009.

- [131] J. Corbett, "Using information systems to improve energy efficiency: Do smart meters make a difference?" *Inf. Syst. Frontiers*, vol. 15, no. 5, pp. 747–760, Nov. 2013.
- [132] C.-F. Chen, X. Xu, and L. Arpan, "Between the technology acceptance model and sustainable energy technology acceptance model: Investigating smart meter acceptance in the united states," *Energy Res. Social Sci.*, vol. 25, pp. 93–104, Mar. 2017.
- [133] J. Kranz and A. Picot, "Is it money or the environment? An empirical analysis of factors influencing consumers' intention to adopt the smart metering technology," in *Proc. 18th Amer. Conf. Inf. Syst.*, 2012, pp. 1–9.
- [134] V. Venkatesh and F. D. Davis, "A theoretical extension of the technology acceptance model: Four longitudinal field studies," *Manage. Sci.*, vol. 46, no. 2, pp. 186–204, Feb. 2000.
- [135] E. Viciano, A. Alcayde, F. Montoya, R. Baños, F. Arrabal-Campos, A. Zapata-Sierra, and F. Manzano-Agugliaro, "OpenZmeter: An efficient low-cost energy smart meter and power quality analyzer," *Sustainability*, vol. 10, no. 11, p. 4038, 2018.
- [136] J. W. Bolderdijk, L. Steg, and T. Postmes, "Fostering support for work floor energy conservation policies: Accounting for privacy concerns," *J. Organizational Behav.*, vol. 34, no. 2, pp. 195–210, Feb. 2013.
- [137] A. Kowalska-Pyzalska, "What makes consumers adopt to innovative energy services in the energy market? A review of incentives and barriers," *Renew. Sustain. Energy Rev.*, vol. 82, pp. 3570–3581, Feb. 2018.
- [138] J. Carroll, S. Lyons, and E. Denny, "Reducing household electricity demand through smart metering: The role of improved information about energy saving," *Energy Econ.*, vol. 45, pp. 234–243, Sep. 2014.
- [139] L. Bastida, J. J. Cohen, A. Kollmann, A. Moya, and J. Reichl, "Exploring the role of ICT on household behavioural energy efficiency to mitigate global warming," *Renew. Sustain. Energy Rev.*, vol. 103, pp. 455–462, Apr. 2019.
- [140] K. Buchanan, R. Russo, and B. Anderson, "The question of energy reduction: The problem(s) with feedback," *Energy Policy*, vol. 77, pp. 89–96, Feb. 2015.
- [141] B. K. Sovacool, "Diversity: Energy studies need social science," *Nature*, vol. 511, no. 7511, pp. 529–530, Jul. 2014.
- [142] F. Wang, L. Liu, Y. Yu, G. Li, J. Li, M. Shafie-khah, and J. Catalão, "Impact analysis of customized feedback interventions on residential electricity load consumption behavior for demand response," *Energies*, vol. 11, no. 4, p. 770, 2018.



ANE IRIZAR-ARRIETA received the degree in art electronic and digital design, the bachelor's degree in graphic design from Universitat Ramon Llull, Barcelona, and the master's degree in user experience design from the Universidad Internacional de la Rioja, in 2016. She is currently pursuing the Ph.D. degree in engineering program for the Information Society and Sustainable Development with the Universidad de Deusto, Bilbao. In 2016, she joined the DeustoTech Social Challenges Unit,

focusing on HCI, user experience and human-centered design applied to the implementation of behavior change techniques through tangible and digital interfaces. She is currently a Research Assistant with DeustoTech, where she is involved in several projects related to experience and interaction design, and user research.



OIHANE GÓMEZ-CARMONA received the B.Eng. degree in industrial electronics and automation engineering from the University of the Basque Country, Bilbao, Spain, in 2015, and the M.S. degrees degree in automation, electronics and industrial control from the University of Deusto, Bilbao, in 2016. She is currently pursuing the Ph.D. degree with the DeustoTech, Deusto Institute of Technology, University of Deusto. She is currently a Research Assistant with DeustoTech,

Deusto Institute of Technology, University of Deusto. Her research centers around the Internet of Things (IoT), the interaction between people and technology-augmented objects, and the optimization of machine learning techniques for embedded devices.



ARITZ BILBAO-JAYO received the bachelor's degree in computer science with the University of Deusto, in 2014, the master's degree in computer science from the University of Deusto, in 2016, while he was working on European Research Projects such as SONOPA (AAL) or MoveSmart (FP7). He is currently pursuing the Ph.D. degree with the Faculty of Engineering, DeustoTech Institute, University of Deusto. He is currently a Research Assistant with the Faculty of Engineering, DeustoTech Institute, University of Deusto. His research centers around the application of deep learning and natural language processing techniques on the political discourse analysis on social networks.



DIEGO CASADO-MANSILLA received the Ph.D. degree in persuasive technologies for sustainability and behavior change from the University of Deusto, in 2016. He is currently an Associate Researcher with the MORElab Research Group and also a Lecturer with the University of Deusto. His research interests are focused on sustainable HCI, persuasive and behavior change technologies, sustainable design, and physical interaction with everyday objects. He has several relevant publications on the topics of sustainable HCI and the Internet of Things (IoT).



DIEGO LÓPEZ-DE-IPÍÑA received the Ph.D. degree from the University of Cambridge, U.K., in 2002. His Ph.D. dissertation entitled visual sensing and middleware support for sentient computing. He is currently an Associate Professor and a Principal Researcher of the MORElab/DEUSTEK Group (<http://morelab.deusto.es/>). He has participated in several big consortium-based research european (PARITY, BD4QoL, EDI, SIMPATICO, CITY4AGE, GREENSOUL, WELIVE, MOVES-

MART, IES CITIES, MUGGES, SONOPA, CBDP, GO-LAB, and LifeWear) involving the adoption of semantic web, social data mining, linked open data, smart cities, open government, and NGI to novel Aml-related application areas such as urban computing, sustainable computing or AAL. He is the Project Coordinator for the European Data Incubator (EDI) (<http://edincubator.eu>) H2020 Project. He has more than 200 publications in relevant international conferences and journals on *Ubiquitous Computing*, *Semantic Web*, *Middleware*, *Smart Cities*, and *Aml*, including more than 65 JCR-indexed journal articles. His main research interests are pervasive computing, the Internet of Things, semantic service middleware, open linked data, social data mining, and mobile-mediated and tangible human-environment interaction.



AITOR ALMEIDA received the Ph.D. degree in computer science from the University of Deusto. He is currently a Researcher and a Project Manager with the Faculty of Engineering, DeustoTech Institute, University of Deusto. His research interests include the analysis of the behavior of the users in intelligent environments, the application of artificial intelligence for smart health, and the study of the users' activity and discourse on social networks.

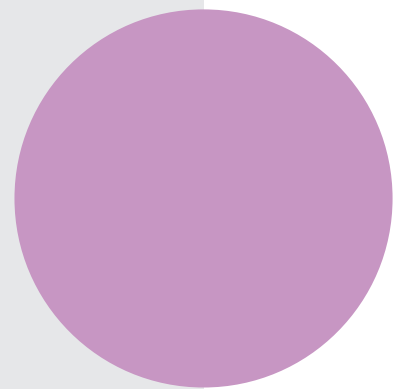
...

*Moderate strength is shown in violence,
supreme strength is shown in levity.*

G. K. Chesterton, *The Man Who Was Thursday*

CHAPTER 4

User perspectives in the design
of interactive everyday objects
for sustainable behaviour





User perspectives in the design of interactive everyday objects for sustainable behaviour



Ane Irizar-Arrieta^{*,a}, Diego Casado-Mansilla^a, Pablo Garaizar^b, Diego López-de-Ipiña^a, Aiur Retegi^b

^a DeustoTech - University of Deusto, Avda. Universidades 24, Bilbao, 48007, Spain

^b Engineering faculty - University of Deusto, Avda. Universidades 24, Bilbao, 48007, Spain

ARTICLE INFO

Keywords:

Internet of things
Persuasive technology
Grounded theory
Human computer interaction
Design for sustainable behaviour change

ABSTRACT

Addressing efficient management of energy has become a central objective due to the scarcity of traditional energy sources and global warming. To cope with this overarching issue, some technological solutions such as Smart Grids, Internet of Things or Demand response are proposed. However, the majority of them overlooks the role of human beings in the equation. Moreover, the very nascent body of research combining human and machine intelligence proposes methods, frameworks, and guidelines which vary depending on the application scenario complicating the selection of gold-standards to ensure seamless cooperation between smart devices and people. Hence, the purpose of this paper is to provide a set of design-hypotheses to devise augmented objects that ally with their users to reduce energy consumption. We expect designers, engineers, makers or even hobbyists in the intersection between technology-enablers (through IoT) and behavioural scientists to benefit from them. To this aim, we describe the results of a long-term study in office-based workplaces, where participants were randomly assigned to different experimental conditions (persuasion, dashboard, and automation) to increase their energy-efficient behaviour. Grounded Theory analysis was applied over qualitative data collected during focus group sessions obtaining five themes around a central category. The resulting themes were linked to design-hypotheses for IoT devices which were then tested through the implementation of a new IoT object also conceived for the workplace.

1. Introduction

In recent years, the Human-Computer Interaction (HCI) and Persuasive Technology communities started to increase their attention to sustainability issues because environmental preservation is strongly dependent on human behaviour. In this field, a large body of previous research from the early XXI century has evidenced the value of persuasive feedback to foster behaviour change (Gustafsson and Gyllenswärd, 2005; Pierce and Paulos, 2012; Thieme et al., 2012). Persuasion for sustainability has its roots in the application of Fogg's framework Fogg (2003) for "computers as persuaders" to the topic of pro-environmental sustainability. Taking the existing context into account, this paper focuses on a single but widespread environmental issue, which is to reduce the energy footprint at the workplace, changing the way employees use private and shared electronic devices by augmenting them with IoT technologies. This interest is supported by scientific evidence, according to Brynjarsdóttir et al. (2012) who found

that more than half of the papers they reviewed in their analysis of persuasive technologies tackled energy-related topics. In the same vein, DiSalvo et al. (2010) reviewed the body of knowledge on Sustainable HCI finding different genres overall focused on ambient awareness, persuasive technology and sustainable interaction design. Similarly, Pierce and Paulos (2012) stated that energy consumption was the primary focus on sustainable HCI works after reviewing 51 papers on the field. More relevant to our research was to understand that the analysis carried out on this topic revealed that there is a growing interest in augmenting legacy or new everyday devices with persuasive technology to help people to form eco-minded behaviours. In Fig. 1 different augmented objects devised to bring awareness about energy consumption through eco-feedback (i.e. a term coined by Froehlich et al. (2010) which provides the idea of informing users and make them reflect over resource waste through ambient feedback) can be observed (Arroyo et al., 2005; Broms et al., 2010; Casado-Mansilla et al., 2014; Cowan et al., 2013; Gustafsson and Gyllenswärd, 2005;

* Corresponding author.

E-mail addresses: ane.irizar@deusto.es (A. Irizar-Arrieta), dcasado@deusto.es (D. Casado-Mansilla), garaizar@deusto.es (P. Garaizar), dipina@deusto.es (D. López-de-Ipiña), aiur.retegi@deusto.es (A. Retegi).

<https://doi.org/10.1016/j.ijhcs.2019.102393>

Received 17 June 2019; Received in revised form 13 December 2019; Accepted 27 December 2019

Available online 03 January 2020

1071-5819/ © 2020 Elsevier Ltd. All rights reserved.



Fig. 1. Persuasive IoT objects found in the literature which were designed for promoting sustainable behaviour change through tangible or ambient interaction.

Holstius et al., 2004; Jönsson et al., 2010; Kappel and Grechenig, 2009; Laschke et al., 2015; Thieme et al., 2012).

Despite this growing interest on smart devices and persuasion for enhancing pro-environmental behaviour, the variety of possible sustainable actions, the desire or undesired willingness to make them, and the diversity of users (profiles, traits, interests, beliefs, etc.) make hard to find in the existing literature a set of comprehensive guidelines tailored for the specific purpose that the designer desires. Furthermore, scholars on Sustainable HCI field raised their concern about the feasibility of persuasion to maintain the target behaviour throughout the time (De Young, 1993; Knowles et al., 2014). A more recent review of the literature did also not found enough evidence to support the hypothesis that feedback through digital technology leads to lasting behaviour change (whereas, it found after reviewing 72 studies that feedback through digital technology has the potential to disrupt undesired habits) Hermesen et al. (2016). In conclusion, with exceptions, the majority of the studies do not last more than one month and, therefore, is still difficult to evaluate the real impact of ICT-based persuasion on behaviour change throughout the time.

Taking these open issues into account, this piece of research seeks to offer an ensemble of design-hypotheses that researchers on the area of sustainability, and specifically in energy awareness through IoT, might follow when approaching the design of persuasive systems. With this purpose, we conducted an empirical intervention instrumenting with sensing technology several capsule-based coffee machines in different work environments for more than one year. Three experimental conditions were evaluated which entailed leveraging various features on the appliances: (i) persuasive feedback; (ii) energy monitoring through a dashboard; and (iii) automated operation to avoid forgetfulness. After analysing the quantitative and qualitative data gathered from experiments and focus groups with the participants of the study, we are able to provide cues on how to transform the design recommendations into a real IoT device also conceived for office-based workplaces.

2. Related work

The selection criteria of the body of research reviewed was based on the idea that the targeted works should have presented a physical object aiming to promote sustainable behaviour change either by using aesthetics, ambient feedback, or tangible interaction. Besides, the works should have explicitly stated that their approaches contribute to the Internet of Things, Ubiquitous computing (UbiComp) or Pervasive computing fields. Furthermore, the studies where the physical interactive objects were conceived for the work environment were preferred

over those more oriented to private settings. However, in some cases, these were complemented with devices designed for other use contexts.

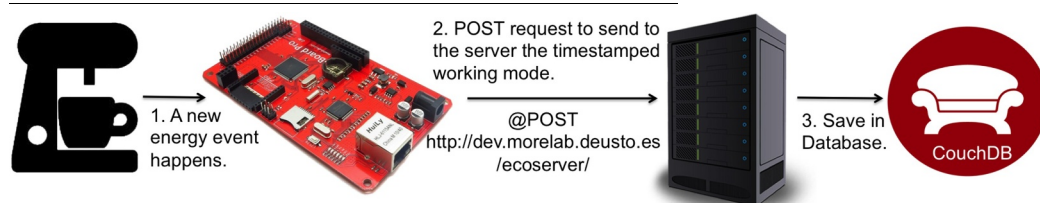
Power-aware Cord is an electrical power-strip in which the cord was augmented to expose the electricity being consumed in real-time through ambient light. The bigger the energy drawn by the power-strip plug, the brighter the cord is (Gustafsson and Gyllenswärd, 2005). In this work, the light is used emotionally and qualitatively, aiming at symbolising the energy in a more understandable way than the abstract information that offers the raw energy data (e.g. kWh). Very similar to the Power-aware cord, Quintal et al. (2017) devised a common two spots type F wall socket redesigned with two main goals: to process consumption data by using a microcontroller and to provide the capability to display just-in-time visual information (through the ambient LED's built-in on the socket that changed from green to red by comparing the real-time consumption with a baseline for the device it is connected to). Waterbot is another device that provides ambient feedback about water usage in a kitchen's sink through visual and auditory reminders (Arroyo et al., 2005). While using ambient light to offer visual reminders, it also uses the sound as an eco-feedback technique to motivate the water saving. Similarly, 'Show-me' displays the amount of water that is being used during the shower through an LED strip assembled to the shower's stick (Kappel and Grechenig, 2009). These three ambient displays apply ambient light to visualise the impact of some common misbehaviour in the use of basic resources such as electricity and water metaphorically.

Stroppy Kettle is an augmented appliance that aimed to break the user's kettle overflow behaviour applying barriers to goal-attainment and punishment. This approach is based on the idea that rational information is not enough to change the desired behaviour. The barrier is applied to only who performs the negative behaviour (Cowan et al., 2013). Besides, the punishment as a behaviour change strategy is also remarkable through the creation of a barrier to habit execution.

Watt-lite Jönsson et al. (2010) and Energy-Aware clock Broms et al. (2010) are two works that aim to explore tangible data and non-obtrusive interaction to reduce energy consumption. Both works implement displays through playful interactions and visualisations to engage the users and let them explore the energy-related data to improve the understanding of the energy. Although these works do not address behaviour change as a principal objective, they are intended to reach the awareness and the motivation of the individuals in a social context (e.g. families or workplaces). Social-coffee maker (Casado-Mansilla et al., 2014) applies social norm strategies to improve the awareness of employees in shared spaces, increasing the motivation through the influence of the group and peer pressure. The coffee maker published tweets whenever someone left it switched on after preparing a coffee as well as it tweeted its daily energy consumption in order to be tracked by its followers on the Social Network. Thieme et al. (2012) devised BinCam, a social persuasive rubbish-bin with a built-in camera to motivate tenants to adopt recycling habits and reduce food waste. This work also applies social influence to foster awareness through behaviour change. Besides, it uses a Social Media network to provide social pressure, punishing the individuals who performed the adverse action through the publication of their bad habit in the site. Interactive living plants were designed by Holstius et al. (2004). The authors created a robotic analog of a plant that mimics photo-tropic behaviour, combining living organisms and technology. These plants were used to display information as they do in their natural context, implementing emotional and qualitative information in the interface and improving the impact of the display in the individual's awareness through intuitive and organic interactions and visualisations. Also using tangible interactions through shaping memory alloys, Laschke et al. (2015) created The Never Hungry Caterpillar, a device aimed at avoiding energy waste from keeping TVs, screens and similar electronics products in standby mode unconsciously. The Caterpillar is a power socket that mimics a living animal that is connected to the device. When using the devices typically, it moves smoothly, as if it was breathing. However, whenever

the device is put in standby mode, the device starts to twist in awkward ways as if it was on pain and the only way of overcoming that “pain” is by switching the device off completely.

There are also some products commercially available in this area. Wattson¹ from DIY Kyoto shows the overall electricity use in numbers and colours. This energy monitor captures real-time information of the energy consumption displaying it in different metrics, both quantitative (kWh and economic value) and qualitative (glows in colours depending on the quantity of electricity used). Another product that can be found in the market is the Ambient Orb.² It is a frosted-glass ball that illuminates a varying degree of colours to represent critical peak demand conditions on the smart grid. Finally, the Nest Thermostat³ is an intelligent device that aims to learn the user’s heating and cooling habits to help optimise scheduling and power usage. The machines reward the



users with a Leaf if they set up the temperature according to the Nest recommendations to save energy. Although the temperature can be set by automated processes, the rewards offer a motivational approach addressed to the user, aiming at improving the desired behaviour and motivating the user to maintain the sustainable habit.

The majority of the works reviewed devised everyday things taking into account the emotional bond that final users may create with the object or the objective that these pursue. Besides, the behavioural approach is mainly focused on the improvement of the ease of use, being the barriers and obtrusiveness significantly less applied (e.g. stropic kettle). Furthermore, existing research mainly targets individual awareness rather than groups. It promotes an easy and intuitive positive use of smart objects to facilitate the interaction to adopt or maintain the targeted behaviour. Besides, there is a unanimity of works that decided to apply the central or direct route of persuasion for providing nudges instead of the peripheral one (Cialdini, 1993). It means that the body of research aims at making people reflect on their actions rather than nudging them to do actions subtly (e.g. using emotions as triggers or subliminal priming). Finally, most of the works were only tested during short periods with exceptions on the context of the household. Sustainable HCI field demands more long term results to examine ICT-based persuasion results over longer periods as some voices raised their concern about the feasibility of persuasion to maintain the target behaviour throughout the time (De Young, 1993; Knowles et al., 2014).

3. Long-term study

We carried out an experimental intervention of one year designed to test the effectiveness of persuasive techniques to raise energy efficiency awareness in the mid and long-term in office environments. To this aim, we designed a between-group field study related to the use of electrical coffee machines separated into two phases: baseline creation and piloting. In the former stage, we calculated the energy consumption baseline of the coffee maker. In the latter stage, we continued mon-

itoring energy consumption. Still, we introduced three different experimental conditions linked to the appliances to cope with energy inefficiency: Persuasion, Web-based dashboards, and automation.

3.1. Initial setup and baseline creation

In general terms, we embedded energy measurement equipment within the electrical capsule-based coffee machines of fifteen different workplaces distributed between two big cities of Spain (Madrid, Bilbao). Specifically, the tracking and monitoring of energy were done by embedding in each coffee maker an Ethernet-based Arduino board with an energy meter that was able to send the consumption data to an own remote server (Casado-Mansilla et al., 2016) (see Figure 3.1).

The energy consumption data flow from the Arduino microcontroller to the remote server where the data was stored for future processing and analysis.

The reasons why we selected coffee machines for the field study were: 1) they are pretty common in work environments and are an element of shared use; 2) they consume large amounts of energy compared to other work appliances such as monitors or laptops (A report on appliances’ consumption holds that some models of coffee machines can exceed the electricity consumption of A-class ovens or A++ refrigerators along the year because of continuous pump pressure maintaining and water heating (Nipkow et al., 2011)). More than one hundred people were recruited from the different fifteen work-offices that participated in the long-term study. They were all recruited following a snowball procedure, and their participation was voluntary (we raffled an energy monitoring system among participants who completed the whole study).

During the initial set-up of the experiment to calculate the energy baseline, five out of the recruited fifteen groups dropped out the long-term study before its completion.⁴ Having evaluated the impact of this dropout rate on the validity of the experimental results according to Slack et al. (2001), we decided to carry on with the remaining ten groups ($N = 90$) which are described in Table 1.

In order to help with the understanding of the different participants’ profiles, in Appendix A we describe the groups and some of their main characteristics.

3.2. Between-groups intervention

As have been observed in Table 1, the random assignment of the experimental conditions among the ten workplaces remained as follows: 1) *Persuasive feedback (4 workplaces)*: a combination of real-time ambient feedback and subtle visual hints to support the user’s decision-making about when to switch off the appliance; 2) *Energy-dashboard (3*

⁴ The main reasons for attrition during this experimental phase were: 1) some groups changed or ended their business activity during the piloting; 2) other groups changed from capsule-based coffee maker to filter-based appliances being the researchers unable to track individual usage of the coffee machines; finally 3) whereas we raffled an energy monitoring system some work-groups decided voluntarily to not follow up with the experiment - recall that no pecuniary rewards were given.

¹ <http://www.diykyoto.com/>.

² <http://www.ambientdevices.com/about/consumer-devices>.

³ <https://nest.com/thermostats/nest-learning-thermostat/overview/>.

Table 1

The column's name refer to: name of the groups that participated in the study, the city (BIO - Bilbao or MAD - Madrid), the treatment they were assigned to, the type of work which is performed within these groups, the number of users of the coffee-maker in each space and the average age of them.

	Treatment assigned	Type of workplace	Participants & average age
Bailen (BIO)	Persuasion	Coworking	8 (33)
Comunica (BIO)	Automation	Administrative services	8 (35)
Computing (BIO)	Dashboard	Tech. Research group	4 (28)
IEEC (MAD)	Dashboard	Tech. Research group	4 (42)
Life (BIO)	Automation	Tech. Research group	12 (28)
Mobility (BIO)	Persuasion	Tech. Research group	15 (28)
MORElab (BIO)	Automation	Tech. Research group	9 (28)
ServGen (BIO)	Dashboard	Administrative services	3 (43)
Techabout (BIO)	Persuasion	Tech-based SME	4 (33)
Tecnologica (MAD)	Persuasion	Tech-based SME	23 (38)
TOTAL			90



Fig. 2. The three different experimental treatments that were randomly assigned to the participating groups.



