Systemic Design for the innovation of home appliances
The meaningfulness of data in designing sustainable systems

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30th Cycle

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By Eleonora Fiore

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Politecnico di Torino
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I would like to dedicate this thesis to my family, the one from which I came and the one that is going to be.

Declaration

I hereby declare that, the contents and organization of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

Eleonora Fiore
2018

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Abstract

This work addressed the domestic environment considering this context as a complex system characterised by significant impacts in terms of resource consumption. Within the theoretical framework of Systemic Design (SD), this thesis focused on home appliances, in order to understand how to reduce the impact directly attributable to them, while optimising and simplifying daily tasks for the user. A design methodology towards environmental sustainability has been structured, by focusing on the use of data for design purposes and on creating value for the user through meaningful products. It considers the user, the product and the environment as central topics, by giving them the same relevance and the literature review is structured accordingly, investigating needs and requirements, ethical issues, but also current products and future scenarios. During my experience at TU Delft, I spent six months in the Department of Internet of Things at the Faculty of Industrial Design Engineering. Together with computer scientists, we developed a prototype to collect some missing data, establishing the importance of grounding the decision-making on reliable information. IoT and data gathering open a variety of possibilities in monitoring, accessing more precise knowledge of products and households useful for design purposes, up to understand how to fill the gap perceived by the user between needs and solutions. It considered the potential benefits of using IoT indicators to collect missing information about both the product, its use and its operating environment to address critical aspects in the design stage, thus extending products' lifetime. This thesis highlighted the importance of building multidisciplinary design teams to investigate different classes of requirements, and the need for flexible tools to cope with complex and evolving requirements, the co-evolution of problem and solutions and investigating open-ended questions. This approach leaves room for addressing every step of the traditional life-cycle in a more circular way, shifting the focus from the life-cycle centrality of the previous century to a more complex vision about the product.

Contents

Preface

Nowadays, society is experiencing a significant number of changes such as increasing competitiveness and the expansion of technological resources (de Arruda Torresa, 2017). These changes are also experienced in design research. Simona Morini in her opening speech at FRID 2017 tried to answer the two questions: 'how does design research change?' and 'why does it change?' She identified among the causes, (i) the introduction of new technologies and communication tools, (ii) a change of scale from local to global, (iii) a change in methods and in the idea of 'knowledge' itself (i.e. Artificial intelligence, robotics, IoT). Among the other factors that are fuelling this fire, more demanding and informed consumers, as well as the rise of sustainability concerns in an unstable environment, with financial crises of traditional economies (de Arruda Torresa, 2017). Moreover, de Arruda Torresa (2017) highlights some trends to express the influence of this changing scenario on society with the role of 'experience' that has overcome the need for owning things, the uncertainty of a networked society, creation of intangible value, products and services merging, low barrier to the creation of new business models, the explosion and influence of social networks and the birth of an ethical green economy. Bauman (2000) describes this change in values as a move from 'solid modernity' to 'liquid modernity'. After investigating the field of investigation in chapter 1, focusing on the smart appliances, in chapter 2 I introduce the shift from a deterministic mechanical image of the world, to complex non-linear systems. Increased complexity adds more and more factors and makes it difficult to simplify in a complex world, leading to fluid and unclear situations. In this complex scenario designers, however, can use methods to simplify a certain node of the complex system network. In the same chapter, we can see how the evolution of the role of designer consists in the art of dealing with open-ended questions (Sanders and Stappers, 2008), accepting that he/she will not be able to answer all questions. In chapter 2 I addressed the fluidity of design, while I look at the ethical perspective in chapter 3, addressing designer's responsibilities and ethical implications of dealing with new ubiquitous technologies. I see the 'potential' in new technologies and the data they make available to be used in the design process, overcoming our computational brain limits and thus playing a role in problem-solving. For this reason, throughout this thesis, I tried to answer the question: ''which analytic guidance can Systemic Design approach combined with data-driven design provide designers?'' I believe that framing the problem, understanding stakeholders involved, contexts and relationship generated is more relevant than identifying a unique design solution to that problem. Quoting the inspiring words of Morini, solutions will emerge at a certain equilibrium point, when the system stabilises. Besides, I believe that asking questions is the effort of intelligence that designers are required to provide, as well as framing the research, understanding where we want to go and how. Although innovation is often attributed to R&D centers of large companies, which financed laboratories and research that would lead to market their discoveries (de Arruda Torresa), in this thesis I decided to go beyond the firm's immediate stakeholders and boundaries (Ceschin and Gaziulusoy, 2016), keeping companies out of this thesis. I took this decision in particular for the first stage of the research because dealing with socio-technical systems was quite challenging and I preferred to avoid adding further complexity by including other constraints, goals and interests, especially when these are tightly related to the size of big-players (plants, machinery, suppliers, global dynamics). The size of a start-up would have been more congenial to this type of research, however, I would need at least 20 different professional figures with different backgrounds working in it. If I had built it from scratch, I would have work with local suppliers for electronics, components and services. However, this is not the case since I do not have the entrepreneurial attitude needed. I decided to provide what it is expected from design research, according to Zimmerman et al. (2007), i.e. an intention to produce knowledge for the research and practice communities, not to make a commercially viable product nor immediately inform a commercial product.