Fig. 3. The persuasive coffee makers provided just-in-time visual cues to help users in energy efficiency decision-making. On the first image, a user approaches its finger to switch off the device. In the second and third pictures, the augmented appliance detects the motion close to the button and informs the user to not switch it off by activating a built-in visual alert. As can be observed in the first picture of Fig. 2, the subtle message to prevent the operation of the appliance is “Please, leave me on”.

workplaces): participants were provided with a Web site to track their energy consumption associated to the appliance (i.e. self-monitoring and rational information through comparisons with historical energy data); and 3) *Automation* (3 workplaces): coffee makers were modified to autonomously switch the appliances off whenever they were not in use (i.e. the rationale behind automation was providing a sense of comfort to the users relieving them from the task of switching the appliance on and off). The three experimental conditions are depicted in Fig. 2. As the persuasion condition holds the hypothesis of this study, it

has been represented in Fig. 3 for a better understanding of its operation.

It is important to emphasise that both persuasive feedback and automation rely on an underlying ARIMA model, which is a statistical method for time series forecasting. Thus, the smart coffee makers were able to predict the number of users that were about to use the coffee maker in 1-hour slots during the day (Ventura et al., 2014). With this information, in the persuasive condition, the appliance suggested users operate the on-off button (e.g. Fig. 3), while in the automation condition, the appliance switches on or off deliberately without human intervention to minimise the energy waste.

3.3. Quantitative results

At the end of the study, it was demonstrated quantitatively that the IoT-based Persuasive treatment helped to save most energy than the other two treatments (Mansilla, 2016). Specifically, we found that the IoT-based Persuasive treatment helped to save most energy than the other two treatments reducing the energy waste by 44.53%. The Automation treatment also helped to reduce energy waste by 14.19%. Finally, the Dashboard approach did not lead to a reduction of energy waste remaining with a similar percentage as the beginning of the experiment. For the sake of better understanding, we refer to “save energy” to the fact that the coffee makers diminished the quantity of wasted energy due to the generalised abuse of standby mode on these appliances (i.e. substantially reducing the time that a coffee machine is switched on but is not preparing coffee). This amount of energy is not negligible since the coffee makers are periodically maintaining the pressure pump ready to be used or heating the water for the next coffee cup.

Because of this finding, we wanted to grasp detailed qualitative information from users to understand the causes of the persuasive intervention being more effective than automation or dashboard.

3.4. Qualitative analysis

While science has a strong reliance on quantitative and experimental methods, there are many complex, socially-based phenomena in HCI that cannot be easily quantified or experimentally manipulated. Within HCI, there is the recognition that the focus on tasks is not enough to design and implement an effective system. Therefore, identifying users’ emotional and social drives and perspectives; their motivations, expectations, trust, identity, social norms, and so on are paramount for creating more than ‘just appealing’ designs (Adams et al., 2008). Hence, at the end of the between-group study (i.e. when the experimental conditions were removed from all workplaces), we ran several focus group sessions with participants who volunteered to join the dynamics from each of the study-groups of Table 1 according to Merton et al.’s guidelines Merton et al. (1990). We managed to have ‘at least’ one representative from each of the ten remaining groups. Audio data from each session were recorded and manually transcribed for further analysis through Grounded Theory (GT) (Charmaz, 2006). In the following, we describe what GT is and how we applied this methodology to the data obtained from groups who interacted with the coffee-makers augmented with IoT-based persuasive systems to extract design-insights that help to inform the design for similar everyday intelligent devices created in the future. Following the specifications



Fig. 4. The different phases of applying Grounded Theory over qualitative data coming from all three experimental conditions.

Table 2

Set of unitary codes along their axial categories extracted from people who interacted with the IoT-based persuasive coffee-maker.

Interaction	Attachment / Confidence	Mediator / Emotion	Context	Behaviour
Automation	Similarity	Group Awareness	Extrapolate behaviour	Acceptance
Satisfaction	Adherence	Generate discussion	Export to other devices	Adaptation
Understandable	Pleasure	Elicits Interest	Hawthorne effect	Pro-environmental self-perception
Comfort elicits awareness	Trust	Group inefficiency (-)	Private vs. Public setting	Aware of B. change
Comfort elicits efficiency	Dependency (-)	Media equation	Patterns	Group awareness
Comfort elicits inefficiency (-)	Disregard (-)	Proudness	Mirror effect	Comfort elicits awareness
Misunderstanding (-)	Expandable behaviour		Social-proof	Sense of control elicits efficiency
Disgruntlement (-)	Non-expandable B. (-)		Behaviour at home	Comfort elicits inefficiency (-)
Subject-expectancy effect (-)	Preservation			Consistency (-)
Efficacy vs. Efficiency	Proudness			Dependency (-)
Efficacy	Acceptance			Durability
Aesthetics	Transparency			Efficacy vs. Efficiency
Inefficiency (-)				Incomprehension (-)
Intelligent system				Learned helplessness (-)
Playfulness				Group inefficiency (-)
Data to take decisions (-)				Scale Consumption
Need of insightful data (-)				Low durability (-)
Different HCI model (-)				Obsolescence
Personal vs Group data				Patterns
Tailoring				Tailoring
Nudges				Unaware of behaviour change (-)
Useful				

exposed by Hekler et al. (2013) about the epistemic status of design guidelines, and due to the limited amount of empirical data, in this work, the guidelines derived from the study will be named as “design hypotheses”, which will need further validation.

3.4.1. Grounded theory-based approach

According to Charmaz and Belgrave (2007), GT is an established method for studying qualitative information where codes are generated from the data rather than relying on pre-existing categories. Thus, it can be considered as an inductive method. It includes Open, Axial, and Selective Coding as phases to generate a new theory, as can be observed in Fig. 4. We applied this methodology to analyse the qualitative data extracted from the focus group sessions to produce design insights for creating augmented persuasive IoT devices that promote energy efficiency practices taking into account the social phenomena of the workplace context.

There are other methods with a recognised reputation in HCI for analysing qualitative data, such as Content Analysis Kabicher et al. (2008) or Thematic Analysis Brown and Stockman (2013). We selected GT because this methodology allows us to construct theories, concepts, hypotheses and propositions starting directly from the data and not from the *a priori* assumptions, from other investigations, or existing theoretical frameworks.

The purpose of the GT's Open Coding phase after transcribing the qualitative data is to identify entities, to group them into categories, and to describe relevant properties and dimensions pertaining to a category. The codes are extracted iteratively from the data in the process of analysis. Then, Axial Coding identifies relationships between initial categories as well as conditions, context variables, and resulting consequences. Finally, Selective Coding focuses on deliberately setting a focus on the analysis. Thus, core-category is selected. As suggested by Armstrong et al. (1997), inter-rater reliability of the extraction of the codes and grouping them into categories was assessed by two researchers along the whole process of the GT analysis.

In the Open coding phase, 132 unitary codes were extracted. Attributes such as frequency, target, intensity or duration were annotated together with each of the emerging codes (some samples of the codes extraction can be observed in Table B.3 in Appendix B of this paper.) These samples provide an example of the quotes and the codification process we carried on.

Following the constant comparative method (Charmaz, 2006), a saturation of codes and categories were reached in the Axial phase,

according to the two researchers. At this stage, five categories emerged from the initial codes: 1) interaction, 2) mediator|emotion, 3) attachment|confidence, 4) context, and 5) behaviour. As an example, Table 2 shows the codes from the people who interacted with the IoT-based persuasive appliance that emerged during the Open and Axial phases as well as the thematic categories in which these were grouped.

Finally, the purpose of the Selective coding phase is to define the central category as the catalyst for the thematic categories. We elucidated that the central theme of the theory was the relationship between the people (employees) and the augmented IoT-based appliance to cope with energy inefficiency jointly. This central theme encompasses the other five axial categories, as can be observed in the diagram of Fig. 5.

According to Charmaz (2006), the diagram is devised to organise the nascent theory and to see the relative power, scope, and direction of the categories in the analysis as well as the connections among them for linear narrative purposes. Therefore, the diagram should not be understood as a predictive or causal model that is mandatory to be followed to succeed in creating new IoT systems. What the incipient theory aims to bring attention is that for ‘Behaviour’ change to occur (final theme) by means of ‘Interacting’ with IoT objects (initial theme), categories such as (Mediator|Emotion), (Attachment|Confidence) and Use-context shall be taken into account when designing IoT-based persuasive systems. Thus, IoT augmented Things in the workplace context should provoke certain emotions to users, mediate between conversations among human beings, create a sense of attachment to them, and generate confidence to bring pro-environmental awareness or effectively change the behaviour. Furthermore, not all the paths interlinking the categories have to be pierced. In fact, those connections between themes that we considered non-compulsory have been depicted with a dashed lines.⁵

4. User perception-based design hypotheses

As mentioned before, we applied the GT to the data obtained from

⁵ We considered Emotion|Mediator and Confidence|Attachment as non-compulsory themes because we were unable to guarantee according to our analysis whether these themes that shared unitary codes could be merged or separated in sole categories as Interaction, Use-context or Behaviour. Further qualitative investigation through constant comparison and theoretical sampling (methods proposed by Glaser and Strauss (2017)) should be carried out to decide on the unification or separation of these emerging themes.

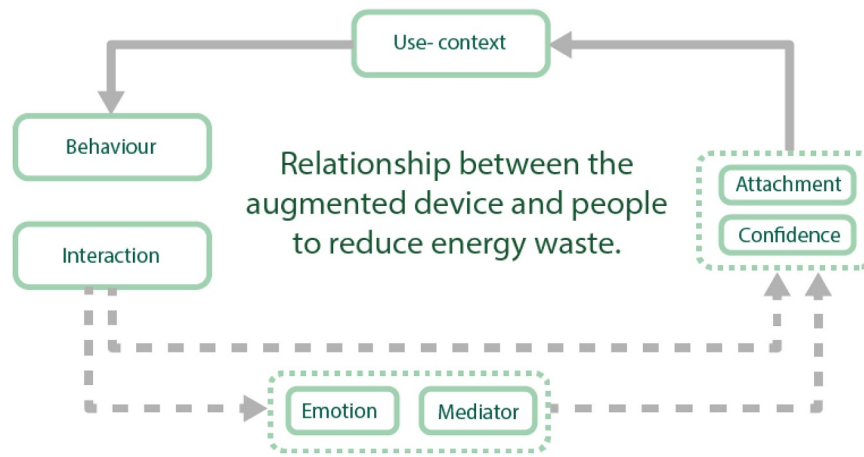


Fig. 5. The emerging theory obtained by analysing the qualitative data coming from all three experimental conditions through Grounded Theory.

groups who interacted with the coffee-makers augmented with IoT-based persuasive systems to extract design-insights that help to inform the design for similar everyday intelligent devices in the future. Several quotes for all the conditions were gathered. Still, for this paper, only relevant quotes from participants that interacted with the persuasive IoT-based coffee maker are reported in this section regarding each of the five/seven emerging themes. These quotes are jointly offered with a discussion over the implications that the themes have for the design of augmented objects that promote sustainable behaviour, offering design-hypotheses in order to facilitate the implementation of the exposed ideas for future designs.

4.1. Interaction

This category covered one of the most recurrent topics in the focus group sessions, and it captured the majority of unitary codes in the GT analysis, as can be observed in the first column of Table 2. Notably, we received positive and pleasant feedback when participants evaluated the interaction with the Interactive coffee maker. “*What did serve us well, were the red LEDs on the periphery of the coffee-maker to make us to the idea of how we were going*” or “*I think the visual feedback from the device has also given us clues as to how to go about doing it.*” In the referred table, the reader can also observe negative symbols between brackets when feedback was considered unfavourable. For instance, “*there were times when it turned red too quickly ... we think it turns red very fast for the coffee we drink ... that will be 4–6 coffees a day ... and then it is red*”. However, constructive criticism to improve the proposed design was provided by some people, P1: “*I lacked some audible eco-feedback when I put my mug on the appliance. Something like the NFC/RFID-based readers that one can find in the turnstile of the Metro stations that give you feedback about your pass checking*”. Surprisingly, some participants that interacted with the persuasive IoT appliance missed some of the aspects that were implemented in other experimental treatments, P2: “*I would like to have a Web-dashboard where I could track my kWh*”. The overall conclusion of this category is that people felt satisfied with the feedback received because it was intuitive and helpful to behave in an energy-efficient fashion.

Design-hypothesis: According to the conclusions extracted in the previous paragraph, and with our own experience in this experiment, to improve the intuitiveness in the different users, the designers should be aware that the ‘one-size fits all’ approach will not cover all user needs. As an example, the persuasive IoT-based coffee-maker was the most efficient according to the quantitative data. However, the users missed features of other treatments with lower or none effectiveness (Quintal et al. (2017) also reported a similar situation. After receiving ambient visual cues to promote energy awareness, participants in their study missed other extra features such as using historical data, social

comparisons, presenting the impact on the environment or the energy origin). Such finding let us understand that it is impossible to please everyone with one design even when it seems to be just right for the envisaged purpose.

Further, in the qualitative phase, it is more than probable that some of the interviewees will miss features that the literature reckons that do not work for changing the intended behaviour in the mid and long term (e.g. provide kWh without comparisons, or provide financial incentives). These opinions should be taken with extra care in the design phase because they may blur the goal of changing the behaviour. We argue that this design-insight is comparable to other contexts of HCI beyond IoT. Still, we consider that a designer should be firm with the interactive proposal if it has been validated through appropriate design methodologies.

4.2. Mediator/emotion

Whereas the majority of the feedback provided about the interaction was positive, the proposed persuasive design provoked polarised emotions that were voiced in the focus group sessions. For example, P3 stated: “*Despite the suggestions of the augmented appliance to leave it on, I felt cross leaving the coffee maker switched on after preparing a coffee*”. The opinions of P4 were more positive: “*I loved to know that we have a smart appliance in the office*” or P5: “*It is funny to have one (the appliance)... for me, it is like it was another member of the department*”. This latter quote resonates to the ‘Media Equation Theory’ that states that media and computers are sometimes treated by people as if they were real humans (Reeves and Nass, 1996). Moreover, P5’s comment and that of P6: “*The coffee-maker sparked conversations about energy consumption among colleagues. Overall during the initial weeks of the set-up*” correlated with the idea that augmented smart objects may have the role of mediators to bring about reflections and conversations centred in the topic that the designer wants to change.

Design-hypothesis: We want to emphasise the idea that augmented objects seem to be more than mere relays of eco-feedback, and they should be conceived as new interactive actors in these situated environments. This idea is not new in IoT Atzori et al. (2014) and was thoroughly investigated by Nass et al. (1997) when personal computers started to be widespread. In the case of the persuasive coffee maker, sometimes office employees considered the device as a new ally to cope with energy inefficiency, and they responded to smart object personalities as the same way they responded to human personalities. The peculiarity of these new actors is that they can cause mixed emotions to users. These emotions are important because they are predictive factors for technology adoption and technology appropriation.

4.3. Attachment/confidence

As well as the previous category, again, two themes were brought together by participants, and therefore they are presented into a single category. On the one side, attachment to the smart persuasive appliance was found on several participants that were upset when we communicated to them that the smart devices were about to be removed, P7: “I will miss the appliance. I changed my perception of it... from being a bare device to consider it as something that is doing well for the environment”. On the other side, confidence in the technology was a recurrent theme because of the long time that people shared with the device daily (one year), P8: “I will always heed the eco-coffee machine’s advice without any doubts... whenever it says ‘leave me on’, I leave it on without thinking twice”.

Design-hypothesis: We acknowledge that to strengthen these two themes, the augmented everyday objects should be designed to remain close to the people to keep the positive influence on the users throughout time. For that, it is important to provide dynamic feedback that maintains the engagement (this finding is in line with the critical review about persuasion and eco-feedback pursued by [Hermsen et al. \(2016\)](#) which was partially addressed by [Lu \(2018\)](#) in the context of contextual adaptive IoT systems). Moreover, the information provided by the IoT objects have to be clear and transparent and efforts should be put on making the IoT objects to become a relevant authority in the field of application (in this case, many users trusted in the coffee-maker information. Thus, Cialdini’s authority principle of persuasion played a leading role in this case ([Cialdini, 1993](#))).

4.4. Use context

The context of use is defined as “the actual conditions under which a given artifact is used in a normal working situation”. According to [Pierce et al. \(2008\)](#), there are two important dimensions when designing eco-feedback technologies for use-contexts: dweller control and third-party control. The workplace lays into “low dweller control, high third-party control”. Surprisingly enough, the comments from experiment participants were not only related to the place they work, and therefore, where they use the coffee machine daily. Instead, the majority of opinions pointed out that some behaviours that one does or learn in one use-context (e.g. at work) and export them to another, maybe different, use-context (e.g. home settings - “high dweller control, low third-party control”). For example, P9 stated: “Because here [at the workplace] I switch off the coffee-maker, when I’m at home I pay more attention to energy efficiency”. However, care must be taken when designing objects to form new behaviours in a specific context, P10: “Sometimes at home, I forget the coffee maker switched on because at work I’m used to leaving it on since it (the augmented appliance) beg to me to do so”.

Design-hypothesis: the IoT designers of persuasive everyday things should take into account the spillover effects ([Nilsson et al., 2017](#)). The spillover effect proposes that engaging in one behaviour affects the probability of engagement or disengaging in a second behaviour (consciously or unconsciously). Therefore, the formed behaviours may be beneficial at one use-context (in our case in the workplace) but are offering detrimental consequences in other contexts (e.g. at home when no intelligent devices are there to remind the user to do sustainable actions). Hence, they should be designed with the context in mind and take into account all the consequences that may appear in on-the-wild fields. For that, we suggest using unconventional probe tools [Nielsen \(1994\)](#) or diary studies ([DeLongis et al., 1992](#)) in the design phase.

4.5. Behaviour

According to the last column of [Table 2](#), this category, along with that of interaction, was the most popular topic in the conversations that

aroused in the focus group sessions. The participants that interacted with the Persuasive condition were found to be the most aware individuals of the energy inefficiency issue at the workplace, which was in line with the quantitative data presented. Moreover, the comments from participants offered initial hints of behaviour change, P11: “We were fully aware of our misleading behaviour at the beginning of the experiment because the coffee maker turned red due to excessive energy consumption” or P12, “The coffee maker has made me aware of energy consumption. Now... sometimes after preparing a coffee, I take two steps back to double-check if I’ve left the appliance on or off”. The voices from participants that assured that the newly formed behaviour will remain throughout the time were the most relevant finding, P13: “Somehow I have started forming a habit.. even if it is something unconscious” or P14: “At the end, we all have got used to switching off the appliance. I believe that we will maintain this easy course of actions”.

Design-hypothesis: one of the main problems that designers of IoT for pro-environmental behaviour may find in successful studies (such as the one reported here in terms of energy-reduced), is to witness a relapse effect when the researcher completely removes the experimental conditions. The same might occur even when participants diminish the use of the ICT-based intervention after the novelty effect disappear. Such design-insight is pretty much in line with [Pereira et al. \(2013\)](#) or [Peschiera et al. \(2010\)](#) who reported evidence on response-relapse patterns on studies related to eco-feedback and energy awareness interventions. Thus, the question we raise is: What would be the contingency plan if there were no hints or advice to facilitate the decision-making anymore? Or, if the rewards finished suddenly? Or, if the gamification process became annoying to participants because of its repetitiveness? Etc. The designer of augmented everyday objects should carefully plan the longitudinal extent of his/her system and reflect upon foreseeable consequences of feedback removal. A proposal would be to taper the feedback off during intervals instead of doing it abruptly or creating context-aware gradually adaptive systems based on the most up-to-date user status (this latter approach was studied experimentally in a controlled environment by [Lu \(2018\)](#)).

5. Applying emerging guidelines on a new IoT device

Each of the categories derived from the analyses represent a thematic design-hypothesis, enabling researchers to build effective interventions in the workplace that place in the centre the relationship between people and the augmented device to reduce energy waste: from how people will interact with the device, through the emotions which the device may arise, the conversations that the device itself might foster among users, the confident or attachment to the suggestions provided by the intelligent device, the environment or context where the device will be used, and finally, the behaviour to be promoted. With this conceptual framework, in the following, we implement each of the design-hypothesis on a new everyday IoT object that aims at improving the energy efficiency of equipment in workstations in an office-based work environment. Firstly, ideation and development of the prototype are introduced to contextualise the theoretical implementation. Then, the emerging theory is applied in the context of the presented device, linking each of the five emerging themes with the different design features and design decisions.

5.1. The interactive coaster

To deepen in the research and understand the practical issues that emerged in the theoretical approach, an interactive IoT prototype was developed. The Interactive Coaster (IC) is a device intended to help the users become more aware of the energy that they use through the electronic devices that surround them in their workspace (e.g. a computer, monitor or the mobile phone charger). The IC supports the user in the daily routine at work by periodically showing visual information about their energy consumption level and also serves to its primary



Fig. 6. The IC showing some of the states that can display.

function (i.e. act as a coaster for placing on top of it a coffee mug or a bottle of water). Besides, it also provides alerts to use the devices more efficiently (e.g. to turn off the screen when it is not used (during breaks), foster the usage of the sleep mode, or switch off the computer when leaving the workplace during longer periods). To do so, the IC is connected to a smart plug that collects the energy consumption of the whole workstation. The IC (which can be observed in Fig. 6), is a rounded coaster made of wood and includes concentric methacrylate circles that cast light through RGB LEDs. A coaster was selected among other design ideas due to its high visibility in the desktop environment. Besides, it is always visible and can be used by everyone at any moment. To improve the effectiveness of the feedback provided, the diameter of the coaster is slightly higher than an average mug or glass. In this way, the individual can (almost) always observe the outer lighting, although a recipient is on top of it.

The lights of the coaster show a different colour depending on the average energy expenditure. Green is used to inform that the energy consumption is low; yellow to report that the waste is raising; orange to alert that the user is close to its average consumption and red when energy usage has overtaken the average consumption of previous days. The IC features different modes and visualisations to enhance user awareness and motivation about energy efficiency. 1) A historical energy consumption visualisation (when the user pushes the central button of the IC the four different circles of the coaster show a different colour depending on the energy expenditure of each time unit - previous day, current week, current month, current year); 2) an automatic visualisation alerts about the energy consumption consumed during the workday; 3) a vibration alarm buzzes when different energy expenditure levels are exceeded (the colour coding remains the same as current consumption or historical information); 4) “party mode” lights a visualisation with random colour coding, aiming at offering playful value through colourful and animated visual effects; and 5) a “snooze mode” is activated when the user flips over the Interactive Coaster switching off all the lights until it is flipped over again. The IC is able to connect to the Internet extracting all the information about energy consumption through a Wi-Fi module built-in the System on Chip (SoC), which controls the whole operation of the IoT device.

The coaster has been designed following a user-centric approach, and its design was addressed in a previous work of the authors Irizar-Arrieta et al. (2018). A summary of the steps followed to design the IC from scratch were: 1) the first ideation process, where the goal was to establish an initial approach to generate new ideas, prototypes or mockups based on the users’ needs; 2) the development of a Low-Fi prototype of the IC. This early version was intended to provide an initial approach of the physical design of the coaster, the information that it would provide, and the main interactions that should be implemented on it; 3) user research with the device, where we sought to share the first design ideas with them to understand their insights; and 4) the refinement of the prototype, implementing the design with the ideas emerged from the qualitative study. During the design process (third phase), we involved seven end-users following a semi-structured interview approach after letting them interact with the early versions of the IC. Expressly, the interviewees were initially provided with free time (2–5 min) to interact with the device, and then, the two researchers started asking questions. We asked them about their opinion of the IC, which metrics were preferred to understand their energy consumption, the colour-

coding preferred, which kind of feedback was more understandable for them, where they would place the coaster within their workstation, etc. With this information and the qualitative insights from the GT approach, we finalised the design of the new IoT object. In the following section, we shed light on how the nascent theory and its design-hypotheses were implemented in the IC.

5.2. Implementing the emerging theory on the IC

The central idea extracted from the results of the Grounded Theory analysis sets the basis of the incipient theory about the relationship between the augmented IoT device and people to reduce energy waste. The five/seven design-hypotheses of the emerging themes (interaction, mediator/emotion, attachment/confidence, use context, and behaviour) are used as drivers to face the design phase in the ideation and development of the IC.

5.2.1. Interaction

The interaction was one of the most relevant topics in the evaluation sessions. Therefore, it should be a key driver to improve the relationship with the device. To facilitate the understanding of the “Interaction” term and to avoid comprehension issues, we consider it necessary to clarify the approach of the terminology used in this work. In this context, interaction is understood as the actions and relations between an individual and an interface. To go in-depth through this generic conception of the term, the approach proposed by Diefenbach et al. (2013) is used, where the Interaction term is classified through three different levels: 1) the Why level, the most general. This is related to the experience, emotions, and subjective impression when interacting with something; 2) the What level, related to the functionality of any interaction, and 3) the How level, related to concrete operations, motor-actions and elementary attributes. Following the design-hypothesis from the Interaction theme (i.e. “One size does not fit all” He et al., 2010) and the Diefenbach’s rationale explained above, we devised the IC through a user-centric approach, developing an iterative process of design and evaluation and involving the user in the process. The heterogeneity of the individuals and their different needs, emotions or perspectives were specially addressed in the evaluation sessions to extract design features to implement in the IC. Hence, different features were implemented, aiming at offering different and complementary strategies to cover the needs of the existing different user stereotypes/segments. Thus, automatic visualisation of energy expenditure, the historical visualisation of the average consumption of different time units, and alarms or warnings when certain expenditure is raised. These design strategies were developed taking into account the research developed by Lockton (2012) and Petkov et al. (2012) where they offer specific design solutions addressed to the user diversity based in the behavioural models of the human system (Lockton, 2012) and the personal norms, values and beliefs (Petkov et al., 2012). In essence, in the IC different interactive approaches were implemented, offering end-users a wide range of feedback to address the diversity of needs (e.g. messages with different cognitive load, context-feedback in time through the warnings, delayed feedback through automatic visualisation and feedback on-demand through historical energy consumption). We can not ensure that with this, we have covered all user needs, but we believe that this approach will reduce the end-user expectations considerably on missed features. Further explanation about how the IC addresses the user diversity can be found here (Irizar-Arrieta et al., 2018).

5.2.2. Emotion/mediator

The emotions were another factor that emerged from the relationship between the device and the individuals. As the qualitative results showed, feelings and emotional bonding are inherent to the relationship with the device, and thus they must be taken into account when designing interactive smart artifacts. The idea of the device as a



Fig. 7. People at workplace placing the IC on different locations of their desktop.

mediator of conversations or interactions around energy efficiency is also linked with the feelings derived from this emotional bond. That is, if the values offered by the device resonate with the emotional needs of the user, the device can act as a mediator not only to conversations but also for the behaviour that the device aims to change.

The IC implements the emotional factors through product design. The top side of the IC has been designed taking into account the idea of the tree trunk and its rings. This strategy offers a visual metaphor that is intended to impact the emotional side of the individual. In order to strengthen this metaphor, the material selected for the case was wood. Besides, the visual design of the RGB lights and the appealing party mode are features intended to enhance the emotional properties of the device through design patterns.

The mediator theme was also implemented on the IC through its intended placement on the workstation to foster high visibility of the device at any moment by its owner and close colleagues and peers. Furthermore, we implemented a colour-coding that resonates with the traffic-light analogy. This corresponds to an emotional codification based on the work proposed by Gao and Xin (2006); Valdez and Mehrabian (1994).

5.2.3. Attachment/confidence

Attachment and confidence are abstract and complex factors closely related to the relationship between the device and the individuals. Therefore, special care must be put when addressing these concepts to avoid strategies that may cause a negative effect on them. A variety of strategies can be followed to improve the level of attachment of the user towards the IC and gain confidence in the long term. Taking into account the design-hypotheses, the device should be located close to the user or, at least, in his/her field of view (whilst being careful not to create continuous attention theft). In this regard, the device has been designed to be small and easy to be moved to one place or another within the workstation in order to not be obtrusive to employees (See Fig. 7).

The confident theme is implemented by offering consistency over the visual information provided and openness. On the one side, we explain to the users that what they observe with colours in the IC is an analogy of the real energy consumption being monitored by a smart plug connected to their workstation. To provide adaptive feedback as suggested by Hermesen et al. (2016), the IC calculates the maximum target consumption for each day providing different colour-based interactions depending on how close the user is to exceed the calculated target. On the other side, we offer them the option of visualising the energy consumed in a digital time-series graph to corroborate that the visual cues built-in the device correspond to the power being drawn

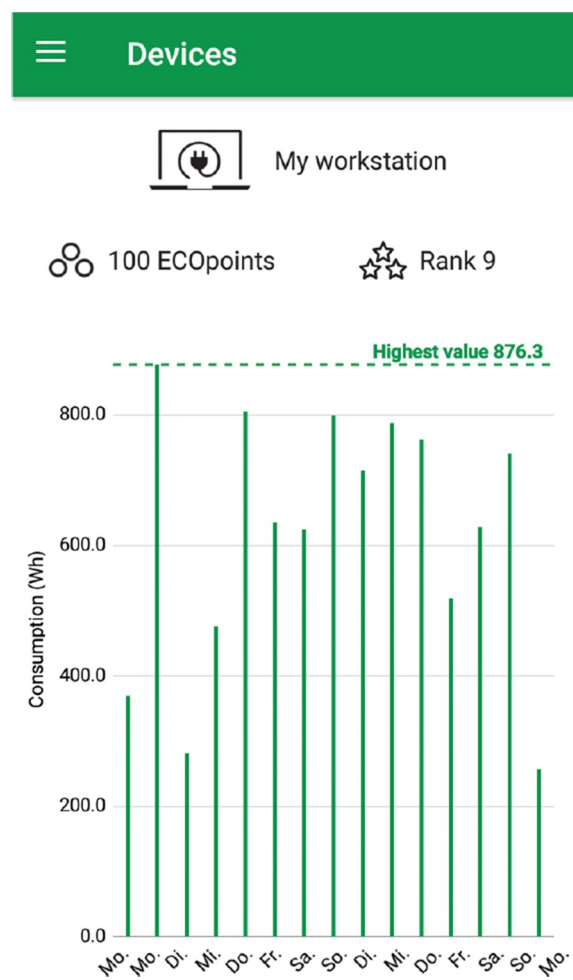


Fig. 8. An example of one of the Web-based graphs. Users are able to select the time interval and the energy data frequency (15mins, 1h, 1day) of their associated smart plug. In this example, the user has selected observe its consumption in a daily-basis.

(see Fig. 8).

5.2.4. Use context

The Interactive Coaster is intended to promote energy efficiency in an office-based work environment and therefore, the limitation of this narrow context should be taken into account. To minimise the potential negative spillover effects related to a cause-effect design (e.g. forgot to switch off the monitor at home because the user does not have a blinking coaster in its private setting), the IC is designed to provide overall awareness about energy-efficiency. Although the device is not designed to send alerts at specific moments (e.g. vibrate if the user is about to go home in order to recall him/her to switch everything off), it is possible for users to learn how the IC works and to see the existing causal relationships between their everyday actions and work patterns and the different colours that the IC shows. Through the everyday visualisation, the users are invited to reflect on their behaviour and energy expenditure rather than expect triggers and alerts from the coaster at specific moments during the day. Therefore, the IC's objective is to enhance overall awareness and eventually energy savings rather than recall a specific undesired action continuously. We believe that this design is prone to provide positive spillover effects in other contexts.

5.2.5. Behaviour

The Interactive Coaster has been primarily designed to enhance awareness and to serve as an energy ally to the user. Although the

promotion of the pro-environmental behaviour is the objective, the implications of the use context place the performance of the action as a consequence of the awareness generated by the eco-feedback (this is in line with Azjen's Theory of Planned Behaviour where intentions are the pivotal determinant for behaviour to occur [Hardeman et al., 2002](#)). Therefore, and taking into account, the design-hypothesis of this theme, the potential relapse effect derived from the elimination of the technology at the end of the experimental phase should be less unfavourable. Besides, the own energy usage patterns learned by users after having interacted with the coaster for a short period could drive to more sustainable actions. Moreover, these might be more likely to stick because the behaviour change is not linked to the device but to the motivation and new energy-related knowledge of the individual.

6. Conclusions

In this article, the qualitative data derived from a set of focus groups after carrying out a longitudinal experiment on energy awareness at the workplace were analysed using the Grounded Theory approach. GT analysis was applied to produce new insights into the design process of novel persuasive physical interfaces or augmented everyday objects that promote energy-efficient behaviour change that sticks throughout the time at the workplace. The emerging theory presents five categories: 1) interaction, mediator/emotion, 3) attachment/confidence, 4) context, and 5) behaviour. Each of these categories derived from the analyses represents a thematic design-insight, enabling researchers to build effective interventions in the workplace that place in the centre the relationship between people and the augmented device to reduce energy waste (the central category of the emerging theory). In a linear fashion the emerging theory shed light on how design IoT devices taking into account the interactions that users will have with them, through the emotions which the device may arise, the conversations

Appendix A. Offices and bussines description

Bailen: It is a coworking space in an old building in Bilbao where architects, urban planners, designers, and multimedia producers coexist. All the people who work in this space are in a room with shared tables, leaving the coffee area in a separate room. In addition to the coffee machine, there are other appliances: microwave, dishwasher and water heater for tea. In this type of space, it is easy to forget a device switched on and be in this state unnoticed during all the time in which the room is unoccupied.

Comunica: It is an administrative office within a university in Bilbao. Each of the people who work there develops management or communication functions and therefore has a personal desk. The coffee machine is hidden in a cupboard and every time they want to use it they have to carry out the following process: open the cupboard, turn on the coffee machine, put the capsule, make the coffee, remove the capsule, the cup and leave everything clean, for last, close the closet again. Being so specific and conscious of the process of preparing a coffee, it is difficult for people in this space to leave the appliance on. The reason for having the coffee machine hidden is because it is a space where many outsiders get in and employees do not want to have the device in view to visitors.

Computing, Life, Mobility, and MORElab: The four groups do research in computer science and belong to a research center attached to a university in Bilbao. The four groups are arranged in separate places within a clear space of 2000 m². Being such a large place, there is no interaction between the groups or visual contact as the researchers develop their functions in semi-isolated cubicles. As they are different groups, each of them has a coffee machine for personal use that is located in one of the free tables corresponding to their work units. In each group, there are members who have visual contact with the coffee maker and others who do not. As a particularity, it should be taken into account that the members of the Mobility group usually coincide when it comes to making the coffee break, while in the other groups, each person usually prepares the coffee individually. Some of the groups have a microwave and refrigerator.

ServGen: It is a workspace that serves as the secretariat of a research center attached to a university in Bilbao. In this space, there are several offices for private use and common rooms where administrative staff works. The coffee machine is placed in one of these spaces. Only one of the workers has direct visual contact with the device.

IIEC: It is a research group related to computer science and education belonging to a university in Madrid where its members are divided into 2 separate offices. Their coffee machine is located inside a working laboratory along with other mechanical machines such as drills and lathes. This laboratory is separated from the two offices, therefore there is no visual contact with the appliance. Hence, it is easy to leave it switched off due to absentmindedness.

Techabout: It is a cabin located in a business incubator of technology-based companies in Bilbao. Being a small room does not have separate spaces and therefore the coffee machine is on top of a piece of furniture in the center of the room. Each of the people who work there has their own table and they all have visual contact with the coffee machine.

Tecnologica: It is a technological company in Madrid with a diaphanous space of about 1500 m² where the workers are grouped in round tables organized by ongoing projects. The space of the coffee machine is separated into an adjoining room that is a full kitchen. In addition to all the appliances that can be found in a conventional kitchen, this space has vending machines. In that place, people can eat or relax because there are tables, sofas, and access to the outside. There are many people in the company who usually have coffee together at the same time.

that the device itself might foster among users, the environment or context where the device will be installed and used, and finally, the behaviour to be promoted. To gather more data and deepening on this research line, a new interactive IoT device (a coaster) was developed by implementing one by one each of the themes extracted from the user perception-based theory. The difficulties of addressing the mapping from theory to design have been pointed out throughout the article. We deem that the endeavour of designing a new device within the premises of the theory has enriched the framework substantially since we demonstrated that it can be applied on a real interactive design. As a future line of work, the evaluation of the effectiveness of the new IoT device will provide new arguments and enhancements over the validity of the themes. We expect designers, engineers, makers or even hobbyists in the intersection between technology-enablers (through IoT) and behavioural scientists to benefit from the presented work.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work has been partially supported by the European Commission through the project HORIZON 2020 (H2020-EE-2015-2-RIA (EE11. New ICT-based solutions for energy efficiency) Grant No: 696129). We gratefully acknowledge the support of the Deustek Research Group under the Grant no.: IT 1078-16 D. We also acknowledge the support of the Spanish government for Sentient Things under Grant no.: TIN2017-90042-R

Appendix B. Transformation from quotes to codes in GT

Table B1

Three samples of the Open coding phase: From the quote, to the intermediate action to the final codes.

Quote	Intermediate Action	Unitary Codes
I have continued to use the coffee maker as I did before and it has not meant any change to how I have used it or even thought about it	* Showing comfort and transparency about the research * Ensuring that he/she has not changed the way the coffee maker is used	* Transparent measurement. * Consistency * No change in conscious habit
To me personally, it has not made me more efficient / conscious with other energy consumption devices	* Ensuring that you have not changed efficiency habits * Showing security when it comes to saying that you have not extrapolated the habit to other devices * There is no self-perception of behavior change with other electrical appliances.	* do not extrapolate * change of non-conscious habit
but now, having the visual stimuli there. Even though there are times we say: "why is it red if we have not done anything" ... then having it invites you ... to say ... uh I'm going to turn it off.	* Attributing to the interaction of the coffee maker the improvement in the efficiency of the group * Showing contrariety to interaction at certain times	* useful interaction * initial disappointment * adaptation

References

- Adams, A., Lunt, P., Cairns, P., 2008. A qualitative approach to HCI research. In: Cairns, P., Cox, A. (Eds.), *Research Methods for Human-Computer Interaction*. Cambridge University Press, Cambridge, UK, pp. 138–157.
- Armstrong, D., Gosling, A., Weinman, J., Marteau, T., 1997. The place of inter-rater reliability in qualitative research: an empirical study. *Sociology* 31 (3), 597–606.
- Arroyo, E., Bonanni, L., Selker, T., 2005. Waterbot: exploring feedback and persuasive techniques at the sink. *Proc. of CHI'05*. ACM, pp. 631–639.
- Atzori, L., Iera, A., Morabito, G., 2014. From "smart objects" to "social objects": the next evolutionary step of the internet of things. *IEEE Commun. Mag.* 52 (1), 97–105.
- Broms, L., Katzeff, C., et al., 2010. Coffee maker patterns and the design of energy feedback artefacts. *Proc. of DIS'10*. ACM, pp. 93–102.
- Brown, N., Stockman, T., 2013. Examining the use of thematic analysis as a tool for informing design of new family communication technologies. *Proceedings of the 27th International BCS Human Computer Interaction Conference*. British Computer Society, pp. 21.
- Brynjarsdóttir, H., Håkansson, M., Baumer, E., DiSalvo, C., Sengers, P., Pierce, James, 2012. Sustainably unpersuaded: how persuasion narrows our vision of sustainability. *Proc. of CHI'12*. ACM, pp. 947–956.
- Casado-Mansilla, D., López-de Armentia, J., Ventura, D., Garaizar, P., López-de Ipiña, D., 2016. Embedding intelligent eco-aware systems within everyday things to increase people's energy awareness. *Soft Comput.* 20 (5), 1695–1711.
- Casado-Mansilla, D., López-De-Armentia, J., Garaizar, P., López-De-Ipiña, D., 2014. To switch the coffee maker or not: that is the question to be energy efficient at work. *Proc. of CHI'14 (E.A.)*. pp. 2425–2430.
- Charmaz, K., 2006. *Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis*. SAGE Publications.
- Charmaz, K., Belgrave, L.L., 2007. *Grounded Theory*. The Blackwell Encyclopedia of Sociology.
- Cialdini, R., 1993. *Influence (rev): The Psychology of Persuasion*. HarperCollins.
- Cowan, B.R., Bowers, C.P., Beale, R., Pinder, C., 2013. The stropy kettle: an intervention to break energy consumption habits. *CHI EA '13*. ACM, pp. 1485–1490.
- De Young, R., 1993. Changing behavior and making it stick. *Environ. Behav.* 25, 485–505.
- DeLongis, A., Hemphill, K.J., Lehman, D.R., 1992. A structured diary methodology for the study of daily events. *Methodological Issues in Applied Social Psychology*. Springer, pp. 83–109.
- Diefenbach, S., Lenz, E., Hassenzahl, M., 2013. An interaction vocabulary. describing the how of interaction. *CHI'13 Extended Abstracts on Human Factors in Computing Systems*. ACM, pp. 607–612.
- DiSalvo, C., Sengers, P., Brynjarsdóttir, H., 2010. Mapping the landscape of sustainable HCI. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, pp. 1975–1984.
- Fogg, B.J., 2003. *Persuasive Technology: Using Computers to Change What We Think and Do*. 18 Morgan Kaufmann Publishers.
- Froehlich, J., Findlater, L., Landay, J., 2010. The design of eco-feedback technology. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, pp. 1999–2008.
- Gao, X.-P., Xin, J.H., 2006. Investigation of human's emotional responses on colors. *Color Res. Appl.* 31 (5), 411–417.
- Glaser, B.G., Strauss, A.L., 2017. *Discovery of Grounded Theory: Strategies for Qualitative Research*. Routledge.
- Gustafsson, A., Gyllenswärd, M., 2005. The power-aware cord: energy awareness through ambient information display. *Extended Abstracts of CHI'05*. ACM, pp. 1423–1426.
- Hardeman, W., Johnston, M., Johnston, D., Bonetti, D., Wareham, N., Kinmonth, A.L., 2002. Application of the theory of planned behaviour in behaviour change interventions: a systematic review. *Psychol. Health* 17 (2), 123–158.
- He, H.A., Greenberg, S., Huang, E.M., 2010. One size does not fit all: applying the transtheoretical model to energy feedback technology design. *CHI '10*. ACM, pp. 927–936.
- Hekler, E.B., Klasnja, P., Froehlich, J.E., Buman, M.P., 2013. Mind the theoretical gap: Interpreting, using, and developing behavioral theory in HCI research. *CHI '13*. ACM, pp. 3307–3316.
- Hermesen, S., Frost, J., Renes, R.J., Kerkhof, P., 2016. Using feedback through digital technology to disrupt and change habitual behavior: a critical review of current literature. *Comput. Hum. Behav.* 57, 61–74.
- Holstius, D., Kembel, J., Hurst, A., Wan, P.-H., Forlizzi, J., 2004. Infotropism: living and robotic plants as interactive displays. *Proceedings of the 5th Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques*. ACM, pp. 215–221.
- Irizar-Arrieta, A., Casado-Mansilla, D., Retegi, A., 2018. Accounting for user diversity in the design for sustainable behaviour in smart offices. *2018 3rd International Conference on Smart and Sustainable Technologies (SpliTech)*. IEEE, pp. 1–6.
- Jönsson, L., Broms, L., Katzeff, C., 2010. Watt-lite: energy statistics made tangible. *Proc. of DIS'10*. ACM, pp. 240–243.
- Kabicher, S., Kriglstein, S., Figl, K., Motschnig-Pitrik, R., 2008. Using eportfolios enhancing for learning through computer-mediated interaction in a course on HCI. *Symposium of the Austrian HCI and Usability Engineering Group*. Springer, pp. 113–124.
- Kappel, K., Grechenig, T., 2009. Show-me: water consumption at a glance to promote water conservation in the shower. *Persuasive '09*. ACM, pp. 1–6.
- Knowles, B., Blair, L., Walker, S., Coulton, P., Thomas, L., Mullagh, L., 2014. Patterns of persuasion for sustainability. *DIS '14*. ACM, pp. 1035–1044.
- Laschke, M., Diefenbach, S., Hassenzahl, M., 2015. "Annoying, but in a nice way": an inquiry into the experience of frictional feedback. *Int. J. Design* 9 (2), 129–140.
- Lockton, D., 2012. Models of the user: designers' perspectives on influencing sustainable behaviour. *J. Design Res.* 10 (1/2), 7.
- Lu, C.-H., 2018. Iot-enabled adaptive context-aware and playful cyber-physical system for everyday energy savings. *IEEE Trans. Hum. Mach. Syst.* 48 (4), 380–391.
- Mansilla, D.C., 2016. *Promoting long term energy-efficient behaviour in work environments through persuasive technologies*. Universidad de Deusto Ph.D. thesis.
- Merton, R.K., Fiske, M., Kendall, P.L., 1990. *The focused interview: a manual of problems and procedures*, second ed. The Free Press.
- Nass, C., Moon, Y., Morkes, J., Kim, E.-Y., Fogg, B., 1997. Computers are social actors: a review of current research. *Hum. Values Design Comput. Technol.* 72, 137–162.
- Nielsen, J., 1994. *Guerrilla HCI: using discount usability engineering to penetrate the intimidation barrier*. *Cost-Justifying Usability*. pp. 245–272.
- Nilsson, A., Bergquist, M., Schultz, W.P., 2017. Spillover effects in environmental behaviors, across time and context: a review and research agenda. *Environ. Educ. Res.* 23 (4), 573–589.
- Nipkow, J., Bush, E., Josephy, B., Pilon, A., 2011. For a tasty but efficient coffee. *Proc. of ECEEE 11*, 1453–1470.
- Pereira, L., Quintal, F., Barreto, M., Nunes, N.J., 2013. Understanding the limitations of eco-feedback: a one-year long-term study. *International Workshop on Human-Computer Interaction and Knowledge Discovery in Complex, Unstructured, Big Data*. Springer, pp. 237–255.
- Peschiera, G., Taylor, J.E., Siegel, J.A., 2010. Response-relapse patterns of building occupant electricity consumption following exposure to personal, contextualized and occupant peer network utilization data. *Energy Build.* 42 (8), 1329–1336.
- Petkov, P., Goswami, S., Köbler, F., Krmar, H., 2012. Personalised eco-feedback as a design technique for motivating energy saving behaviour at home. *Proceedings of the 7th Nordic Conference on Human-Computer Interaction: Making Sense Through Design*. ACM, pp. 587–596.
- Pierce, J., Odom, W., Blevins, E., 2008. Energy aware dwelling: a critical survey of interaction design for eco-visualizations. *Proceedings of the 20th Australasian Conference on Computer-Human Interaction: Designing for Habitus and Habitat*. ACM, pp. 1–8.
- Pierce, J., Paulos, E., 2012. Beyond energy monitors: interaction, energy, and emerging energy systems. *Proc. of CHI'12*. ACM, pp. 665–674.
- Quintal, F., Barreto, M., Luis, F., Baptista, V., Esteves, A., 2017. Studying the immediacy of eco-feedback through plug level consumption information. *2017 Sustainable Internet and ICT for Sustainability (SustainIT)*. IEEE, pp. 1–4.
- Reeves, B., Nass, C.L., 1996. *The media equation: how people treat computers, television,*

- and new media like real people and places. Cambridge university press.
- Slack, M.K., et al., 2001. Establishing the internal and external validity of experimental studies. *Am. J. Health Syst. Pharm.* 58 (22), 2173–2181.
- Thieme, A., Comber, R., Miebach, J., Weeden, J., Kraemer, N., Lawson, S., Olivier, P., 2012. We've bin watching you": designing for reflection and social persuasion to promote sustainable lifestyles. *Proc. of CHI'12*. ACM, pp. 2337–2346.
- Valdez, P., Mehrabian, A., 1994. Effects of color on emotions. *J. Exp. Psychol.* 123 (4), 394.
- Ventura, D., Casado-Mansilla, D., López-de Armentia, J., Garaizar, P., López-de Ipina, D., Catania, V., 2014. Ariima: a real IoT implementation of a machine-learning architecture for reducing energy consumption. *International Conference on Ubiquitous Computing and Ambient Intelligence*. Springer, pp. 444–451.