> *Although the importance of the design project needs to be recognised [..], it should never become the central purpose of the research project, [..] the main product of which should remain design knowledge* (Jonas, 2007).

The work presented in this thesis is hopefully a small step towards increasing the sustainability of product design. For this reason, chapter 4 focuses on Design for Sustainability, while in chapter 5 the need for the research is explained. In chapter 6 a focus on current products is presented while experiments and results are discussed in chapter 7. Chapter 7 and 8, indeed, summarised the main research findings and provided an overview of foreseeable future in this field. Chapter 9 provides an overview of the methodology used and how it responds to the research questions. The methodology presented should help designers to gain a deep knowledge of processes, context, stakeholders and products and combine it with smart enabling technology able to provide data and quantified knowledge. It prepares the designer to work in trans-disciplinary research projects, with the goal of design meaningful and relevant products for the user, with the environmental sustainability in mind.

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Chapter 1

Field of investigation

Investigating home appliances from a wider scenario, I followed the dynamics of this turbulent market. The appliance industry is closely related to the steel industry that experienced a post-war boom from 1954. Over the decades following the post-World War II up to recent times, household appliance manufacturers have evolved different mechanisms and framed different strategies to make their business successful. Back to the ‘80s most of the companies realised that their markets in Europe and the USA were saturated. They started focusing on emerging markets, and hence, it came to the need for globalisation (Fiore et al., 2017). The strategy developed leads to economies of scale, product synergies and a strong brand presence (Shyam, 2008). However, from the beginning of the new century, this industry has faced several challenges (Fiore et al., 2017), including the incursion of low-cost-country competitors, which pushed the manufacturers to lower prices, while replacing the production at the expense of quality (Bernard, 2007). Later, they found at their own expense that these strategies could not be considered as effective, since they lead to losing market share, undermining companies' competitive position (Spanos et al., 2004). From 2009 to 2013 a deep crisis affected the industry (Mintel, 2016). This event led to the failure of small companies and the reduction of jobs, highlighting a general lack of new strategies (Fiore et al., 2017). Nevertheless, some producers began to focus on the design process, with the aim to innovate the industry. Technological improvement has occurred, and the vigorous progress in the Internet of Things (IoT) solutions promoted the development of connected devices (Fiore et al., 2017).

1.1 Market and strategies

Before the crisis, the entrance of a low-cost competitor was generally followed by companies' differentiation of products, cutting of prices or both (Bernard, 2007). Nevertheless, strategic success could be identified on how manufacturers adapt to changes in a turbulent market (Shyam, 2008). Although the competition from low-cost countries is a relevant issue, some big players tackle the problem by increasing investment in R&D, segmenting their products to reach the needs of different regions and developing connected appliances (Electrolux, 2015). Among the strategies developed, in addition to those concerning mergers and acquisitions (i.e. Haier and General Electrics, 2016; Whirlpool and Indesit, 2014), we can include the cooperation with big players in other industries. Indeed, Electrolux is currently working with Google to implement connected appliances integrated with Google's smart home platform, while both Electrolux and Whirlpool are working with Ikea to develop built-in solutions with smart features. This trend suggests many other partnerships (Fiore et al., 2017).