*Even the moon is only poetical
because there is a man in the moon.*

G. K. Chesterton, *The Man Who Was Thursday*


CHAPTER 5

Exploring the Application
of the FOX Model to Foster
Pro-Environmental behaviours
in Smart Environments



Article

Exploring the Application of the FOX Model to Foster Pro-Environmental Behaviours in Smart Environments [†]

Ane Irizar-Arrieta ^{1,*} , Diego Casado-Mansilla ¹ , Aiur Retegi ², Matthias Laschke ³ and Diego López-de-Ipiña ¹ 

¹ DeustoTech, University of Deusto, Avda. Universidades 24, 48007 Bilbao, Spain; dcasado@deusto.es (D.C.-M.); dipina@deusto.es (D.L.-d.-I.)

² Engineering Faculty, University of Deusto, Avda. Universidades 24, 48007 Bilbao, Spain; aiur.retegi@deusto.es

³ Ubiquitous Design, Universität Siegen, 15, 57072 Kohlbettstraße Siegen, NRW, Germany; matthias.laschke@uni-siegen.de

* Correspondence: ane.irizar@deusto.es

[†] This manuscript is an extended version of the conference paper “FOX: A Flexible and Heterogeneous Mixed User Model to Address Sustainable Behaviour in Smart Environments” presented at the 13th International Conference on Ubiquitous Computing and Ambient Intelligence UCAmI 2019, Toledo, Spain, 2–5 December 2019.

Received: 30 June 2020; Accepted: 11 August 2020; Published: 14 August 2020



Abstract: The heterogeneity and dynamism of people make addressing user diversity and its categorisation critical factors, which should be carefully considered when developing pro-environmental strategies and interventions. Nevertheless, the complexities of individuals complicates the creation of modelling and classification systems. The aforementioned issue opens a research opportunity, which should be tackled to improve the development of human-centric systems and processes. Throughout the present piece of research, our objective is to bridge that gap by extracting knowledge and insights relating to how to address user diversity when designing technologies considering sustainable behaviour. For this, we explore the possibilities of the FOX model—an early meta-model to approach the diversity of individuals when addressing pro-environmental behaviour—to classify and understand individuals while taking their heterogeneity into account. After introducing the model, a qualitative survey of eight experts is conducted. From this study, relevant findings are analysed and exposed. Taking into account the gathered knowledge, three user profiles are developed, based on the dimensions proposed by the model. Furthermore, scenarios are created for each profile, presenting three case studies where different application modes of the model are described (personalised interventions, prediction and forecasting, and individual and collective interventions). Finally, the extracted findings are analysed, discussing the main issues related to the development of pro-environmental technologies and systems.

Keywords: sustainable behaviour change; human–computer interaction; design for sustainable behaviour; user modelling; behavioural theories; smart environments

1. Introduction

Due to the increasing relevance of sustainability, environmental impact has become a critically relevant issue in the development of technologies, particularly in the field of smart environments and cities [1]. In this context, the present paper offers a continuation of a previous conference paper [2], aimed at addressing the human factor in the context of sustainable person-centric technological systems. Following the approach of Mankoff et al. [3], sustainability can be described through two

main conceptualisations: (1) sustainability in design, which is related to the optimisation of the materials and processes of the associated hardware and software; and (2) sustainability through design, which refers to influencing sustainable lifestyles and the decisions of individuals. In this line, Sustainable Human–Computer Interaction (SHCI) [4] aims to enhance the environmental impact of technologies addressing the human factor. Hence, SHCI considers the relations and interactions of the individual with digital/physical systems or technologies to improve sustainability [4]. Therefore, user interactions and behaviours are analysed to (1) better understand how to face the challenges derived from the human factor; and (2) enhance the management of technological devices, systems, and processes, in order to minimise their impacts on the environment. This is a paramount factor in human-centred intelligent environments [5], where actions are usually recognised to adapt interventions and to offer feedback related to the characteristics and needs of people. Therefore, it seems necessary to assume the complexity of the individual and to understand the different issues that may influence his/her behaviours and actions. [6] In essence, the study of the diversity of individuals emerges as a relevant requirement. In this context, the fact that people are different from each other may be critical. Nevertheless, individuals themselves also differ, depending on the context and due to many various factors (e.g., an individual with the habit of always taking the stairs, instead of the lift, may change this behaviour due to a temporary injury). As Hekler et al. stated, to influence sustainability in people, behavioural theories must be taken into account [7]. Therefore, heterogeneity may be studied as a flexible and dynamic attribute to face the contextual barriers and uncertainties that could influence individual actions and behaviours. For that, as mentioned previously, this paper follows a previous research piece [2], in which the FOX model (an early meta-model to face heterogeneity understanding the behavioural constructs and dimensions) was introduced and explained. This model was created after discovering the need for implementing more flexible and multidimensional user characterisations [8,9]. In the present paper, this research work is continued, exploring the potential applications of the model and applying it to the development of user profiles and scenarios.

1.1. Applied Research Methods

In the following, the research approach followed in this work is explained, together with the tools and specific methodologies that are applied in this work. Figure 1 exposes the workflow and the different stages of the research process followed in this paper. The phases of the present work were followed in a linear and sequential way. However, in order to extract more information and to refine the results and insights, more iterations may be needed. This will be addressed in future research work, in order to improve and validate the findings exposed in the present paper.

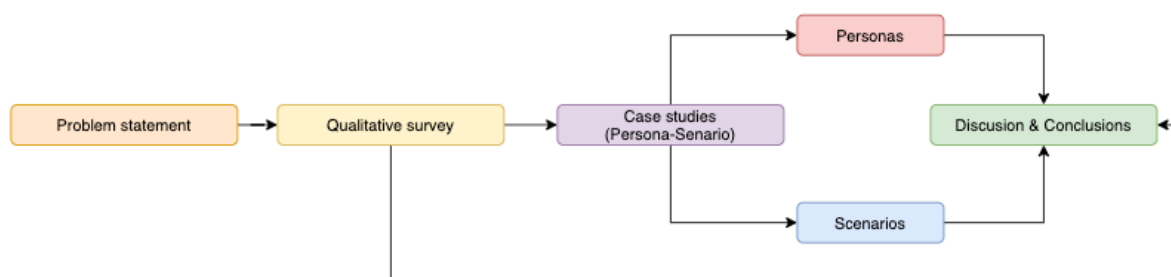


Figure 1. The steps of the research methodology followed in the present work.

Problem statement. The first step of the process starts with the definition of the problem and the research question. As the main objective is to gain knowledge on the potential applications of the FOX model, the research question arose as: How can the FOX model be applied? The complementary

objective of this paper is based on gaining understanding on other relevant implications of the FOX model (i.e., improvements, shortcomings, application context, and so on).

Experimental design: qualitative survey and case studies. In order to answer the research question and to reach complementary objectives, the experimental design was centred on the analysis of the FOX model and its implications, in relation to the diversity of individuals. For that purpose, qualitative tools were selected, in order to gather rich insights and other promising information. Following the ideas exposed in a previous work [10], where the relevance of online survey tools was explained, these kinds of tools promote a user centred approach. Besides, although ethical considerations must be taken into account [10], this methodology offers a flexible and affordable method for data gathering. In addition, the importance of online surveys was already exposed by Evans and Mathur [11], providing information for approaching practical implications. The objectives of the qualitative survey were: (1) to test if the model is easily comprehensible by researchers and practitioners; (2) to discover if the FOX model is applicable in the context of smart environments; (3) to understand how and why it can be applied in those elicited contexts; and (4) to extract additional improvements and insights. This study was conducted with experts in the computer science field, and as all of the participants were already familiar with the model, it was decided to implement an online survey as a method for qualitative data gathering, following the ideas exposed by the previously mentioned research works. As the participants were used to working with the Google Suite, this survey was conducted through an online Google form, in order to provide an easy and affordable means for information collection.

Aiming at exploring how the model can be applied and to better understand the target users in their context, three qualitative case studies were developed. Following the approach of Schwandt and Gates, there is no single definition of “case study” when trying to understand the behavioural implications of individuals [12]. Besides, the authors ensured that there were considerable variations across disciplines. Taking this into account, in this paper, the definition of Schwandt and Gates is used; that is, understanding a case study as a detailed description and analysis of any specific issue, being a method widely used to perform qualitative research [12].

For the development, the Persona-Scenario method [13] was applied. This procedure integrates the Persona method with scenario building. Persona [14,15] is a common methodology in the field of HCI, which is intended to define user archetypes. It aims at envisaging a real individual, in order to gain an understanding of target users. It provides an idealisation of any given user profile, including all the relevant elements to understand the main attributes, lifestyle, emotions, feelings, and other relevant information. This tool is useful to define and visualise individuals, in relation to any given context. A recent study explored the utilisation of this tool to increase the creativity in ideation processes [16]. Hence, by developing Personas, the profile of an individual can be understood and envisaged in more depth. This is in line with the approach followed by He et al. [17] when describing the application of the transtheoretical model [18], a behavioural model to foster pro-environmentalism, and with the approach of Coskun et al. [19] when exploring user diversity. In addition, the description of the preferences and other relevant insights helps researchers and practitioners to understand better how any given intervention would be received by the potential users. The creation of scenarios is the next step of the Persona-Scenario method, which involves the exploration of the performance of the Personas in any specific context and/or system. This tool helps to envisage how any system or framework, in the context of the Personas, would work and to identify potential design problems in early stages. To better understand this behaviour, the scenarios are built using storytelling techniques, following the findings of Madsen and Nielsen [20,21]. For this, the Personas and scenarios are described as short histories, in order to better envisage the insights and implications emerging from the Personas and their interactions with the context and the system.

The paper is structured as follows: Section 2 analyses the state-of-the-art by describing the most relevant theoretical frameworks for understanding behavioural processes. Other approaches that are

relevant to addressing the user diversity for sustainable behaviour are also exposed. In Section 3, the FOX model is briefly introduced to contextualise and frame the involved dimensions. In Section 4, a qualitative study to explore the potential applications of the model is exposed. Taking into account the extracted insights, three user profiles and their use contexts are described, applying the FOX model to frame them. The objective is to understand how a potential user would behave in three stereotypical contexts, according to the model. In Section 6, the results and findings are discussed, exposing relevant insights. Finally, the conclusions extracted from the research work are summarised and future research lines defined.

2. Background

In this section, the state-of-the-art is described, in order to analyse the most relevant works related to the research presented in this paper. Different approaches to cope with the decision-making process have been examined in the existing literature. In fact, Coskun et al. conducted an extensive review on the design of sustainability and behaviour change [22]. A recent work overviewed the main studies in relation to behavioural technologies [23], highlighting the need to address the heterogeneity of individuals when developing pro-environmental strategies in the conclusions. In order to frame the theoretical context, first, we expose behaviour change models applied to sustainability. Then, other complementary user models and characterisations are described, including other studies that may provide indirect, but valuable, background. Finally, the conclusions of the analysis are summarised, in order to better frame the contribution that this work provides to the research community.

2.1. Theoretical Frameworks of Sustainable Behaviour Change

In order to frame the relevant ideas that contextualise the present work, three relevant behavioural models that offer different approaches to frame the actions of individuals are highlighted.

Transtheoretical Model (TTM): The TTM [18] is a longitudinal model that analyses the process of change, in order to understand how it happens. It divides behavioural change into six stages: pre-contemplation, contemplation, preparation, action, maintenance, and termination. This behaviour model has been applied to boost sustainable actions and lifestyles by some scholars: He et al. [17] developed one user archetype based on this model and specific strategies to boost pro-environmental behaviour in the different stages of change; Wising, Chirez, and Adams [24] proposed a work using TTM to enhance industrial energy efficiency targeting the change of the energy culture; and in a recent work, Xiao studied how to motivate consumers in the context of sustainability by applying the TTM [25].

The theory of Values-Beliefs-Norms (VBN): VBN is a theoretical framework for sustainable behaviour based on values and norm-activation processes. The main idea of VBN is that individuals who accept a movement's basic values believe that the valued objects are threatened. Due to this, they trust that their actions can help to restore those values and experience an obligation (personal norm) for pro-movement action, which creates a predisposition to contributing and/or giving support at different levels [26]. The values are intrinsic to the individual, but they may be aligned with the environmentalism and develop increasing beliefs that end up in the development of a pro-environmental personal norm. Beliefs appear with the acceptance of the fact that human actions harm the environment. The next step is to be aware of the consequences, followed by the ascription of responsibility. Next, the norm will be created, and the individual adopts behaviours and actions according to this norm. This approach was refined later by Stern et al. [27]. Petkov et al. applied this model in the context of pro-environmental technologies and developed a study addressing specific personalised interventions for different user types, depending on the different values outlined by Stern's theory [28].

The Theory of Planned Behaviour (TPB): The TPB [29] is a conceptual theory that addresses intentions as the immediate antecedent of behaviour. These intentions are influenced by beliefs, attitudes,

and behavioural control (the perceived self-efficacy over a specific action). This framework helps to understand how people's behaviour can be changed or tailored with a series of predictable aspects that can influence their intended conduct. This framework has been applied to the pro-environmental context by Coskun and Erburg, in order to face the diversity of individuals in relation to sustainable behaviour [6] by developing user profiles. Furthermore, Greaves, Zibarras, and Stride analysed intentions in relation to sustainability using TPB theory, in the workplace context [30].

2.2. Existing User Models and Characterisations in the Context of Pro-Environmentalism

In addition to behaviour change models, some studies have explored user diversity to understand how the individuals behave. In this way, Lockton et al. developed user profiles for sustainable behaviour, taking into account the differences in behavioural traits by defining the Pinball, Shortcut, and Thoughtful user types, based on the different models of the human system [31]. Coskun and Erburg proposed another categorisation based on the TPB [19] and identified four personas in the context of the sustainability [6]. Petkov et al. [28] applied the VBN to develop a user categorisation to implement personalised eco-feedback. Moreover, He et al. [17] used the TTM for the same purpose. Cor and Zwolinski identified two types of individuals using questionnaires to measure key factors [32]. Lilley, Bailey, and Charnley developed Personas [14] focusing on the self-repair behaviour, among other factors [33]. Halko and Kientz addressed the differences in individual personalities concerning behaviour change techniques [34]; while Kaptein, Lacroix, and Saini developed profiles based on the persuasion level [35]. In a later work, they continued investigating within the field of persuasive technologies, exposing that these can be more effective if they are personalised [36]. Table 1 summarises the main idea of each proposal.

Table 1. Existing user models and characterisations in the context of pro-environmentalism. TTM, Transtheoretical Model; VBN, Values-Beliefs-Norms.

Authors	Description and Key Points
He et al., 2010 [17]	Application of TTM to define interventions for one specific Persona.
Halko and Kientz, 2010 [34]	Understanding differences in personality, in relation to behavioural techniques.
Kaptein, Lacroix, and Saini, 2010 [35]	User profiles linked with the persuasive level and personalised inputs.
Lockton et al., 2012 [31]	Definition of three user profiles in relation to behavioural traits.
Petkov et al., 2012 [28]	Application of VBN, identifying profiles to address personalisation.
Lilley, Bailey, and Charnley, 2013 [33]	Development of three Personas and specific strategies for them.
Cor and Zwolinski, 2014 [32]	Identification of two types of individuals to set design interventions.
Coskun and Erburg, 2016 [19]	Identification of four personas based on the TPB.

2.3. Other Approaches to Sustainable Behaviour

Design for Sustainable Behaviour (DfSB) [37] seeks to minimise environmental impact by framing people's behaviour. Although not specifically focused on user diversity, Michie proposed strategies and techniques for addressing pro-environmentalism, further defining a taxonomy of techniques [38]. In addition, the same author explored the relation of behaviour change techniques with behavioural determinants [39], proposing the Behaviour Change Wheel (BCW) [40], a tool that groups 19 frameworks of behaviour change. The Theoretical Domain Framework (TDF) [41] sets an in-depth analysis of individual behaviours. This model has been applied to foster recycling behaviours [42]. Following the idea of understanding individuals better, Morgan et al. analysed the role of co-design in a large organisation [43]. They exposed ideas extracted from user studies and developed an early prototype to enhance energy efficiency in the workplace. Other related work was proposed by Yun, Aziz, and Lasternas [44], who explored the online feedback and control strategies for sustainability in the work environment. Finally, the work proposed by Bao et al. [45,46] explored the impact of quantitative and emotional

feedback, highlighting the relevance of providing both feedback types. Table 2 shows the key points of the exposed works.

Table 2. Other approaches to sustainable behaviour. DfSB, Design for Sustainable Behaviour; BCW, Behaviour Change Wheel; TDF, Theoretical Domain Framework.

Authors	Description and Key Points
Michie, 2008 [39]	Exploration of behaviour change techniques with behaviour determinants.
Lilley, 2009 [37]	Definition of DfSB, a framework to address behavioural interventions.
Michie, 2011 [38], Michie, 2011 [40]	Definition of a taxonomy of behaviour change techniques. Development of BCW, a tool to select the best behavioural strategy.
Gainforth, 2016 [42]	Application of TDF to foster recycling behaviours.
Bao et al., 2016 [46]	Analysis of quantitative and emotional eco-feedback.
Atkins, 2017 [41]	Definition of TDF, a framework addressing behaviours of individuals.
Yun, Aziz, and Lasternas, 2017 [44]	Analysis of online feedback and control strategies in the workplace context.
Morgan et al., 2018 [43]	Research work about co-design in a large organisation to boost sustainability.
Bao et al., 2019 [45]	Analysis of emotional eco-feedback.

2.4. Insights Extracted from the Literature Analysis

After the review of the related work, some conclusions can be highlighted, in order to guide research into how to better understand the human factor to influence sustainable lifestyles and actions. Following the statement of Coskun and Erburg [19], there is no standard method to explore user heterogeneity, and it is complicated to extract valid knowledge. Each author applied a different approach with specific criteria in a specific context. Thus, it can be difficult to extrapolate knowledge and to further analyse the impacts of these proposals. Moreover, most of the proposals are based on a single dimension of the user. Therefore, the application of existing taxonomies may lead to several shortcomings, derived from the narrow view due to the lack of understanding of the different factors that influence the individual [7]. Finally, the difficulty of finding a dynamic categorisation of the users in the literature presents a major gap that should be tackled, in order to improve the understanding of individuals in every context.

3. The Proposed FOX Model

The FOX model [2] offers a framework in which the most relevant approaches to change behaviour are included, maintaining the original relations and meanings of different constructs and dimensions, while offering a general perspective on the key elements to cope with user diversity in the context of pro-environmental behaviour. This early model has been developed to be dynamic; that is, the end-user categorisation can be updated throughout time when changes in the individuals are detected. Furthermore, the model is also flexible. Thus, the dimensions of behaviour can be complemented with others (e.g., demographics) and can be prioritised, structured, and organised depending on the requirements of the application context. Nevertheless, the relations of the different dimensions of current models of behaviour change and the overall structure of these models should be taken into account, in order to avoid shortcomings. To improve the understanding of terminology, it should be clarified that the different elements involved in the behavioural theories and frameworks are called Constructs. On the other hand, the elements that compound the user meta-model are called Dimensions, which are based on the behavioural constructs in most cases. These dimensions are understood in the context of behavioural technologies addressed to enhancing awareness towards sustainable behaviour. Taking into account the analysis of the state-of-the-art, the frameworks were selected in relation to their complementary nature, selecting those that could be complemented with others, aiming at providing a more detailed conceptualisation of individuals. Another relevant factor to select the dimensions for the meta-model is related to its application to the context. All selected theoretical models have been previously applied

for framing sustainable behaviour. This ensures the suitability and relevance of the selected dimensions, in relation to pro-environmentalism.

In the following subsections, the mapping of the model is explained, and the different dimensions are introduced. More detailed explanations can be found in the previous research work [2].

3.1. Mapping the Dimensions: The Meta-Model

The dimensions are mapped into a novel meta-model that combines the behavioural approaches found in the literature. Mixing and linking the most common theoretical models and user classifications may help to avoid a narrow perspective of each individual model by offering a more complex way to understand the behaviour. As exposed previously, different behavioural models complement each other, addressing the complexity of individuals. To better connect different items, Figure 2 illustrates the links through arrows. Following this idea, each dimension complements the others and reinforces the different approaches proposed by the theoretical frameworks.

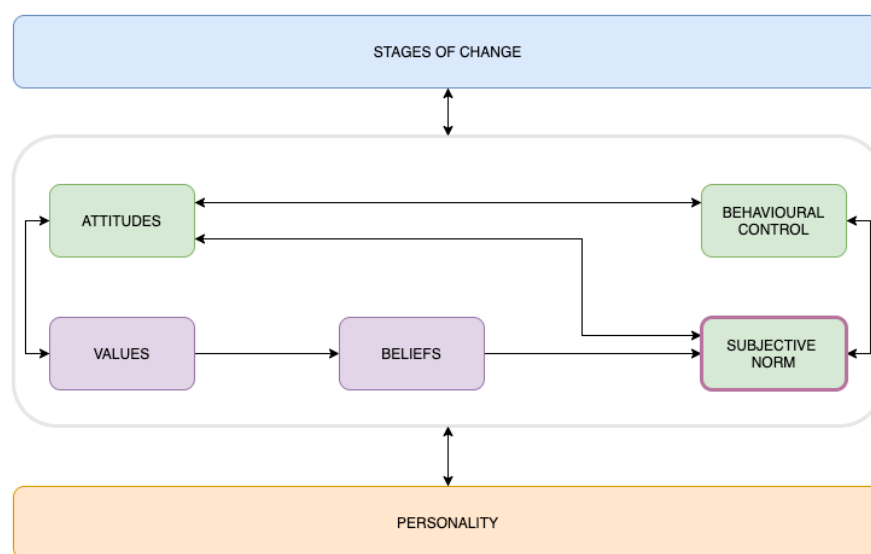


Figure 2. The FOX model, with the involved dimensions and relations.

3.2. Stages of Change

The TTM approaches the behavioural process by taking into account the stages of change over time [18]. Thus, Stages of Change are included in the model as a whole dimension of the user, where the phases are understood as the elements of this dimension. Following the pro-environmental approach proposed by He et al. [17], the stages of change are classified as: (1) pre-contemplation: the user has no intention to take action in the next six months; (2) contemplation: the individual intends to take action in the next six months; (3) preparation: the individual intends to take action within the next month and has taken behavioural steps to face it; (4) action: significant changes in behaviour within the past six months; and (5) maintenance and relapse: besides significant changes in the behaviour for more than six months, the person tries to sustain the acquired actions and to prevent relapse.

3.3. Personality

When developing behavioural technologies, the diversity among individuals with similar contexts, values, and habits (e.g., siblings or friends) implies a differential factor. Thus, diverse personalities can

be determined by the acceptance and adoption of inputs. In this context, the characterisation proposed by Lockton et al. [31,47] fits well, due to the understanding of behaviour by approaching personality. This author identified three user types: (1) Shortcut users are human models that regulate their behaviour and are understood as narrowly rational users, making choices to minimise energy or cognitive expenditure; (2) Pinball users are linear human systems, implying a user who only reacts simply to inputs and does not think about any decisions; and (3) Thoughtful individuals are learning human systems—people who analytically think about what they are doing and why, being able to set and modify their own goals.

3.4. Attitudes

Following the ideas of the TPB, behavioural beliefs produce a favourable or unfavourable attitude toward behaviour, which changes dynamically depending on the situation and the behavioural values [48]. Attitudes are categorised incrementally, as follows: (1) No Environmental Attitude—the individual does not see benefits or immediate positive impact on sustainable behaviour; (2) Low Environmental Attitude—the individual thinks that a pro-environmental attitude may be positive, but does not see its benefits or its immediate positive impact. Besides, he/she may perceive several barriers; (3) Medium Environmental Attitude—the individual thinks that a pro-environmental attitude is positive, but perceives several barriers that obscure fully positive beliefs towards his/her behaviour change; and (4) High Environmental Attitude—the individual's beliefs towards sustainable behaviour are at the maximum level, believing that a pro-environmental attitude is very positive.

3.5. Behavioural Control

Behavioural control is another construct proposed by the TPB, which is linked with the control beliefs of the user towards the specific target behaviour [48]. The classification proposed for this dimension is: (1) No Behavioural Control—the user perceives that they have no control over a specific behaviour; (2) Low Behavioural Control—the user thinks that the desired behaviour is difficult and that there are many barriers to carrying out the desired action or behaviour; (3) Medium Behavioural Control—the user thinks that it is not difficult, nor easy to achieve the target behaviour and that some barriers make the change difficult; and (4) High Behavioural Control—the user perceives that the target behaviour is easy and affordable.

3.6. Subjective Norm

The subjective norm is based on how sustainable behaviour is perceived by the individual and his/her context. It is related to the internal rules of the individual and his/her context. In this way, the Subjective Norm dimension is categorised as: (1) No Subjective Norm—the individual does not have subjective rules about pro-environmental behaviour and has neither internal, nor external pressure to adopt it; (2) Low Subjective Norm—the individual feels that pro-environmental behaviour is not a bad idea, but it does not feel important in his/her own life, due to the absence of a personal or social norm; (3) Medium Subjective Norm—the individual feels that pro-environmental behaviour is a positive idea, but is not fully convinced and feels relaxed about the need to adopt the behaviour; and (4) High Subjective Norm—the individual feels that pro-environmental behaviour is an obligation, due to social and personal rules.

3.7. Values

Values are a dimension extracted from the VBN theory, which involves a user's personal concerns related to sustainability. Stern's paradigm proposes four types of values [27]. Nevertheless, according to Petkov et al., values alone are not enough to boost behaviour change [28]; therefore, this dimension should be complemented with others. The classification for this dimension is: (1) Altruistic—these values are

focused on avoiding threats for other people; thus, altruistic individuals are those who care about others and equality; (2) Egoistic—these values are related to the needs and wants of the individual (e.g., their gains and losses); (3) Traditional—values related to security and to maintaining the current status to preserve habits and traditions; and (4) Openness to change—values related to curiosity, involving individuals who are interested in different problems such as sustainability.

3.8. Beliefs

Beliefs are the last dimension extracted from the VBN, which involve the concerns related to the effects of human activity on the environment [27]. These are derived from values, following the idea that things relevant to those values are under threat. The categories are: (1) Conscious—this category involves the beliefs of the individuals who accept a new ecological paradigm; (2) Aware—this category classifies individuals who are aware of the adverse consequences for valued objects due to environmental problems; and (3) Responsible—this category involves individuals that perceive their ability to reduce the threat and, therefore, are more willing to take action and adopt sustainable behaviours.

4. Exploring Potential Applications of FOX

The FOX model is promising and based on other scientific contributions, but still needs to be validated, in order to demonstrate its contribution towards human–environment interaction solutions promoting sustainability. As a theoretical framework, its potential applications are diverse and can vary over time. Thus, in order to better understand the potential possibilities that this model can offer, an early study involving experts in the field of smart environments was carried out.

4.1. Procedure

For the development of this study, several steps were performed. First, a group of eight researchers and practitioners in the field of computer science and smart environments was selected. Recruitment was carried out by asking colleagues for voluntary participation. As the approach of this study is qualitative and exploratory, different degrees of expertise and experience were not differentiated. Due the nature of the survey, the researchers considered all kind of ideas to be welcome. Therefore, the next step was to define the method to extract the required information. As most of the participants were already familiar with the model, implementing an online survey as a method for qualitative data gathering was decided. This survey was conducted through an online Google form. For this, after introducing the FOX model, some open questions were asked about the potential applications of the framework. Taking into account the exploratory nature of the study and in order to encourage reflective answers from participants, the questions were short, general, and open, inviting individuals to explain their ideas in detail.

4.2. Results and Insights

After the implementation of the questionnaire, the responses were analysed and reviewed. From the gathered information, some promising ideas and relevant issues that may improve the development of the model could be extracted. In the following, the insights of each participant are described. Then, the findings are analysed, exposing the main conclusions of the study. Figure 3 shows a sample of the obtained results. The gathered data are publicly accessible. (all of the raw data are hosted and available at the following URL: shorturl.at/hANZ8) All of the respondents to the survey confirmed that the model was applicable in their field of work (e.g., Internet of Things, demand response, blockchain, or ambient assisted living). Thus, the obtained information was rich, varied, and diverse. In the following, the most relevant quotes from each participant are provided.

What is your main expertise?	Do you think the model is applicable?	How and why would you apply it? Please, take your time and try to explain your ideas in detail	Does it have more than one application? Can you please give us a list of which ones do you envisage?	What do you think is the main potential of the model?	How would you improve/extend the model according to your research field?	Rate the potential application of the model from 1 to 10	Any other comments or suggestions we can have to improve the model?
Artificial Intelligence	Yes	I work in the research of health-related AI applications. In several of our projects we model and analyze the behaviour of the patients to detect the early risks related to several pathologies. Once we detect a risk and identify the behaviours that cause it we propose interventions to address them. These interventions are in several cases aimed to change those behaviours. When proposing the interventions, we usually have to tackle two problems. First, we need to identify which intervention is better for the specific patient pathologies and the detected risks. Then, we need to formulate an adequate strategy for the patient to accept the intervention and adhere to the proposed changes. I think that the FOX model could be useful for this second step. It could be used to define which are the best strategies for each user depending on their psychological, cognitive and behavioural profiles.	In my field it would be mainly used for the interventions to address health risks.	The identification of the best strategy for behaviour change for each person.	Right now, the model is mainly focused on sustainability and it would need to be adapted to the health domain. It would also need to include things like what are the patient's preferences regarding their treatments (i.e. some patients may prefer a higher QoL while living a shorter period of time) and the patients capabilities (i.e. some patients may have reduced cognitive capabilities due to several circumstances, so the strategies would need to be adapted accordingly). The model would need the flexibility to be adapted to different pathologies (i.e. is not the same to work with elders, cancer patients or patients with multimorbidities).	9	
Researcher at ICT in education	Yes	Personalised environment during playing an educational game where gender, culture, personality etc. will be taken into account.	Personalised learning path, educational platform dropout prevention, engagement to online educational material, multicultural education.	Providing an environment that does not exclude anyone and the diversity is taken into account in a positive way and also changes dynamically is the main asset of the model IMO.	I would add some dimensions related to student's specific behaviour and characteristics.	10	I understood that the aim of the model is the inclusion of all users but I would be very careful with the fact that maybe characteristics such as race, gender etc. exclude users from several aspects and might become at some cases a biased model.

Figure 3. A sample of raw data obtained from the qualitative study.

4.2.1. Interviewee 1: Male, Post-Doctoral Researcher in Health-Related Artificial Intelligence Applications

For Interviewee 1, the main application of the model would be to implement personalised interventions to address health risks: *“When proposing the interventions, we usually have to tackle two problems. First, we need to identify which intervention is better for the specific patient pathologies and the detected risks. Then, we need to formulate an adequate strategy for the patient to accept the intervention and adhere to the proposed changes. I think that the FOX model could be useful for this second step. It could be used to define which are the best strategies for each user depending on their psychological, cognitive and behavioural profiles”*. Thus, the main potential of the model would be identification of the best strategy for behavioural change for each person. In relation to improvements, the main issues were related to the adaptation of the model to the health domain: *“It would also need to include things like what are the patient’s preferences regarding their treatments (i.e., some patients may prefer a higher quality of life while living a shorter period of time) and the patients’ capabilities (i.e., some patients may have reduced cognitive capabilities due to several circumstances, so the strategies would need to be adapted accordingly). The model would need the flexibility to be adapted to different pathologies (i.e., is not the same to work with elders, cancer patients or patients with multimorbidities)”*.

4.2.2. Interviewee 2: Female, Pre-Doctoral Researcher in the Field of ICT in Education

For this person, the model could be applied to implement a *“personalised environment during playing an educational game where gender, culture, personality etc. will be taken into account”*. Other relevant application fields were also related to the educational domain: personalised learning path, educational platform dropout prevention, engagement with online educational material, and multicultural education. Regarding the main potential, in the respondent’s words: *“providing an environment that does not exclude anyone and the diversity is taken into account in a positive way and also changes dynamically is the main asset of the model”*. Regarding the improvements, she *“would add some dimensions related to student’s specific behaviour and characteristics”*. Furthermore, this participant added a relevant suggestion that should be taken into consideration: *“I understood that the aim of the model is the inclusion of all users but I would be very careful with the fact that maybe characteristics such as race, gender etc. exclude users from several aspects and might become at some cases a biased model”*.

4.2.3. Interviewee 3: Male, Post-Graduate Student in Computer Science and Research Assistant in an H2020 Project Related to Energy Efficiency

The main application of the FOX model for this respondent was related to *“evaluating behaviour change interventions in work environments, such as offering food menus that include less animal meat or none at all”*. Any other applications would include similar measures or strategies that expose the individual to improve their pro-environmental behaviour. Thus, the main potential of the model was *“knowing how to help each person adopt pro-environmental behaviours without excessive profiling”*.

4.2.4. Interviewee 4: Male, Researcher in the Field of Energy Efficiency

For this respondent, the application was related to energy efficiency: *“We will use the variables of the FOX model as external inputs in a causal model that will try to explain the motivations that will push a person to participate in different actions related to the use of energy. We will do so because it provides a comprehensive description of the psychological aspects that could explain the behaviour observed”*. Besides, he believed that this model can be applied in different contexts: *“we are going to assess 5 aspects: usage of energy, participation on energy efficiency or demand response actions, installation of distributed generation and the electrification of services”*. For this participant, the main potential of the proposed framework was the understanding that it offers regarding the psychological aspects of any given behaviour. Nevertheless, this participant set a relevant challenge, as *“it is difficult to define interventions (artificially set a variable to a value) according to the model”*, providing a research question to address in future work: *“Have you studied how to foster the change from one category to other in each of the variables?”*.

4.2.5. Interviewee 5: Male, Researcher in the Field of the Internet of Things and Human-Computer Interaction

The fifth participant also thought that that FOX model was applicable in his field of work. In his own words: *“In my research I have to model users to understand what are their motivations to follow external guidelines or signals coming from “demand response systems” or “smart grids” to change their typical load of energy consumption. Therefore, this categorisation seems to be relevant to understand the family unit as a whole instead of individuals. I might incorporate some ideas from FOX to better understand the intrinsic and extrinsic motivations to behave in an efficient way when managing energy or to be in line with energy/load signalling”*. Regarding other possible applications of the model, the interviewee suggested the following: *“Yes, besides the energy sector. I think that the model would be beneficial in any vertical application in which the user is involved. For example, sustainable mobility, recycling, e-government or participation in citizen services”*. For this person, the main potential of the model is its versatility. Nevertheless, a relevant issue emerged from his following insight: *“Let me say also the main drawback I see. I struggle to imagine how to capture/measure in real time all the factors to infer the status of each of the constructs involved in FOX”*. This idea is in line with the answer related to improvements. The participant stated that he would improve or extend the model by *“defining factors and explicit measurements to derive the levels under each construct. I guess that questionnaires may work at the initial stage. But what if things changes dramatically? How can a system detect that? What are the implications about privacy? How the user grant access to their information to draw over its behaviour to detect the stage in which he/she is?”*.

4.2.6. Interviewee 6: Male, Researcher in the Field of Artificial Intelligence Applied to Natural Language Processing and Activity Recognition

For this participant, *“In the area of active ageing, one of the objectives is to promote active ageing through a series of interventions in areas where the patient is falling behind or is beginning to show signs of problems (lack of socialisation, exercise, cognitive decline). Therefore, if these interventions could be further refined in order to provoke a more positive reception by the user in accordance with his or her profile, this would be of great help”*. Besides, for this

individual, the model also could be applied *“when designing any intervention in any user/patient. That is, we can set some generic interventions but FOX could help to further refine those interventions so that they have more effect on users through ad-hoc recommendations. No matter the scope, I am focusing on active ageing but surely it can be applied to other types of users such as patients with a particular disease, children for education, etc.”*. For him, the main potential of the model was *“the facilitation of modelling different types of users taking into account aspects that are key to achieving a change in someone’s behaviour”*. Taking into account these ideas, the insights gathered in relation to improvements or difficulties were according to measurements and rules to classify users: *“What I find difficult when applying it to my field is how to classify each of the users in those dimensions. It would be interesting to be able to collect this information in the least intrusive way possible (questionnaires that are not tedious, hidden questions)”*.

4.2.7. Interviewee 7: Female, Researcher and Software Developer in Energy Efficiency-Related Research Projects

The following participant also agreed on the applicability of the model. *“Lately, I’ve been working on projects which main objective is to apply a set of ICT tools to improve behavioural change. Most of the time, the software solutions that are developed, even though they are intended to a specific target group, they may not follow or may not be capable to be adapted to the specific case of each user. Therefore, the software is “static” and does not accompany the user in the change”*. Thus, she believes that the FOX model could help to improve this issue. Regarding other applications, the respondent asserted that these could be *“Tracking citizen behaviour through Social Networks (could we classify social interactions according to this model?) or tailoring of adequate Social Actions/ICT tools needed to, for example, apply a Pay As You Throw scheme in a municipality or prevent Food Waste”*. Besides, for her, *“the main potential is that it takes into account several theoretical models to create a meta-model that analyses behavioural change from several aspects. It identifies the specific characteristics of the user along the process of behavioural change allowing to determine specific interventions customised to their needs”*. Regarding the improvements and future steps in the development of the model, her answer was in line with the other participants: *“I would improve the model maybe trying to define a set of variables that can determine how external variables for the environment can affect the intervention”*.

4.2.8. Interviewee 8: Male, Researcher in the Field of Next-Generation Internet

For this participant, *“we are far away still of being able to produce fully personalised solutions, we must fit into 3-5 categories and that is it. Thus, it is necessary to find more sophisticated user models that enable to tune solutions to the attitudes, values, beliefs. Still, end users need not to be cluttered with too many extra questions”*. The framework proposed by the FOX model presents a starting point to improve the modelling process, according to these issues. For this respondent, the application of the model was linked with behaviour change interventions in the broad sense, as *“behaviour change is paramount to give place to more human-centric solutions which are more acceptable, usable and accessible for end users”*. Taking this into account, the potential of the model was linked to the personalisation of software systems and smart objects. Regarding improvements, this participant *“would analyse the impact that considering each dimension may have in the data gathering task: technical feasibility, obtrusiveness for users, ethical aspects”*.

4.3. Conclusions and Insights for the Potential Future Performance of the Fox Model

After the analysis of the results and understanding the gathered data, we extracted the first conclusions of the study. For this, the implications of the FOX model were exposed and defined, analysing the relevant information that should be taken into account when developing and implementing the framework.

The importance of personalised interventions. All of the respondents agreed on the applicability of the model in their own fields. Furthermore, they also agreed on the potential of the FOX model to

implement personalised interventions based on specific and related dimensions. Thus, in this preliminary study, the model appears to be interesting and valuable for the research community in different contexts. Besides, the coverage of the different theoretical frameworks was valuable for Interviewee 7, reinforcing the idea of the importance of taking into account the different perspectives of behavioural frameworks to address the diversity of individuals.

Specific and complementary dimensions to foster the inclusion of individuals. In line with the previous idea, another relevant conclusion extracted was the importance of complementing behaviour-related dimensions exposed in the FOX model with non-behavioural dimensions. These need to be specific to each context and may include social and demographic data to better frame and conceptualise user profiles. Following the ideas raised by Interviewee 2, it can improve the suitability of heterogeneous user modelling, in order to avoid the exclusion of vulnerable social groups. Therefore, context is paramount when selecting dimensions, and it seems that it needs to be done without neglecting profiles (more static characterisation) and preference analysis (more dynamic and linked with context).

Flexible and updated model to accompany the individual. As Interviewee 7 exposed, one of the shortcomings of traditional user modelling is static characterisation. For that, the flexibility of the model is a relevant key point that should be addressed in any of its applications; that is, the system should be able to detect any change in its categorisation, update the status of the user profile, and offer inputs related to it. In this way, the system can accompany the individual over time and throughout the entire process of behaviour change.

Diverse context of application. Another insight extracted from the qualitative study was the applicability of the FOX model in different contexts. Although this framework was created to foster pro-environmental behaviour, Respondents 1, 2, and 6 explicitly exposed its possible application to their own fields, such as education and health. Other possible contexts of application could also be envisaged. Nevertheless, in order to apply the exposed framework to any given context, it seems crucial to study the relevant dimensions and/or variables for each context, adapting the model according to them.

Rules and measures to categorise individuals. As this preliminary model proposes a novel classification mechanism, some participants questioned the idea of how to distribute people. Thus, specific rules and measures are needed to organise individuals, according to the dimensions, and to define specific interventions for each of them. How these measures can be set implies the understanding of the requirements of the contexts and systems and, further, the study of each variable and how it was defined in the original behavioural theory. Nevertheless, this emerges as a relevant factor to develop and successfully apply a personalised user modelling framework. Seven lines of study arise from this work—one per variable—in order to analyse how to monitor and measure them, either in the context of smart environments or using self-evaluation tools.

Neither intrusion nor tedious systems for data gathering. In following with the previous idea, the data gathered for the modelling should be done with non-intrusive systems that provide a good experience. Thus, the relevance of the design-specific and non-intrusive data gathering tools emerges as a need to further develop the FOX model. Nevertheless, how the data can be gathered depends on the technological capability and the context. Although gathering the data through questionnaires and other traditional tools can be very tedious, in most cases, data collection can now be done through smart devices and specific sensors located to capture information with no intrusion, while taking into account the privacy of the individual.

Avoid biases to foster diversity. As a final conclusion, a relevant insight from Interviewee 2 should be taken into account: As the FOX models offer early user classification to understand the heterogeneity of individuals better, it is highly important to be careful with the fact that the inclusion of some characteristics (e.g., demographics such as gender, race, country, and so on) may bias the model. Thus, the inclusion of complementary dimensions and the definition of the specific rules for each dimension should be studied and analysed in detail, in order to ensure that the model does not include any bias.

5. Applying the FOX Model

Once the main potential applications were explored, we sought to understand how the model can be applied to tackle user heterogeneity when influencing sustainable actions, when specific user profiles are defined. Thus, a simple textual example of three possible user archetypes using a Persona [14,15] is used in the following; these profiles are described below. In addition, Figure 4 shows the Persona of Jon, Figure 5 the Persona of Lily, and Figure 6 the Persona of Sua.

JON ZABALA

“ I know the environmental problem is serious and I do my best to try to be sustainable. However, I’m very busy and I can not think too much on it.”

AGE 34
LOCATION Berlin, Germany
OCUPATION Architect
STATUS Lives with his boyfriend
ARCHETYPE Busy & lazy

PAINS
 Sometimes Jon feels that he does not do enough for the environment. He thinks it is difficult to be sustainable.

GAINS
 Jon is happy when he does his best. If the choice is affordable, he always chooses the most sustainable option.

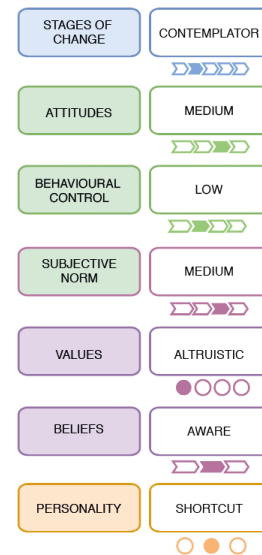
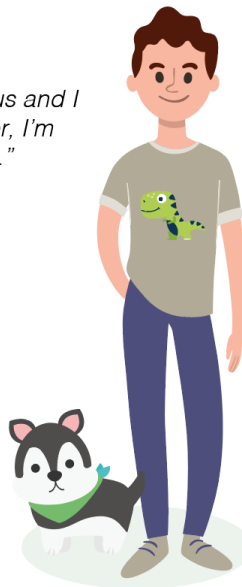


Figure 4. Jon and the main characteristics that are included in the profiling at the initial stage.

LILY RICCI

“It is our problem, our home is in a big danger. We must do whatever we can to solve it.”

AGE 43
LOCATION Catania, Italy
OCUPATION Flower Shop owner
STATUS Single, lives alone
ARCHETYPE Responsible & proactive

PAINS
 Lily wants to do more for the environment but she feels she can not.

GAINS
 Lily is excited about learning new pro-environmental things. Besides, she is very proud of her process and improvements in relation to sustainability.

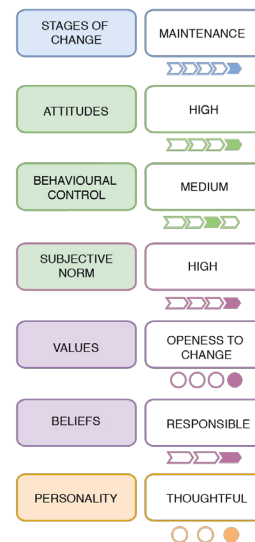


Figure 5. Lily’s Persona profile and her main characteristics at the initial stage, according to the FOX model.

SUA BOIX

"I have a lot of problems in my everyday life and I can not think on this right now. Besides, it is the responsibility of the politicians."

AGE 58
LOCATION Barcelona, Spain
OCCUPATION Teacher
STATUS Married with 2 sons
ARCHETYPE Detached

PAINS

Sua believes that politicians and companies are ruining the environment. She feels she can do nothing about it.

GAINS

Sua is happy because she made some sustainable improvements that also were good for her (e.g. saving energy).

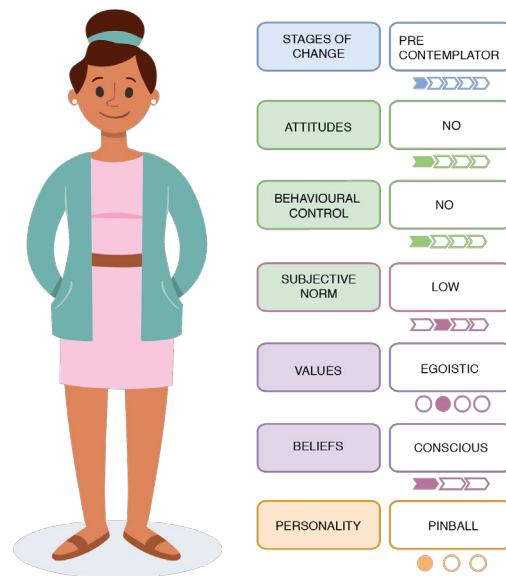


Figure 6. Sua's Persona profile and her main characteristics at the initial stage, according to the FOX model.