1.1.1 Current market

Nevertheless, today the market for household appliances is still remarkable. In 2014, the total turnover of the major appliances weighted USD 44 billion, representing 350 million units sold (Volpe, 2015). This analysis relied on 50 manufacturers and included refrigerators and freezers, washers and dryers, dishwashers, hoods and cooking appliances (Figure 1).
For this reason, the attempt to develop innovative strategies in this area seems to be significant. Indeed from 2013 the appliance sector experiences an average growth rate of around 12 percent per annum (Mintel, 2016). The reason of these increases, along with the renewed purchasing power, could be identified in the entrance of new young and omnichannel consumer asking for new features (37 percent, see chapter 6), while the replacement of a worn-out appliances remains the most common purchase motivation (3/5 of new purchases, around 58 percent). Energy conservation seems to grow in importance since 30 percent of consumers chooses to upgrade their appliance for energy saving options.

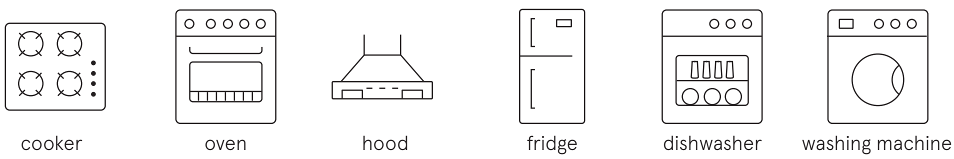


Fig. 1 - Design focus: major appliances or white goods

> *For the last 100 years, dryers, ovens, refrigerators, washing machines and other household appliances have performed the same basic functions, such as keeping food hot or cold and getting clothes wet and dry. But, a new breed of "smart" appliances is emerging, thanks to advanced sensor technology and the Internet of Things (IoT)* (Weber, 2016).

Beyond big players such as Electrolux, General Electric and Whirlpool, the drive towards innovation is also bringing out other smaller players (small start-up companies), that can afford to experiment more easily, thanks to their smaller size (Weber, 2016). Among other implications, this consideration hides a new unexplored potential in the field of home appliances, made of start-ups and new business models.

Nearly 1/4 (22 percent) of Americans replaced their last appliance to get a bigger model (Fiore et al., 2017). This trend has been confirmed also in a study in the Netherlands (Bakker et al., 2014) limited to refrigerators addressed in chapter 6. Finally, 1/5 (19 percent) consumer replaced appliances as part of remodelling or renovation (Mintel, 2016).

1.1.2 Problem definition

Smart appliances seem to be the future of the appliance industry (Acquiti Group, 2014; 2016) and appliance manufacturers continue to innovate with new smart features and technologies their products (chapter 6). However, many market research reveals that smart appliances so far have failed to spark significant interest in households (Figure 2), which is confirmed their low purchase rate (Gfk, 2016b; Mintel 2016).

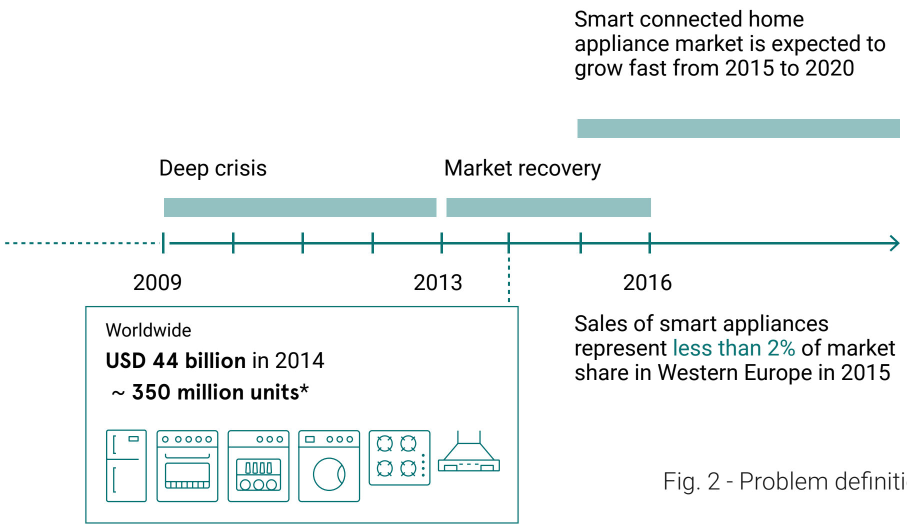


Fig. 2 - Problem definition

> *Despite years of trade show displays and prototypes, sales of smart, connected large home appliances remains a tiny fraction of overall sales* (Weber, 2016).

Nevertheless, many good reasons would see a profitable development of smart appliances, not only as additional techno-push solutions and features. I made some assumptions to validate them through the thesis. I have therefore identified the positive aspects of using smart products, from performing predictive maintenance, remote control and so forth, up to improve the energy efficiency and resource management by focusing on usage dynamics. In my opinion, smart products could also positively effect circular economy (CE) strategies, increasing the knowledge about the status of the products currently used and provide a network of services.

1.1.3 Identification of causes

What hinder this adoption? Gann, Barlow and Venables (Gann et al., 1999) made a comparison between the development of smart home systems and the early market of electric appliances. I adapted the comparison, introducing 'smart appliances' instead of 'smart home systems in general', to compare two groups of defined objects: the early developed appliances and the smart-connected ones.

> *Before demand for electrical appliances took off, a number of preconditions had to be met, including a cheap supply of electricity, cheap and reliable appliances and the installation of a distribution and wiring system* (Aldrich, 2003 p.23).

Nowadays the scenario is not so far from that. As mentioned by the social scientist Frances K. Aldrich (2003) the high initial investment is still an obstacle to the consumer take-up as well as the reliability of those products, the dependence on old housing stock, which pushes equipping houses retrospectively (Fiore et al., 2017). We can identify some barriers to market development in poor usability in addition to a strong technology push by suppliers (Aldrich, 2003). Several years have been passed, and we continue to identify the same problems.

> *Effective product design and innovation are the results of an integrated, thoughtful process that focuses on making things that simplify, delight, or enrich the lives of people. [..] Companies have been pushing IoT technology rather than addressing the pull of customer needs and tastes.* (Nelson and Metaxatos, 2016)

Moreover, according to Vitali et al. (2017), a product can be defined as smart when its interface and functions are connected to real user needs and habits. A traditional appliance cannot learn based on its consumer's needs. However, many traditional appliances have sophisticated electronics that lead consumers thinking they are 'smart' (Weber, 2016). In general, according to de Arruda Torresa (2017), the industry fails to keep up with people changing needs and desires, not addressing real problems, daily problems. From recent market studies (Accenture Interactive, 2015; Downes, 2016; Gfk, 2016a) we can draw some conclusions about what currently hinders a widespread adoption of connected appliances, i.e. a future adoption that has been widely lauded as heralding economic and social benefits (Lindley et

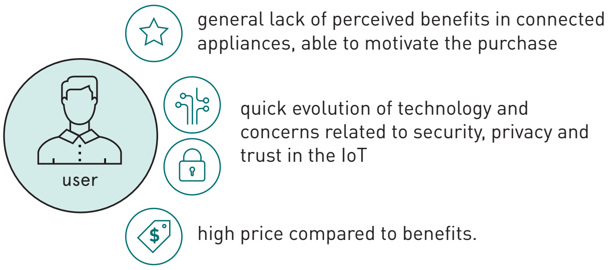


Fig. 3 - Obstacles to the development of connected appliances

al., 2017), highlighting some common causes (Figure 3):

1. General lack of perceived benefits in connected appliances, able to motivate the purchase;
2. Quick evolution of technology and concerns related to security, privacy and trust in the IoT (Lindley et al., 2017);
3. High price compared to benefits.

We do now have a plethora of devices with computer technology inside that are partially connected and with which we interact differently than before. At the same time, the market has brought to life many devices which are redundantly technically enhanced (Schurig and Thomas, 2017) and fail to improve the wellbeing of their users (Mink, 2016).

This research addresses the home environment as a complex system, understanding how to design meaningful and relevant products for the user, with the environmental sustainability in mind. Part of this work is then dedicated to coping with the general lack of perceived benefits in new connected products.

> *Since making functional products that are of value to users and enhance our human traits is what design should truly aim for* (Streitz, et al., 2005)

For this reason, in this section I started to focus on the last two points (technology and price) that are easier to circumscribe, developing the first point in the remaining of this thesis.