5.1. Developing User Profiles: Jon, Lily, and Sua

In the following, three Personas are exposed by defining and understanding all the relevant aspects to envision the user archetype as a real individual. These profiles were developed taking into account the different personalities proposed in the FOX model. Thus, Jon is a Shortcut user, who makes choices to minimise effort; Lily is a Thoughtful user, who analytically thinks about what she is doing and why; and Sua is a Pinball user, who reacts simply to inputs, doing the same thing each time the same stimulus is applied. These user profiles have been categorised in the context of the FOX model, complementing the dimensions with demographic data and other insights to enrich the modelling and to take into account other relevant dimensions that complement and contextualise the archetypes.

5.1.1. Jon

Jon lives in Berlin with Peter and Zero (their dog). He is a 34-year-old architect who recently started a new job in a very prestigious architecture studio. He is a hard-working person who is always worried about being efficient and productive in his life. He is very familiar with technological devices and gadgets. He has been a fan of the Apple brand for a long time. At present, he owns two Macs, an iPhone, an Apple Watch, AirPods, and an iPad. He likes rock music and going to music concerts. Jon is not a sporty person, but he tries to stay active in his everyday life. Therefore, he goes walking whenever possible and goes hiking on the weekends. Since he was a child, he has loved dinosaurs. He has a great collection of books and other related stuff. His perfect weekend is a concert with friends on Saturday and watching Netflix and relaxing on Sunday. Jon is conscious of the environmental situation and its importance. He cares about the situation of people in danger, and most of his friends are very active in this field. Indeed, pro-environmentalism is a common topic in his everyday life. Due to this, Jon somehow aspires to improve his lifestyle according to his concerns. For example, he eats less meat, and he tries to reduce his waste output. Nevertheless, as he has many things on his mind, he does not make any relevant effort to improve the impact of his actions. He often thinks about it and feels guilty, but due to the fact that he finds it

complicated to make any meaningful impact on the environment, he does not behave fully responsible in terms of sustainability.

5.1.2. Lily

Lily lives in Catania, Italy. She is a 43-year-old woman who lives in a small flat in the city centre together with her two cats, Milos and Alfred. She loves her small flower shop and works hard on it. She is an open-minded person who is calm, optimistic, and polite. She enjoys everyday contact with people and loves working with flowers and plants and being in natural environments. She uses social media in her daily life, mostly to promote her business and to deal with customers. Indeed, she prefers personal relationships. She practices yoga and Tai-Chi once a week. She reads a lot; most of the books are historic and noir novels, and as she is a dreamer, she enjoys visualising herself in these adventures. Lily is a convinced vegan, although she does not like persuading others about it. Her perfect weekend is travelling outdoors to discover landscapes by walking in the middle of nature, followed by having a coffee and cake in a nice place. Lily is very aware of the environmental situation. She feels responsible for it, and she is very active in doing her best to reduce her environmental impact. For Lily and her friends, being environmentally conscious is very important; therefore, they always make the most environmentally friendly choices when eating, travelling, buying groceries, and so on. She always reflects on her actions and tries to improve her behaviour. Nevertheless, she feels that some environmental issues are out of her control, and she feels frustrated about it.

5.1.3. Sua

Sua (58) lives in Barcelona with her husband Josu. They have two sons, Mikel (29) and Aitor (33), who moved out a few years ago, but live near them, at their own places in Barcelona. Sua is a teacher at a high school with 15–16-year-old students. She has worked there for more than 20 years, and she is happy there, although she thinks very often about retirement. Although Sua and her family do not have big problems, Sua is always worried and concerned about her husband and her sons. Sua and Josu love going to the beach. They own a house in a small village near the sea, and they go there very often. Sua likes cooking and gardening, growing vegetables in the small garden they have in their country house. Her perfect weekend is going to the beach early in the morning, then preparing and enjoying a big lunch for all of her family with her own raised vegetables. Sua is not really concerned about the environmental situation. She recognises that it is a problem, but she does not feel it is her problem. She believes that this situation is a direct consequence of the poor management of politicians, and she does not feel responsible for it. As she is constantly worried about her family's economics, she is worried about the specific behaviours that have a direct impact on them, such as the monthly bills. Nevertheless, as she does not think about her actions, she has made some improvements (due to her sons) without noticing them.

5.2. *Understanding Actors in Their Context*

Once user profiles are defined, the next step is to underpin how these archetypes perform their sustainable behaviour by applying the FOX model in the context of smart environments. For that, the first step is to set the main stages and actions of the implementation process to identify the critical areas. Figure 7 shows the workflow defined to apply the FOX model. This tool will help to detail the specific tasks and stages of the process to gain knowledge on how the system will work. Based on the workflow, three specific scenarios are developed, one for each user model: (1) The scenario of Jon is contextualised in his workplace. In this open space, the main devices are shared with other colleagues, but they have a smart system that can detect individual actions and give personalised inputs according to them. Figure 8 exposes the performance of the model in this case. The main device involved in this context is an app that

offers information and other features. As Jon’s workplace is a smart office, this app is connected to the different sensors of the office. (2) The context of Lily involves her home. She has just one smart device, a smart meter, which can learn from Lily’s behaviour and predict her actions, reinforce her behaviour, offer recommendations, and suggest automation strategies. Figure 9 shows the workflow of this scenario. (3) The last scenario involves Sua and her family. Their context involves a smart home (an individual space with a smart system installed), where the key factor is the inclusion of different profiles, offering common interventions to reinforce the group, as well as personalised inputs, according to the different user profiles. In this way, all the individuals have a common goal while preserving their individuality. The devices involved in this scenario are mainly the app and other home appliances connected to the Internet, such as the vacuum cleaner, the lights, and the thermostat. Figure 10 visualises the process of this context. In the following lines, the three scenarios are described, aiming at understanding how the individuals would perform their activities, taking into account the framework proposed by the FOX model.

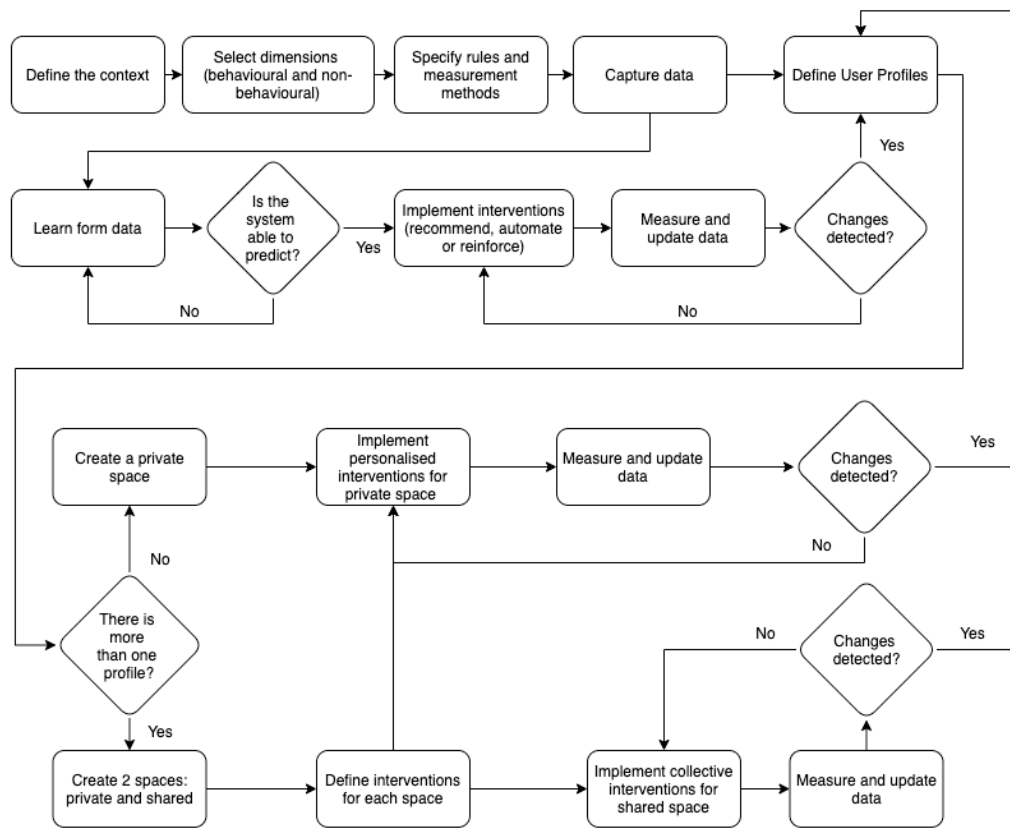


Figure 7. The workflow defined to identify the main stages in the application of the FOX model.



Figure 8. The key stages of Jon’s scenario.

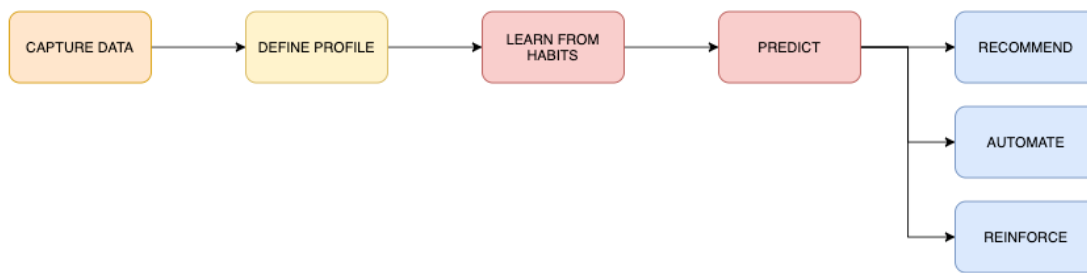


Figure 9. The key stages of Lily's scenario.

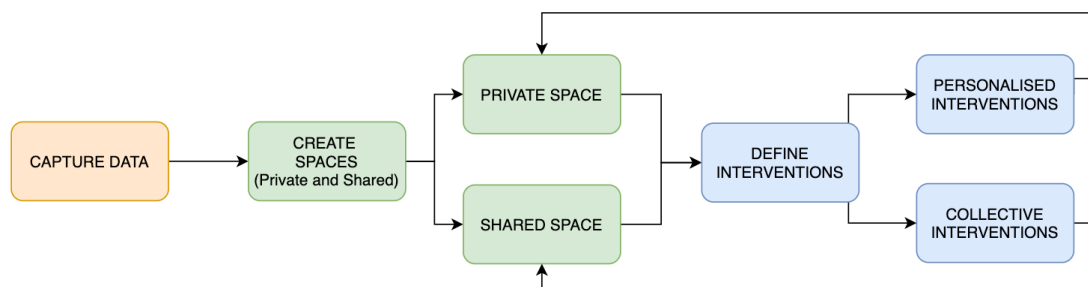


Figure 10. The key stages of Sua's scenario.

5.2.1. Jon and His Workplace

At Jon's new job, they are very concerned about the environmental impact of their buildings. They try to reduce the energy demands of the buildings they design and try to consider the sustainability of their workplace. Due to this, they have installed sensors across the building to capture data and optimise the usage of processes and devices. Furthermore, they created a smartphone app named Foxi, which offers feedback and data about environmental concerns to motivate and influence workers. This application includes four main sections: (1) Information, where different data and information related to sustainability are provided; (2) Control, where the user can connect to devices and control them; (3) Social, where an individual can interact with other people; and (4) User settings, in order to manage user profiles and to personalise some features. This application was inspired by a prototype presented in a previous research work [8], where user diversity was addressed by offering personalised strategies and techniques. Nevertheless, with the inclusion of the dimensions presented in the FOX model, the Foxi app could offer more complex and personalised strategies than the initial prototype.

Understanding Jon. In his second day at work, at lunchtime, Jon decides to download and use the app that his company developed, in order to boost his awareness about the importance of sustainable behaviour. To create his profile, he answers some questions in the app. Next, he goes to his desktop and works normally. In the following days, the smart environment of the workplace obtains relevant data about Jon, and by comparing it with the data of the app, a preliminary categorisation is implemented: (1) Jon is categorised as a contemplator, as he recognises some problematic behaviours and thinks of how to improve them; (2) his values are categorised as altruistic; (3) Jon has been included in the aware category, taking into account his environmental beliefs; (4) the Subjective Norm of Jon is medium: in his work environment, the norm is very high, but in other environments (e.g., at his home), there is not a pro-environmental norm; (5) the attitudes of Jon regarding sustainable behaviour are categorised as

medium; (6) the behavioural control of Jon in the context of his workplace is low; and (7) the personality of Jon is categorised as Shortcut.

Implementing interventions. Once Jon has been located in the dimensions of the FOX model, specific interventions can be implemented to improve his pro-environmental lifestyle awareness. Taking into account the existing categorisation of Jon, the following strategies are implemented: (1) In order to motivate Jon to change to the next stage, preparation, the application gives information about the benefits of being sustainable. (2) The Foxi app offers a data visualisation of the impact of climate change on other people in different parts of the world, in order to enhance the importance of sustainability values. Jon can also access other relevant data related to other factors (e.g., economic information and information about the impact on animals and plants). (3) Taking into account the data gathered by specific sensors in Jon's workplace, they decide to implement an awareness campaign showing the data of the average energy waste of a single individual at work and tips to avoid it, aimed at motivating workers to be responsible with their own actions. (4) To boost the Subjective Norm in relation to sustainability, the Foxi app shows the profile and data of prominent pro-environmental people (in this case, famous architects). Further, it offers a social network to boost relationships with other people with similar interests. (5) Aiming at enhancing pro-environmental attitudes, Jon's company showcases a documentary film about the impact of climate change. (6) The Foxi app offers reminders that can be personalised by Jon. In this way, he does not forget to turn off his devices when leaving the office. Finally, (7) as a Shortcut user, he makes the effortless choice. Therefore, the Foxi app has every single process set by default (favouring the most pro-environmental options).

Updating the model. Once the interventions have been implemented, the next step is to compare whether there have been improvements in motivation about sustainable behaviour. Through a short survey (using the Foxi app) and the data gathered by the smart environment, the new status is recognised, and the model is updated. (1) After the interventions, Jon started to plan new pro-environmental actions. Therefore, the model updated this dimension, and now, Jon is in the preparation stage. (2) The values of Jon were aligned with pro-environmental issues, and now, the altruism of Jon involves sustainability concerns. Besides, he has consulted data related to expenses and money saving. Therefore, the Foxi app improved the visibility of these data, and the categorisation of Jon changes from the altruistic to the egoistic dimension, depending on the most-viewed data. (3) Jon has taken responsibility for the environmental problem. Therefore, his categorisation changed to responsible. (4) After the interventions, the Subjective Norm of Jon rose and is now categorised as high. (5) In the update of the model, the attitude of Jon about sustainability rose, and Jon now has a high pro-environmental attitude. (6) After the interventions, the behavioural control of Jon was categorised as medium. (7) Jon maintains the Shortcut behaviour, most of the time, but the system detected that (mostly on the weekends), he checked other data (such as his historic energy expense). Therefore, in those days, the app will give feedback to boost his knowledge and to help him to learn about his behaviour.

5.2.2. Lily at Her Home

Lily is very aware of her pro-environmental behaviour. She always tries to make the most sustainable choices, and therefore, she wants to manage the energy expenditure of her house efficiently. For this reason, following the advice of a friend, she bought a smart meter. This device is connected to the main electricity board of her house and gathers information about her electricity consumption. It is also connected to the Internet and has a linked mobile application to visualise and manage some settings. In the words of Lily's friend, *"this will help you a lot to understand your consumption patterns and to save energy accordingly"*. With this idea in mind, she acquired the device, and after some difficulties and two calls asking her friend for help, she finally succeeded in installing it and making everything work.

Capturing and learning. When opening the application for the first time, Lily introduced some data about herself and her lifestyle. At this moment, her profile was created (combining the dimensions proposed by the FOX model with other demographic data) and saved into the server. Then, Lily can tap into some sections, researching and seeking some information. She can visualise the energy consumption of her house and also other relevant information that she did not know. She was very happy, as she could now understand her energy consumption and waste better. Besides, she learned when the energy was less expensive and greener. In the following days, Lily continued checking the app for information. Throughout the process, she learned a great deal, both about general sustainability tips and about her own consumption patterns. She also became very active on the social network of the app. During these days, the system captured data and updated the model periodically, learning about Lily's lifestyle, preferences, and consumption patterns.

Predicting and forecasting behaviour. After a few days, the system learned enough information and was able to make predictions. Lily is still interested and tries to learn, but as she is a very regular and pro-environmental person, her chances for making improvements are minimal. One day, she received a notification from the app: "Predictions are now enabled!". She taps on it and discovers a new section. Here, she sees a historic visualisation of her past consumption. She also finds a forecast of her expected future consumption and a short summary of future predictions related to her behaviours and actions. This was a nice surprise for Lily, as now she can learn about the future and about the impact of her actions.

Recommending, reinforcing, and automating. Once the system is able to predict the actions of Lily, some new interventions can be offered, in order to improve her motivation and to support her pro-environmental behaviour. These are grouped into three main actions: recommend, reinforce, and automate. Based on the predictions created, taking into consideration the FOX model, the system can recommend personalised interventions to boost the motivation of the individual. These can be varied and diverse; for example, information related to Lily's values and beliefs, ideas and strategies to improve her behavioural control, and other data related to the impact of her actions can be offered. The system can also reinforce Lily's future behaviour by offering rewards and other motivational inputs. Finally, taking into account the predictions of the system, some actions may be automated. For example, as Lily spends most of her day at work, the system can suggest to her to automatically switch off the devices that are not needed when she is out, turning them on just before her arrival.

5.2.3. Sua and Her Family

Sua is on vacation with her husband and sons. They just arrived home from the beach. While some of them go to their bedrooms to change their clothes, the others go to the kitchen to prepare some snacks and drinks while they wait their turn for the shower. They speak about what they are going to prepare for lunch while they check what is available in the fridge. At some point, Sua remembers that the tomatoes in the garden are at the perfect point to be harvested, so she goes outside to check them. While walking back to the kitchen, Sua checks her phone. She finds a notification offering ideas for preparing dishes with home-grown vegetables, so she opens the app and searches for tomato salad recipes. Now, in the kitchen again, she chats with her son about the app. He reminds Sua that the app is connected to other devices, such as the lamp or the coffee maker. These devices were a gift from last Christmas from Sua's sons to their parents. As they know that their parents love being at that house and taking care of the garden, they invested their money to transform the beloved beach house of their parents into a smart home.

Creating profiles and spaces. When Mikel and Aitor installed the devices, they also installed the app in their parent's smartphones. Each member of the family created a profile, and the sons taught their parents how to quickly use the management system. Josu liked the system and got used to it very fast. It was quite easy for Sua as well, but she did not really care much about it; so, she ended up forgetting what

she had learned. Nevertheless, Josu was a frequent user of both the app and the connected smart devices; for example, Josu had automated the vacuum cleaner, and he checked the app very often. His preferred feature was space management: as he is always the one managing the gadgets of the house, he can check such common features as their energy and water expenditure and other shared devices, as well as checking his private area, where he can find personalised information and content.

Analysing similarities and differences. While Sua is chopping tomatoes to prepare the lunch, Josu reminds her about the fancy functions that their smart home has. Sua notices some improvements; for example, she acknowledged that the automatic vacuum cleaner is a really nice device that allows her to not worry about cleaning the floor. At that point, Josu starts speaking about other things that Sua did not notice. Thus, she checks the app in her phone. In her private area, she finds out that her stats and information are different from what Josu had shown her in his phone. Indeed, she can edit the information she can see, according to her preferences. In this way, she sets the feature to see how much money they save, regarding their pro-environmental behaviour.

Common and personalised interventions. The family is enjoying lunch after their beach day. Sua continues chatting about the re-discovered app, as she is very happy with the new functions she has learned and is really excited as she can manage money better now. While their sons are joking about the fact that it took some months to discover the benefits of their present, Sua wonders about the “Challenge” feature. They explain to her that this is a feature that involves all of the family members. It is a competition among different groups of user, where the most pro-environmental group wins. Sua checks the ranking, and the family starts speaking about their possibilities in the challenge. Sua is happy because all the family is excited about a common goal, which she likes. She invites her family to participate in the challenge together; however, she is worried, as she liked the other personalised features she discovered, such as the “recipe advisor” and the “money saving calculator”. She asked her sons: “So ... If I join a challenge with you, will I lose my private settings?”. They answer: “No mum, the system offer us common features as a family, but you still have your own space, based on your preferences and activities”. With this idea in mind, Sua was happy because she could have a common activity with her family where of all the different members are included, but still keep her own space to check her personalised content.

5.3. Conclusions and Insights

From the development of the exposed Personas and/or user profiles, some insights that can serve to guide future research work can be extracted. First, it can be ensured that the developed user archetypes provide valuable information and may improve the understanding of the real users. Besides, the complexity of the individual is addressed through the inclusion of the dimensions proposed in the FOX model, in combination with other demographic attributes. In addition, the proposed profiles could help to identify the emotions and feelings related to pro-environmental behaviour. Finally, the contextualisation of individuals in their own context, the novel categorisation framework, and the identification of specific barriers (see Figures 4–6, where the barriers are included under the “Pains” section) are other benefits. From the proposed case studies or scenarios, the main contribution may be the understanding of how each user archetype performs his/her behaviour in his/her own context. This idea could help researchers and practitioners improve their understanding of the performance of individuals in the context of sustainability. Through these case studies, the performance of the model can be exposed: in the first example (Jon), the performance of the model was centred on the implementation of personalised interventions; in the second case, the performance was focused on behaviour prediction and forecasting; finally, in the third case, the performance of the model was centred on the management of different profiles and contexts (combining private and shared spaces).

6. Discussion

In this paper, the potential applications of the FOX model were explored. For this purpose, a qualitative survey with experts was performed (Section 4), with the framework applied to the development of three user archetypes (Section 5.1) and case studies (Section 5.2). This follows the line of other authors, such as He et al. [17], Coskun and Erburg [19], and Lockton et al. [31]. Nevertheless, as the FOX model combines four behavioural frameworks, it may cover several complementary points of view that can help to understand, in a more accurate fashion, the complexity of the individual in different contexts. Of course, these characterisations could be improved by understanding and embracing other relevant issues, such as the specific barriers inherent to each profile. After the development of three Personas (or user profiles), in order to gain knowledge about the behaviours of individuals in their own context and to improve understanding of the performance of the model, three use cases were developed, exploring three different modes of implementation of the FOX model: (1) personalised interventions, (2) prediction and forecasting, and (3) individual and collective interventions. The difference between user archetypes or Personas and case studies is that the former explores an individual's universe and his/her complexity, while the latter explores how these archetypes perform their behaviours and interact with the system in any given context. In this way, the development of Personas may help to better understand individuals, while the development of the case studies may help to comprehend how these user archetypes interact with the system in their everyday life. Furthermore, although more research is needed to validate the findings, the possibilities the FOX model offers can be envisaged through these scenarios. Furthermore, the implementation of the ideas can be conceptualised in an early stage of the process, in order to test whether an idea or intervention works in a given context, before investing resources into it. This is in line with the BCW [40], a behavioural approach where a variety of dimensions are covered. Nevertheless, the work presented in this paper addresses the flexibility of individuals, proposing a dynamic and multilevel characterisation that may help to improve the understanding of the complexity and variability of people.

Another critical factor that should be considered is the importance of complementing the dimensions of the model with other specific data. From the results of the questionnaire, we conclude that the dimensions should vary depending on the context of the application, complementing the core dimensions of the model with other information such as demographic variables. Besides, the proposed case studies show also how the usage of non-behavioural dimensions is a paramount issue. This idea may enhance the inclusion of diverse profiles, especially of the most vulnerable ones. However, how the complementary variables are gathered and selected must be carefully studied to avoid biases in the user modelling process.

Additional relevant topic that should be further investigated relates to the way that rules and measures for classifying individuals should be set up. As the results of the qualitative study show, in order to implement the FOX model in the user modelling process, specific measures are needed to include the individual in each category, depending on their characteristics. For this, the behavioural theories and frameworks must be taken into account, in order to maintain the original settings and classification procedures. Nevertheless, as some respondents stated, data gathering is typically tedious. Therefore, complex questionnaires should be avoided, and the required data should be captured using tools and methods that provide a positive experience. Thus, the rules of each dimension and how the data are gathered should be studied in the specific context of the application. Furthermore, available technologies must be also taken into account; for example, in smart environments, data gathering can be done through non-intrusive methods, by using sensors and other smart devices that maintain the privacy of people.

Finally, from the qualitative study, we also extracted how the FOX model can be applied to different contexts. From health to education, the model may be implemented to cover the diversity of individuals when developing interventions in any target population. Nevertheless, as previously indicated, the selection

of the dimensions, the development of specific rules and measures, and the implementation of data gathering tools must be carefully considered, in order to adapt and apply the model successfully.

To provide a summary of the main insights and findings of the presented research work, Figure 11 exposes the specific ideas and contributions obtained from each stage of the research process: the qualitative survey explained in Section 4 and the case studies developed in Section 5 (Personas and scenarios).

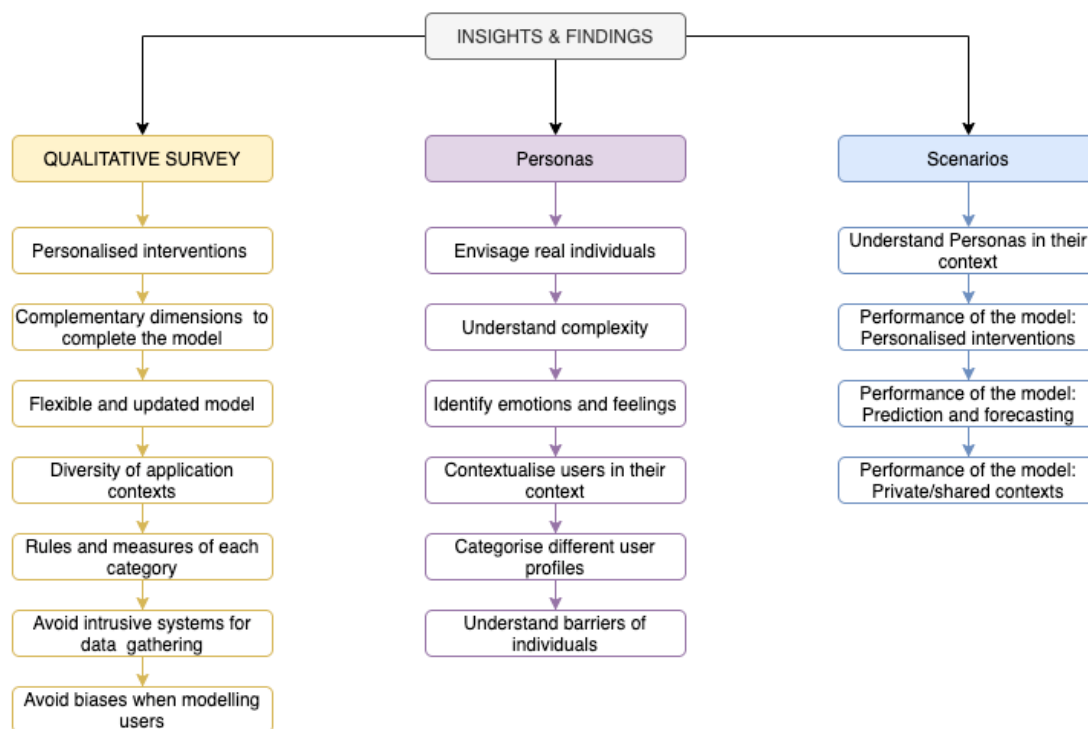


Figure 11. The main insights and findings of the research work presented in this paper.

7. Conclusions

In this paper, a holistic meta-model (named FOX) that classifies individuals by taking into consideration the behavioural dimensions related to pro-environmental behaviours was presented. The FOX model seeks to consider the heterogeneity of the individuals through a dynamic categorisation method with the objective of offering a flexible framework. Aiming at understanding how the model could perform to boost an individual's behaviour, an exploratory qualitative experiment was conducted. In this study, eight experts in the computer science and smart environments fields reflected on the fox model and its potential uses. Then, the mechanisms and processes to apply the FOX model were detailed by defining a guiding procedure (workflow to follow) in order to identify the key tasks and actions needed to put FOX in practice. Moreover, seeking further applications and new insights, this model was applied to the modelling of three specific user archetypes, in order to understand the different concerns of the individuals in relation to sustainability. Furthermore, three case studies were exposed, each of them involving one user profile in the context of smart environments. These use cases demonstrated how the model can perform in different scenarios. From the presented work, it can be concluded that the FOX model is promising, as it is flexible and extendible, for researchers and practitioners in the field of behavioural research, as well as for computer scientists aiming to better understand users. Moreover, the results of the study show that the model may be applied in the context of smart environments, in order to foster

pro-environmental behaviour. Furthermore, the application of the framework to other potential contexts (e.g., health and education) is feasible, by including variables and dimensions specific to the context. The application of the FOX model when defining user profiles and scenarios could provide valuable knowledge for improving the understanding and inclusion of individuals when designing and developing technologies. Although further research is needed to consolidate the findings and insights presented in this paper, the present work sets a starting point to develop a human-centric approach and to target user needs when coping with forming or increasing pro-environmentalism and eco-awareness. Finally, from the present work, some improvements and reflections could be extracted, setting specific future research lines. This future work should be evolved, in order to extract more knowledge and consolidate the findings presented in this paper. These next steps are: (1) define the tools that allow for measuring dimensions, stages, and characteristics of the meta-model; (2) test the model with different groups and individuals (i.e., specific target users, researchers, practitioners, and so on), in order to include valuable insights from different points of view and to validate the proposed framework; (3) complement the model with other specific and context-related dimensions that may influence user behaviours; and (4) explore the application of the model with different methods in different processes, in order to better understand its possibilities. Finally, another iteration of the whole research process (see Section 1.1) may be implemented, in order to refine and validate the knowledge exposed in the present work.

Author Contributions: Conceptualisation, A.I.-A.; Formal Analysis, A.I.-A.; Investigation, A.I.-A.; Writing—Original Draft Preparation, A.I.-A.; Supervision, D.C.-M., A.R. and M.L.; Funding Acquisition, D.L.-d.-I. All authors have read and agreed to the published version of the manuscript.

Funding: This work has been partially supported by the Spanish government through SentientThings under Grant No.: TIN2017-90042-R.

Acknowledgments: We gratefully acknowledge the support of of the Basque Government’s Department of Education for the DEUSTEK Research Group (IT 1078-16 D) for the pre-doctoral funding of some of the authors.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Sánchez-Corcuera, R.; Nuñez-Marcos, A.; Sesma-Solance, J.; Bilbao-Jayo, A.; Mulero, R.; Zulaika, U.; Azkune, G.; Almeida, A. Smart cities survey: Technologies, application domains and challenges for the cities of the future. *Int. J. Distrib. Sens. Netw.* **2019**, *15*, 1550147719853984. [[CrossRef](#)]
2. Irizar-Arrieta, A.; Retegi, A.; Casado-Mansilla, D.; Laschke, M.; López-de Ipiña, D. FOX: A flexible and heterogeneous mixed user model to address sustainable behaviour in smart environments. In Proceedings of the Multidisciplinary Digital Publishing Institute Proceedings, Toledo, Spain, 2–4 December 2019; Volume 31, p. 82.
3. Mankoff, J.C.; Blevins, E.; Borning, A.; Borning, A.; Friedman, B.; Fussell, S.R.; Hasbrouck, J.; Woodruff, A.; Sengers, P. Environmental sustainability and interaction. In Proceedings of the ACM CHI’07 Extended Abstracts on Human Factors in Computing Systems, San Jose, CA, USA, 28 April–3 May 2007; pp. 2121–2124.
4. DiSalvo, C.; Sengers, P.; Brynjarsdóttir, H. Mapping the landscape of sustainable HCI. In Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems, Atlanta, GA, USA, 10–15 April 2010; pp. 1975–1984.
5. Bravo, J.; Fuentes, L.; de Ipina, D.L. *Theme Issue: “Ubiquitous Computing and Ambient Intelligence”*; Springer: Berlin/Heidelberg, Germany, 2011.
6. Coskun, A.; Erbug, C. User diversity in design for behavior change. In Proceedings of the DRS, Umea, Sweden, 16–19 June 2014; pp. 546–559.
7. Hekler, E.B.; Klasnja, P.; Froehlich, J.E.; Buman, M.P. Mind the theoretical gap: Interpreting, using, and developing behavioral theory in HCI research. In Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems, Paris, France, 27 April–2 May 2013; pp. 3307–3316.

8. Irizar-Arrieta, A.; Casado-Mansilla, D. Coping with user diversity: UX informs the design of a digital interface that encourages sustainable behaviour. In Proceedings of the 11th Multi Conference on Computer Science and Information Systems, Lisbon, Portugal, 20–23 July 2017.
9. Irizar-Arrieta, A.; Casado-Mansilla, D.; Retegi, A. Accounting for user diversity in the design for sustainable behaviour in smart offices. In Proceedings of the IEEE 2018 3rd International Conference on Smart and Sustainable Technologies (SpliTech), Split, Croatia, 26–29 June 2018; pp. 1–6.
10. Buchanan, E.A.; Hvizdak, E.E. Online survey tools: Ethical and methodological concerns of human research ethics committees. *J. Empir. Res. Hum. Res. Ethics* **2009**, *4*, 37–48. [[CrossRef](#)] [[PubMed](#)]
11. Evans, J.R.; Mathur, A. The value of online surveys. *Internet Res.* **2005**, *15*, 195–219 [[CrossRef](#)]
12. Schwandt, T.A.; Gates, E.F. Case study methodology. *Sage Handb. Qual. Res.* **2018**, *5*, 341–358.
13. Hosono, S.; Hasegawa, M.; Hara, T.; Shimomura, Y.; Arai, T. A methodology of persona-centric service design. In Proceedings of the 19th CIRP Design Conference—Competitive Design, Cranfield, UK, 30–31 March 2019; Cranfield University Press: Cranfield, UK, 2009.
14. Blomkvist, S. Persona—An overview. Retrieved Novemb. **2002**, *22*, 2004.
15. Pruitt, J.; Grudin, J. Personas: Practice and theory. In Proceedings of the 2003 Conference on Designing for User Experiences, San Francisco, CA, USA, 6–7 June 2003; pp. 1–15.
16. So, C.; Joo, J. Does a persona improve creativity? *Des. J.* **2017**, *20*, 459–475. [[CrossRef](#)]
17. He, H.A.; Greenberg, S.; Huang, E.M. One size does not fit all: Applying the transtheoretical model to energy feedback technology design. In Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems, Atlanta, GA, USA, 10–15 April 2010; pp. 927–936.
18. Prochaska, J.O.; Redding, C.A.; Evers, K.E. The transtheoretical model and stages of change. *Health Behav. Theory Res. Pract.* **2015**, *97*, 125–148.
19. Coskun, A.; Erbug, C. Exploring and communicating user diversity for behavioural change. In Proceedings of the 2016 Design Research Society 50th Anniversary Conference, Brighton, UK, 27–30 June 2016; Volume 4, pp. 1357–1374; doi:10.21606/drs.2016.73. [[CrossRef](#)]
20. Madsen, S.; Nielsen, L. Exploring persona-scenarios-using storytelling to create design ideas. In Proceedings of the IFIP Working Conference on Human Work Interaction Design, Pune, India, 7–8 October 2009; Springer: Berlin/Heidelberg, Germany, 2009; pp. 57–66.
21. Madsen, S.; Nielsen, L. Using storytelling to improve scenarios. In Proceedings of the IADIS International Conference Information Systems, Barcelona, Spain, 25–27 February 2009.
22. Coskun, A.; Zimmerman, J.; Erbug, C. Promoting sustainability through behavior change: A review. *Des. Stud.* **2015**, *41*, 183–204. [[CrossRef](#)]
23. Irizar-Arrieta, A.; Gómez-Carmona, O.; Bilbao-Jayo, A.; Casado-Mansilla, D.; Lopez-De-Ipina, D.; Almeida, A. Addressing behavioural technologies through the human factor: A review. *IEEE Access* **2020**, *8*, 52306–52322. [[CrossRef](#)]
24. Wising, U.; Chirez, S.; Adams, B. Improving industrial energy efficiency by changing the energy culture. In Proceedings of the ECEEE Industrial Summer Study Proceedings, Arnhem, The Netherlands, 2–5 June 2014.
25. Xiao, J.J. Developing action-taking programs in sustainable consumption education: Applying the transtheoretical model of behavior change (TTM). *SSRN* **2019**. [[CrossRef](#)]
26. Stern, P.C.; Dietz, T.; Abel, T.; Guagnano, G.A.; Kalof, L. A value-belief-norm theory of support for social movements: The case of environmentalism. *Hum. Ecol. Rev.* **1999**, *6*, 81–97.
27. Stern, P.C. New environmental theories: Toward a coherent theory of environmentally significant behavior. *J. Soc. Issues* **2000**, *56*, 407–424. [[CrossRef](#)]
28. Petkov, P.; Goswami, S.; Köbler, F.; Krcmar, H. Personalised eco-feedback as a design technique for motivating energy saving behaviour at home. In Proceedings of the ACM 7th Nordic Conference on Human-Computer Interaction: Making Sense Through Design, Copenhagen, Denmark, 14–17 October 2012; pp. 587–596.
29. Ajzen, I. The theory of planned behavior. *Organ. Behav. Hum. Decis. Process.* **1991**, *50*, 179–211. [[CrossRef](#)]
30. Greaves, M.; Zibarras, L.D.; Stride, C. Using the theory of planned behavior to explore environmental behavioral intentions in the workplace. *J. Environ. Psychol.* **2013**, *34*, 109–120. [[CrossRef](#)]

31. Lockton, D.; Harrison, D.; Stanton, N.A. Models of the user: Designers' perspectives on influencing sustainable behaviour. *J. Des. Res.* **2012**, *10*, 7–27. [[CrossRef](#)]
32. Cor, E.; Zwolinski, P. A procedure to define the best design intervention strategy on a product for a sustainable behavior of the user. *Procedia CIRP* **2014**, *15*, 425–430. [[CrossRef](#)]
33. Lilley, D.; Bailey, V.; Charnley, F. *Design for Sustainable Behaviour: A Quick Fix for Slower Consumption?*; Loughborough University: Loughborough, UK, 2013.
34. Halko, S.; Kientz, J.A. Personality and persuasive technology: An exploratory study on health-promoting mobile applications. In Proceedings of the International Conference on Persuasive Technology, Copenhagen, Denmark, 7–10 June 2010; Springer: Berlin/Heidelberg, Germany, 2010; pp. 150–161.
35. Kaptein, M.; Lacroix, J.; Saini, P. Individual differences in persuadability in the health promotion domain. In Proceedings of the International Conference on Persuasive Technology, Copenhagen, Denmark, 7–10 June 2010; Springer: Berlin/Heidelberg, Germany, 2010; pp. 94–105.
36. Kaptein, M.; Markopoulos, P.; De Ruyter, B.; Aarts, E. Personalizing persuasive technologies: Explicit and implicit personalization using persuasion profiles. *Int. J. Hum. Comput. Stud.* **2015**, *77*, 38–51. [[CrossRef](#)]
37. Lilley, D. Design for sustainable behaviour: Strategies and perceptions. *Des. Stud.* **2009**, *30*, 704–720. [[CrossRef](#)]
38. Michie, S.; Ashford, S.; Sniehotta, F.F.; Dombrowski, S.U.; Bishop, A.; French, D.P. A refined taxonomy of behaviour change techniques to help people change their physical activity and healthy eating behaviours: The CALO-RE taxonomy. *Psychol. Health* **2011**, *26*, 1479–1498. [[CrossRef](#)]
39. Michie, S.; Johnston, M.; Francis, J.; Hardeman, W.; Eccles, M. From theory to intervention: Mapping theoretically derived behavioural determinants to behaviour change techniques. *Appl. Psychol.* **2008**, *57*, 660–680. [[CrossRef](#)]
40. Michie, S.; Van Stralen, M.M.; West, R. The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implement. Sci.* **2011**, *6*, 42. [[CrossRef](#)] [[PubMed](#)]
41. Atkins, L.; Francis, J.; Islam, R.; O'Connor, D.; Patey, A.; Ivers, N.; Foy, R.; Duncan, E.M.; Colquhoun, H.; Grimshaw, J.M.; et al. A guide to using the Theoretical Domains Framework of behaviour change to investigate implementation problems. *Implement. Sci.* **2017**, *12*, 77. [[CrossRef](#)]
42. Gainforth, H.L.; Sheals, K.; Atkins, L.; Jackson, R.; Michie, S. Developing interventions to change recycling behaviors: A case study of applying behavioral science. *Appl. Environ. Educ. Commun.* **2016**, *15*, 325–339. [[CrossRef](#)]
43. Morgan, E.; Webb, L.; Carter, K.; Goddard, N. Co-designing a device for behaviour-based energy reduction in a large organisation. *Proc. ACM Hum. Comput. Interact.* **2018**, *2*, 125. [[CrossRef](#)]
44. Yun, R.; Aziz, A.; Lasternas, B.; Loftness, V.; Scupelli, P.; Zhang, C. The persistent effectiveness of online feedback and controls for sustainability in the workplace. *Energy Effic.* **2017**. [[CrossRef](#)]
45. Bao, Q.; Burnell, E.; Hughes, A.M.; Yang, M.C. Investigating user emotional responses to eco-feedback designs. *J. Mech. Des.* **2019**, *141*, 021103. [[CrossRef](#)]
46. Bao, Q.; Shaukat, M.M.; Elantary, A.; Yang, M.C. Eco-feedback designs: A balance between the quantitative and the emotional. In Proceedings of the ASME 2016 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. American Society of Mechanical Engineers, Cleveland, OH, USA, 21–24 August 2016; pp. V007T06A022.
47. Lockton, D.; Harrison, D.; Stanton, N.A. *Modelling the User: How Design for Sustainable Behaviour Can Reveal Different Stakeholder Perspectives on Human Nature*; University of Southampton: Southampton, UK, 2010.
48. Ajzen, I. Perceived behavioral control, self-efficacy, locus of control, and the theory of planned behavior. *J. Appl. Soc. Psychol.* **2002**, *32*, 665–683. [[CrossRef](#)]



© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).

*"Do you understand," said the other,
"that this is a tragedy?"*

*"Perfectly," replied Syme;
"always be comic in a tragedy.
What the deuce else can you do?"*

G. K. Chesterton, *The Man Who Was Thursday*

CHAPTER 6

Conclusions and Future Work



In this chapter, the main results and conclusions of the research work are detailed. Thus, in order to close the present dissertation, the objectives exposed in Chapter 1 are examined aiming at evaluating the achievement of them. In addition, a review of the main contributions presented throughout this thesis is exposed, including the publications related to this PhD dissertation. To conclude the research work, future lines are set and defined, in order to set the upcoming research objectives.

The rest of the chapter is structured as follows: Section 6.1 includes a summary and main conclusion of the research presented in this thesis. Next, Section 6.2 lists the contributions of this dissertation. Section 6.3 explains the achievement of the objectives exposed in Chapter 1. Then, the following section (Section 6.4) lists the scientific manuscripts published during the development of the present research work. Finally, Section 6.5 introduces some future research lines.

6.1 Summary and conclusions

In this thesis, the importance of taking into account diversity when promoting pro-environmental behaviour has been established. During the different stages of the research work presented in this dissertation, this idea has been validated and addressed to define and develop a specific framework that will help researchers and practitioners at implementing successful solutions.

From the revision of the state of the art, we discovered the lack of validated studies to address diversity when promoting sustainability, and the difficulty to implement successful strategies due to the variety of behavioural approaches. Besides, the most relevant challenges in the field have been identified, exposing the key issues that should be taken into account in the following research steps.

Once relevant insights were identified, an incipient theory developed from a long-term study has been studied. The emerged themes from the analysis of qualitative insights set the most relevant dimensions that should be taken into account when implementing pro-environmental strategies through technological systems (i.e. interaction, mediator/emotion, attachment/confidence, use-context and behaviour). Besides, these qualitative findings have been analysed to offer design-insights that will help and guide the im-

plementation of these ideas. Thus, through these insights knowledge from qualitative research is summarised to offer practical information that can be easily understood and applied.

In order to test the importance and accuracy of these findings, a novel device has been created, implementing the emerged design ideas. Thus, the IC includes a wide range of features addressed to boost the sustainable behaviour addressing the diversity through the application of a novel theory. Nevertheless, although the results of the experimentation show some promising findings (e.g. its acceptance and initial attachment, relevance as reminder, its key role to start conversations...), the IC was not complex nor dynamic enough to fulfil the needs of the diverse target users. Since it was designed taking into account only two behavioural approaches ([21] and [26]), other relevant dimensions of individuals were not included. This lack of complexity and the absence of dynamic and personalized feedback have been critical factors that caused individuals to stop using the device. Therefore, the diversity in individuals makes necessary a dynamic strategy, because the evidence shows that different people need and/or want different features and inputs and usually the researchers fall in the pitfall of “one size fits all”.

Thus, the next step in the research process was to set a more complex theoretical framework that includes the main approaches to boost sustainable behaviour. This framework, coined FOX, offers an overview of the key dimensions that are involved in the behavioural process. Nevertheless, this model is not static: the dimensions and connections must be reviewed and studied carefully when implementing them into a specific context.

Once the model is defined, to validate its relevance and to explore its potential application a qualitative survey was conducted with eight experts in the field. From this survey it was discovered the promising value of the model for the community, and the potential applicability to other fields such as health or education. Finally, other relevant insights were gathered as to the importance to set specific rules for each dimension and sub-category, in order to measure the performance of behaviours and actions.

Aiming at better understanding the implementation and performance of the FOX model, three case studies have been defined. These cases have been created by defining 1) Personas: an ideation of a user-archetype that will include all the relevant information of the individual. This helps at envisioning the target audience in a realistic and complex way; and 2) Scenarios: a description of a situation where the Personas interact with technological systems that apply the FOX model. Hence, through these examples we can comprehend the impact of the model in the individuals and how it can be implemented into different contexts and through different devices and systems.

Finally, the key conclusion emerged from the findings presented in this dissertation is the identification of a holistic approach for addressing the diversity of individuals when designing interventions in the context of pro-environmental behaviour. This approach sets a structure composed of two main elements:

1. *A framework to address the ideation and development of technological systems.* The emerging themes and design insights exposed in Chapter 4 addresses the key dimensions that must be taking into account to develop technological solutions. Besides, the specific design-insights offer guidance on how to apply these key themes into the design process.
2. *A framework to understand the individual.* The FOX model (Chapter 5) proposes a scheme to understand the main constructs and relations of the dimensions involved in the individual in relation to behaviour change.