1.1.4 Quick evolution of technology and privacy concerns

Some authors believe that ‘people do not want to interact with computers but want to do tasks’ (Schurig and Thomas, 2017). In other words, *"people do not usually want the technology itself, but the results it achieves"* (Vitali et al., 2017), suggesting that technology should be hidden in favour of performances *"by making it invisible and letting people only aware of its purposes, with a familiar, engaging language"* (Vitali et al., 2017).

> *If the application is successful, then the technology itself becomes invisible. The device becomes a friend, something to rely on, a capable partner* (Semmelhack, 2013).

It follows that technology is something not engaging nor familiar, confirming what comes from consumer surveys. Automated behaviours are not always understandable to the user and thus could lead to possible confusion (Schurig and Thomas, 2017). Dealing with users and technology, we need to deal with the implication of new technologies on user’s life. For this reason, we started with an analysis of the quick evolution of technology and the concerns it raises. As mentioned before, from the user perspective we can glimpse different causes that make the user feel unsafe or inadequate to a certain technology. They can be grouped into four categories.

1. **Control**. Lose the control over automated system’s activities (Bonino and Corno, 2011).
2. **Complexity**. Feel inadequate in facing innovative technologies (Bonino and Corno, 2011).
3. **Obsolescence**. “Disconnection between the long-life expectancy of most major appliances and the far faster life cycle of most technology. Smart features on an appliance sold today may feel dated long before the appliance itself is worn out” (Mintel, 2016).
4. **Interoperability**. Lack of standards and compatibility among connected devices. “Will the appliance I buy today communicate with other things in my home? [..] Maybe, but you can’t be sure. I expect over time this issue will recede, but there is a risk of stranded devices” (Weber, 2016).
5. **Security and privacy**. Provide to strangers an access breach to the household through technology and give data to third parties (Downes, 2016).

These concerns are partly justified since planned obsolescence has been proven to be a business strategy (chapter 4) and the data turned out to be poorly protected by companies. The industry is asking people to install expensive and semi-

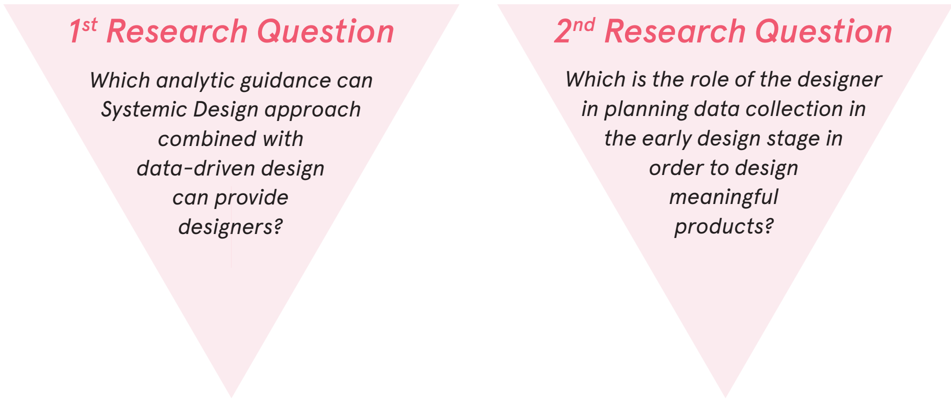


Fig. 4 - Research questions

permanent object in their homes while failing to provide reliability that standards will not last a single year on products that are supposed to last for 10 or 15.

On the other hand, about privacy and security aspects, the Federal Trade Commission (FTC) has already extracted settlements from several manufacturers for failing to protect user data (Downes, 2016). Some recent internet-of-things breaches have been orchestrated by so-called white-hat hackers — security experts hoping to expose the poor practices of connected device manufacturers (Downes, 2016). We addressed the ethical issues related to the technology in detail in chapter 3.

1.1.5 High price compared to benefits

> *Although the youngest, and presumably most tech-savvy, consumers are considerably more likely than their older counterparts to say they would pay more for smart features, the reality is that most don't have the financial means to afford the super-premium price tags that most smart appliances carry* (Mintel, 2016).

It is undeniable the comparatively higher price of connected devices when compared to their unconnected counterparts. This aspect may provide an explanation for the slow adoption of domestic IoT devices, despite their manufacturers' attempts to boost sales (Lindley et al., 2017). However, in the near future, the use of smart enabling technologies may not result in higher cost and, a fortiori, if the benefits were adequate, the price war would not exist.