Therefore, the resulting framework helps to address the diversity understanding the key insights from both people and device's side. Figure 11 shows the diagram of the approach presented in previous lines.

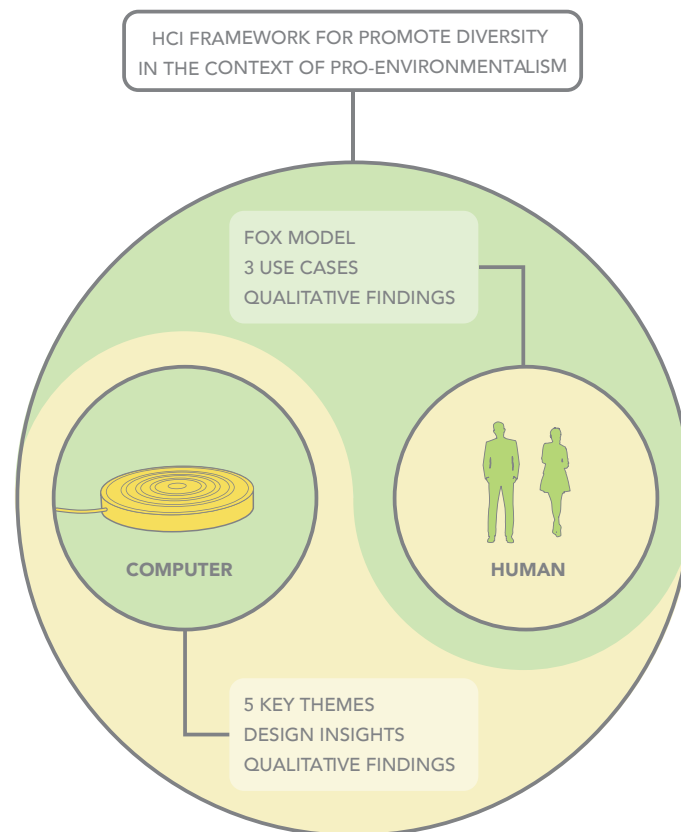


Figure 11. The diagram of the holistic framework created after analysing the findings of the research presented in this dissertation.

To sum up and taking into account the research process described throughout the present dissertation, we can conclude that this thesis contributes to improve the existing knowledge when addressing diversity in the context of sustainable behaviour. This has been done by following a human-centric procedure understanding the complexity of people by improving the experiences derived from the interaction with the systems.

6. 2 Contributions and objective validation

As exposed in previous chapters of this dissertation, the knowledge and findings emerged from this thesis are rich, diverse and promising. In the following lines, a summary of the contributions is presented, aiming at offering an overview of the inputs exposed throughout this thesis. These contributions are linked with the specific goals stated in Section 2.1. In addition, Table 1 shows an overview of the objectives and contributions.

1. *An updated analysis of the state-of-the-art.* The research work and findings exposed in Chapter 2 offer an overview of the current situation of the related works in the field. As we exposed in the mentioned chapter, findings show that it is still complicated to select the best intervention strategy. Besides, as we exposed in this chapter, most of the reviewed frameworks implement a narrow perspective when defining user-categories, and thus, the existing approaches lack accuracy and efficiency when facing diversity. This contribution is directly linked with the achievement of O1 (to study and analyse the current state of the art).
2. *Definition of design hypotheses linked to emerging themes based on qualitative findings.* In order to gain knowledge on how to design technological systems to boost sustainability, we identified five emerging themes from an incipient theory based on qualitative findings from a long-term study. This contribution helps to identify and apply key strategies when designing interactive devices to face pro-environmental behaviour. This is in line with O2 -to identify the key dimensions for designing technologies addressed to boost the pro-environmental behaviour- due to the identification of the themes from the emerging theory presented in Chapter 3. Besides, the design insights exposed also in Chapter 3 fulfil O3: to extract and define evidence-based design ideas of the most relevant dimensions for sustainable behaviour change.
3. *Design of a novel interactive device implementing theoretical findings from previous stages.* As a result of the theoretical research, some valuable findings have been discovered. Then, these have been implemented in a novel device by providing interactive feedback to promote awareness towards sustainable behaviour. This contribution, detailed in Section 3.3, addresses the O4 (To implement theoretical findings in an interactive everyday object addressed to enhance the importance of maintaining sustainable actions).
4. *Long term experimentation and analysis of the Interactive Coaster.* The evaluation of the IC exposed in Section 3.4. helps the HCI community to understand the main challenges and requirements for implementing pro-environmental strategies in technological devices. The findings of the long-term study show that the interaction with the device was satisfactory and provided positive experien-

ces and feelings. This contribution is related to O5 (to analyse if the proposed solution offers positive experiences and interactions through personalised strategies). Besides, through the qualitative analysis we discovered that the IC also improved the attachment, discussions, and awareness about the importance of sustainable behaviour, an idea directly linked with O6 (to analyse if the proposed solution enhances the awareness towards sustainable behaviour).

5. *The FOX model: a novel meta-model to understand user diversity.* After the analysis of the findings exposed in Chapter 3, some challenges were discovered (see Section 3.5). Thus, the next step was focused on the improvement of the theoretical background addressed to face the personalised feedback. Since we discovered that user profiles should be dynamic and include a wide range of dimensions, we proposed the FOX model, a framework that comprises the most common behaviour change models dynamically. This contribution fulfils the O7: to implement findings extracted from the evaluation in a new theoretical framework.
6. *Exploration of the main concerns and potential applications of the FOX model.* After the definition of the FOX model, a qualitative survey was conducted among experts in the field, validating the scientific value of the model and discovering the main concerns of the proposal, as the need to define measures and rules on how to categorise individuals. This is in line with O8 (to identify the challenges and opportunities related to the proposed framework). Besides, the applicability of the presented model was also analysed and validated, and other application contexts were discovered. These findings address the O9: to analyse the potential applicability of the theoretical framework and its main requirements.
7. *Development of three case studies addressed to understand the performance of the proposed framework.* Finally, after understanding the most relevant concerns of the FOX model, it was applied into three case studies to offer an example of how to apply the framework to improve the knowledge about target individuals, their motivations and their lifestyles. This was developed using Persona-Scenario method, and it provides an overview on how the performance of the FOX model through three different approaches would be, considering specific technological solutions and user archetypes. Thus, through this last contribution the O10 is achieved (to apply the proposed framework to gain understanding on how to face an individual's heterogeneity dynamically).

Table 1. The objectives defined in the Chapter 1 are linked to the contributions and publications.

OBJECTIVES	CONTRIBUTIONS	RELATED PUBLICATION
O1. To study and analyse the current state of the art	An updated analysis of the state-of-the-art.	Chapter 3
O2. To identify the key dimensions for designing technologies addressed to boost the pro-environmental behaviour	Definition of design hypotheses linked to emerging themes based on qualitative findings	Chapter 4
O3. To extract and define evidence-based design ideas of the most relevant dimensions for sustainable behaviour change		
O4. To implement theoretical findings in an interactive everyday artifact conceived to stress the importance of maintaining sustainable actions	Design of a novel interactive device implementing theoretical findings from previous stages.	Chapter 4
O5. To analyse if the proposed artifact offers positive behavioural interventions to heterogeneous individuals.	Long term experimentation and analysis of the Interactive Coaster.	Chapter 4
O6. To discover qualitative insights regarding the connection between the solution and the awareness towards sustainable behaviour		
O7. To implement findings extracted from the evaluation in a new theoretical framework	The FOX model: a novel meta-model to understand user diversity.	Chapter 5
O8. To identify the challenges and opportunities related to the proposed framework	Exploration of the main concerns and potential applications of the FOX model	Chapter 5
O9. To analyse and discover the potential applicability of the theoretical framework and its main requirements		
O10. To apply the proposed framework to gain understanding on how to face individuals' heterogeneity dynamically	Development of three case studies addressed to understand the performance of the proposed framework	Chapter 5

As exposed previously, throughout the different research stages, specific steps have been followed to gain understanding on how to address the diversity of individuals. Thus, the main contribution emerged from this thesis is the creation of a holistic framework for tackling the heterogeneity dynamically when implementing strategies to address sustainability. This contribution is directly related to the achievement of the main goal defined in Section 1.2: “To define and develop procedures and frameworks to address user diversity when designing to foster pro-environmentalism”.

Thus, the hypothesis stated at the beginning of the present research work -“Addressing the diversity of individuals when designing behaviour change strategies in the context of pro-environmentalism improves the awareness and performance towards sustainable behaviour”- has been fulfilled by accomplishing the main objective the subsequent specific goals.

6. 3 Publications and awards

As a result of this research work several scientific manuscripts have been published in different journals and conferences. In this section we introduce these publications and their associated references.

6. 3. 1. Publications comprising this dissertation

The main results exposed in this thesis have been published in several International JCR Journals.

The first manuscript, included in the Chapter 3 of the present thesis, is related to a review of the state of the art, and it was published in the following journal:

- * Ane Irizar-Arrieta, Oihane Gómez-Carmona, Aritz Bilbao Jayo, Diego Casado-Mansilla, Diego López-de-Ipiña, Aitor Almeida. (2020) “Addressing Behavioural Technologies Through the Human Factor: A Review” In IEEE Access. vol. 8. p. 52306-52322. DOI: 10.1109/ACCESS.2020.2980785. JCR Impact Factor (2020): 3.745, Q1. November 2020.

Also, the next stage of this dissertation, where the theoretical scope and implementation of the theoretical findings is exposed, has been included in Chapter 4 and published in another relevant journal (International Journal of Human-Computer Studies).

- * Ane Irizar-Arrieta, Diego Casado-Mansilla, Pablo Garaizar, Diego López-de-Ipiña, Aiur Retegi. (2020) “User perspectives in the Design of Interactive Everyday Objects for Sustainable Behaviour” In International Journal of Human-Computer Studies. p. 102393. DOI: 10.1016/j.ijhcs.2019.102393. JCR Impact Factor (2020): 2.006, Q2. November 2020.

Finally, the work presented in Chapter 5, where a novel framework to address the diversity of individuals and the exploration of its potential application is exposed, has been published in another Indexed International Journal.

- * Ane Irizar-Arrieta, Diego Casado-Mansilla, Aiur Retegi, Matthias Laschke, Diego López-de-Ipiña. (2020) “Exploring the Application of the FOX Model to Foster Pro-Environmental Behaviours in Smart Environments” In Sensors MDPI. vol. 20 (16). p. 1-26. DOI: 1424-8220. JCR Impact Factor (2020): 3.275, Q1. November 2020.

6. 3. 2. Other relevant publications

Complementarily to the main JCR manuscripts included in this thesis, another several research pieces related to this dissertation have been presented in International Conferences:

- * Presentation of a preliminary research work including the evaluation and analysis of a digital tool to address sustainable behaviour taking into account the user diversity: Ane Irizar-Arrieta, Diego Casado-Mansilla. (2017) “Coping with user diversity: UX informs the design of a digital interface that encourages sustainable behaviour” In 11th Multi Conference on Computer Science and Information Systems 2017.
- * Presentation of a specific contribution detailing the design and ideation of the Interactive Coaster: Ane Irizar-Arrieta, Diego Casado-Mansilla, Aiur Retegi. (2018) “Accounting for User Diversity in the Design for Sustainable Behaviour in Smart Offices” In Proceedings of conference: 3rd International Conference on Smart and Sustainable Technologies.
- * Presentation of the initial approach of the FOX model: Ane Irizar-Arrieta, Aiur Retegi, Diego Casado-Mansilla, Matthias Laschke, Diego López-de-Ipiña. (2019) “FOX: A Flexible and Heterogeneous Mixed User Model to Address Sustainable Behaviour in Smart Environments” In Proceedings. vol. 31. p. 82. DOI: 10.3390/proceedings2019031082. In Proceedings of conference: 13th International Conference on Ubiquitous Computing and Ambient

The preliminary work that led to this dissertation was extended and published in the following International Journal:

- * Ane Irizar-Arrieta, Diego Casado-Mansilla, Aiur Retegi. (2018) “Evaluation of a digital interface that integrates user diversity to aware individuals about energy” In IADIS International Journal on Computer Science and Information Systems. vol. 13. p. 110-124. ISSN: 1646-3692.

6. 3. 4. Co-authored publications

Other co-authored contributions related to this dissertation are:

- * Diego Casado-Mansilla, Ane Irizar-Arrieta, Pablo Garaizar, Diego López-de-Ipiña. (2018) “Design-insights for Devising Persuasive IoT Devices for Sustainability in the Workplace” In 2018 Global Internet of Things Summit (GIoTS). DOI: 10.1109/GIOTS.2018.8534578.
- * Casado-Mansilla, D., Irizar-Arrieta, A., Solabarrieta-Román, M., Manterola-Lasa, A., Kamara-Esteban, O., Tsolakis, A. C., ... & López-de-Ipiña, D. (2020, Septem-

ber). Lasting and Spillover Effects of Ambient Eco-Feedback in the Office-based Workplace. In 2020 5th International Conference on Smart and Sustainable Technologies (SpliTech) (pp. 1-6). IEEE.

6. 3. 5. Awards

The author of this dissertation has been honored with the Atlas award. A distinction conferred by the prestigious Elsevier publishing house for her contribution and research impact to SDG-12: responsible consumption and production.

Besides, the publication "Coping with user diversity: UX informs the design of a digital interface that encourages sustainable behaviour" was selected for the Best early Career Research Award at the 11th Multi Conference on Computer Science and Information Systems, 2017.

6. 4. Future work

Inspired by the challenges discovered in this dissertation, we have identified the following further research lines:

FOX model: rules and measures. As we exposed in Chapter 4, the FOX model offers a promising framework to understand and face the diversity of individuals dynamically. For that, a relevant future challenge identified when applying the framework is to define the rules, tools and methods for measuring dimensions, stages, and characteristics of the meta-model. This is a paramount factor that should be defined using the less intrusive way for data gathering and taking into account the specific context and the available resources for each context. This will encourage a more accurate and adapted framework. Besides, the model should be tested with different groups and individuals in order to include valuable insights from different points of view and to validate the FOX model. Another future research idea linked to this, is related to the complementation of the model with other specific and context-related dimensions. Thus, the future research could explore and define other complementary and relevant non-behavioural dimensions to improve the coverage of the model such as demographics. Besides, the application of the model could be further explored, implementing the framework through different methods and processes to better understand its possibilities.

Analyse pro-environmental practices. Another relevant future research line discovered in this dissertation is related to sustainable practices themselves. In order to better understand how to improve their acceptance, these should be deeply investigated and understood. Following the approach exposed by Kuijer [19], pro-environmental practices can be contextualised as a unit of design and thus, we can reframe them taking into account

specific design insights. These ideas should be further analysed to extract findings and knowledge that will help researchers and practitioners to design elements that will improve and enhance these practices.

Analyse motivations of individuals regarding pro-environmentalism. In addition to the improvement of the understanding regarding pro-environmental practices, the inherent motivations of the individual must be also studied. Although specific interventions can be addressed in a personalised way by applying the framework presented in this thesis, to define the content and information of each input, the motivations and needs of people should be taken into account to develop successful and meaningful strategies. Thus, taking into account the Self-Determination Theory presented by Ryan and Deci [29], a promising research line could be the contextualisation of pro-environmental practices into the needs and motivations of individuals. This could guide the design of novel technological devices both addressing the pro-environmentalism and inherent motivations and needs of people.



REFERENCES



1. I Ajzen. 2002. Perceived Behavioral Control, Self Efficacy, Locus of Control, and the Theory of Planned Behavior. *Journal of applied social psychology*. 32, 4: 665–83.
2. Icek Ajzen. 1991. The theory of planned behavior. *Organizational Behavior and Human Decision Processes* 50: 179–211. [https://doi.org/10.1016/0749-5978\(91\)90020-T](https://doi.org/10.1016/0749-5978(91)90020-T)
3. Eli Blevis. 2007. Sustainable interaction design: Invention & disposal, renewal & reuse. *Conference on Human Factors in Computing Systems - Proceedings*: 503–512. <https://doi.org/10.1145/1240624.1240705>
4. Stefan Blomkvist. 2002. Persona – an overview. *Proceedings of Theoretical perspectives in Human-Computer Interaction*: 1–8.
5. Jose Bravo and Diego Lopez-de-Ipina. 2011. Theme issue: “ubiquitous computing and ambient intelligence.” *Personal and Ubiquitous Computing* 15, 4: 315–316. <https://doi.org/10.1007/s00779-010-0358-9>
6. Diego Casado-Mansilla. 2016. Promoting long term energy-efficient behaviour in work environments through persuasive technologies. University of Deusto, Bilbao, Spain. Retrieved from <https://morelab.deusto.es/media/publications/theses/diego-casado-mansilla.pdf>
7. Diego Casado-Mansilla, Ane Irizar-Arrieta, Mikel Solabarrieta-Roman, Aratz Manterola-Lasa, Oihane Kamara-Esteban, Apostolos C. Tsolakis, Stelios Krinidis, Dimitrios Tzovaras, Cruz E. Borges, and Diego Lopez-De-Ipina. 2020. Lasting and Spillover Effects of Ambient Eco-Feedback in the Office-based Workplace. 2020 5th International Conference on Smart and Sustainable Technologies, Spli-Tech 2020. <https://doi.org/10.23919/SpliTech49282.2020.9243717>
8. Kathy Charmaz and Linda Belgrave. 2007. Grounded Theory. *The Blackwell Encyclopedia of Sociology* 12, 2007: 4–8. <https://doi.org/10.1002/9781405165518.wbeosg070.pub2>
9. Aykut Coskun and Cigdem Erbug. 2016. Exploring and communicating user diversity for behavioural change. 2016 Design Research Society 50th Anniversary Conference 4: 1357–1374. <https://doi.org/10.21606/drs.2016.73>

10. Aykut Coskun and Cigdem Erburg. 2014. User diversity in design for behavior change. *Proceedings of DRS 2014, JUNE 2014*.
11. Carl DiSalvo, Phoebe Sengers, and Hrönn Brynjarsdóttir. 2010. Mapping the landscape of sustainable HCI. *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10: 1975*. <https://doi.org/10.1145/1753326.1753625>
12. Ha He, Saul Greenberg, and Em Huang. 2010. One size does not fit all: applying the transtheoretical model to energy feedback technology design. ... of the 28Th International Conference on ...: 927–936. <https://doi.org/10.1145/1753326.1753464>
13. Eric B Hekler, Predrag Klasnja, Jon E Froehlich, and Matthew P Buman. 2013. Mind the Theoretical Gap: Interpreting, Using, and Developing Behavioral Theory in HCI Research. *Proc. CHI 2013: 3307–3316*. <https://doi.org/10.1145/2470654.2466452>
14. S. Hosono, M. Hasegawa, T. Hara, Y. Shimomura, and T. Arai. 2014. A methodology of persona-centric service design. *Competitive Design - Proceedings of the 19th CIRP Design Conference, March: 541–546*.
15. A. Irizar-Arrieta, D. Casado-Mansilla, and A. Retegi. 2018. Accounting for User Diversity in the Design for Sustainable Behaviour in Smart Offices. In *2018 3rd International Conference on Smart and Sustainable Technologies, SpliTech 2018*.
16. Ane Irizar-Arrieta, Aiur Retegi, Diego Casado-Mansilla, Matthias Laschke, and Diego López-de-Ipiña. 2019. FOX: A Flexible and Heterogeneous Mixed User Model to Address Sustainable Behaviour in Smart Environments. *Proceedings 31, 1: 82*. <https://doi.org/10.3390/proceedings2019031082>
17. Maurits Kaptein, Panos Markopoulos, Boris De Ruyter, and Emile Aarts. 2015. Personalizing persuasive technologies: Explicit and implicit personalization using persuasion profiles. *International Journal of Human Computer Studies 77: 38–51*. <https://doi.org/10.1016/j.ijhcs.2015.01.004>
18. Julie A Kientz. 2010. *Persuasive Technology. 6137, June 2017*. <https://doi.org/10.1007/978-3-642-13226-1>
19. Lenneke Kuijer and Annelise De Jong. 2009. A practice oriented approach to user centered sustainable design. *Proceedings of the 6th International Symposium on Environmentally Conscious Design and Inverse Manufacturing: 1–6*. Retrieved from http://studiolab.ide.tudelft.nl/studiolab/kuijer/files/2011/12/EcoDesign2009_Kuijer_copyright-JSME.pdf
20. Debra Lilley. 2009. Design for sustainable behaviour: strategies and perceptions. *Design Studies 30, 6: 704–720*. <https://doi.org/10.1016/j.destud.2009.05.001>

21. Dan Lockton, David Harrison, and Neville a. Stanton. 2012. Models of the user: designers' perspectives on influencing sustainable behaviour. *Journal of Design Research* 10, 1/2: 7–27. <https://doi.org/10.1504/JDR.2012.046137>
22. Daniel Lockton, David Harrison, and Neville A. Stanton. 2008. Making the user more efficient: design for sustainable behaviour. *International Journal of Sustainable Engineering* 1, 1: 3–8. <https://doi.org/10.1080/19397030802131068>
23. Jennifer C Mankoff, Eli Blevis, Alan Borning, Batya Friedman, Susan R Fussell, Jay Hasbrouck, Allison Woodruff, and Phoebe Sengers. 2007. Environmental Sustainability and Interaction. In (CHI EA '07), 2121–2124.
24. Susan Michie, Michelle Richardson, Marie Johnston, Charles Abraham, Jill Francis, Wendy Hardeman, Martin P. Eccles, James Cane, and Caroline E. Wood. 2013. The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: Building an international consensus for the reporting of behavior change interventions. *Annals of Behavioral Medicine* 46, 1: 81–95. <https://doi.org/10.1007/s12160-013-9486-6>
25. Andreas Nilsson, Magnus Bergquist, and Wesley P. Schultz. 2017. Spillover effects in environmental behaviors, across time and context: a review and research agenda. *Environmental Education Research* 23, 4: 573–589. <https://doi.org/10.1080/13504622.2016.1250148>
26. Petromil Petkov, Suparna Goswami, Felix Köbler, and Helmut Krcmar. 2012. Personalised eco-feedback as a design technique for motivating energy saving behaviour at home. *Proceedings of the 7th Nordic Conference on Human-Computer Interaction Making Sense Through Design - NordiCHI '12*: 587. <https://doi.org/10.1145/2399016.2399106>
27. Jeffrey Pfeffer. 2010. Building sustainable organizations: The human factor. *Academy of Management Perspectives* 24, 1: 34–45. <https://doi.org/10.5465/AMP.2010.50304415>
28. K.E.; Prochaska, J.O.; Redding, C.A.; Evers. 2015. The transtheoretical model and stages of change. In *Health Behavior: Theory, Research, and Practice*. San Francisco, USA, 125–148.
29. Richard M Ryan and Edward L Deci. 2000. Self-Determination Theory and the Facilitation of Intrinsic Motivation, Social Development, and Well-Being. 55, 1: 68–78.
30. T.A. Schwandt and E.F. Gates. 2017. Case study methodology. In *The Sage Handbook of Qualitative Research*. SAGE Publications Inc., 341–358.
31. P. C. Stern, T. Dietz, T. Abel, G. A. Guagnano, and L. Kalof. 1999. A value-belief-norm theory of support for social movements: The case of environmental-

- lism. *Human Ecology Review* 6, 2: 81–97. <https://doi.org/10.2307/2083693>
32. Paul C. Stern. 200AD. Toward a Coherent Theory of Environmentally Significant Behavior. *Journal of Social Issues* 56, 3: 407–424. <https://doi.org/10.1111/0022-4537.00175>