1.2 Research questions

The two research questions addressed during my PhD are the following:

1. Which analytic guidance can Systemic Design approach combined with data-driven design provide designers?
2. Which is the role of the designer in planning data collection in the early design stage in order to design meaningful products?

The literature review was structured according to these research questions, (Figure 4) covering main areas regarding the user, the product, the environment and the context. The more we add variables, the more we need a multidisciplinary approach, different skills and expertise. The methodology developed in this thesis aims to cope with this complexity. It provides a guide in addressing trans-disciplinary research projects on sociotechnical systems, in which the designer/research group wants to explore messy, problematic situations characterised by conflicting perspectives of the stakeholders, that cannot be accurately modelled and cannot be addressed using other design approaches. However, we need to explain why a designer should be involved in those trans-disciplinary teams, introducing the concept of 'designing at the edge of different disciplines', before proceed with the literature review.

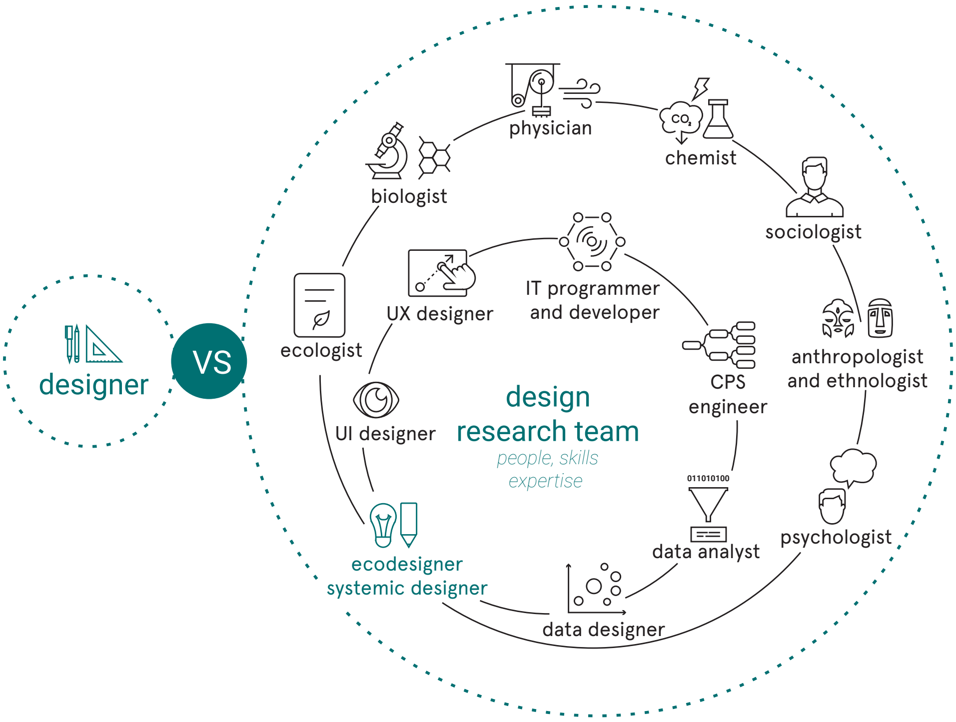
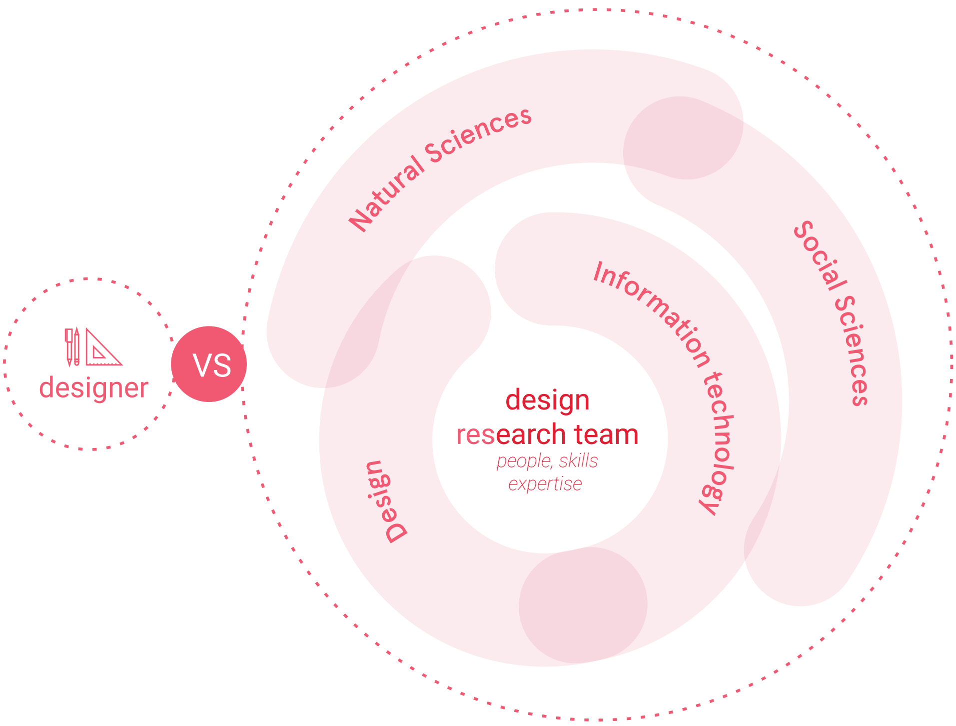


Fig. 5 - The role of the research team in designing connected appliances



1.2.1 Designing at the edge of different disciplines

Design is a field that constantly evolves and the role of the designer also changes over time. Design thinking has provided the typical design overview to other sciences or practical applications, emphasising design's dynamism and its ability to evolve. Recently it has been experiencing a significant change towards multidisciplinary contaminations with other disciplines. This change is bidirectional. On the one hand, more and more companies, start-ups ff and research centres are experiencing the benefits of including designers in their teams and the value of multi-disciplinary activities. This is partly due to the applied dimension of design, whose 'design thinking' is successfully applied to other topics. Recently, the EU is enhancing the design in policymaking, leading to trans-disciplinary research projects able to explore design values to other disciplines. On the other hand, designers find new spaces for the application of his/her expertise. Product design as such is experiencing a loss of interest of researchers, in favour of design at the edge of different disciplines. This is the case for collaboration between design, Business and Management in Product-Service Systems (PSS); Psychology and Sociology for the study of behaviour, feedback and consumer acceptance; Medicine and Sociology in Design for Healthcare, Computer Sciences for the development of IoT products.

In this last scenario, I hypothesised an ideal work team for the development of connected and smart devices, which includes several designers and engineers, as well as other experts from both Natural and Social Science (Figure 5). In fact, designing products in sociotechnical systems requires the designer to work with other experts in order to explain the dynamics he/she faces. This aspect will be clarified in chapter 2 and further specified in the thesis

Designer will have to collaborate with other experts, but also accept another point of view, that comes from IoT objects, in which the product itself constitutes a form of design agency (object-centred approach; Lindley et al., 2017; Cruickshank and Trivedi, 2017; Thing Ethnography - Giaccardi et al., 2016).

1.3 Literature review

We reviewed the design research literature investigating different topics, although not all belonging to the design sphere. Together with design in general, design for sustainability (DfS) and Systemic design (addressed in chapter 2 and 4), we investigated also papers from management engineering, energy engineering, computer science, ethics and philosophy. The variety of sources gives an idea of the variety of topics covered, shown in Figure 6, with the effort to always bring them back to the design of STS as pieces to add to the methodology. This literature review means to ground my inquiry, focusing on my research questions, with the ambition of generating a positive impact on future product development, increase the product sustainability by decreasing the environmental impacts attributable to it, increasing the strategies towards a CE as well as the impact on policies.

Considering design papers only, they derive from scientific journals such as Design Issues, Design studies and International Journal of design; She Ji when it comes addressing the Systemic Design; International Journal of Sustainable Engineering, Journal of Cleaner Production and Journal of Industrial Ecology for those concerning DfS. For the literature review related to Human-Centred Design, instead, Interactions provided some interesting papers to the debate. Considering the conferences, instead, much of the literature in design of this area is related to a few conferences such as EAD (European Academy of Design Conference), DRS (Design Research Society Conference), Cumulus (International Association of Universities and Colleges of Art, Design and Media), PLA∑TE (Product Lifetimes and the Environment Conference), two of which (EAD and PLATE) have been attended by the author in 2017.

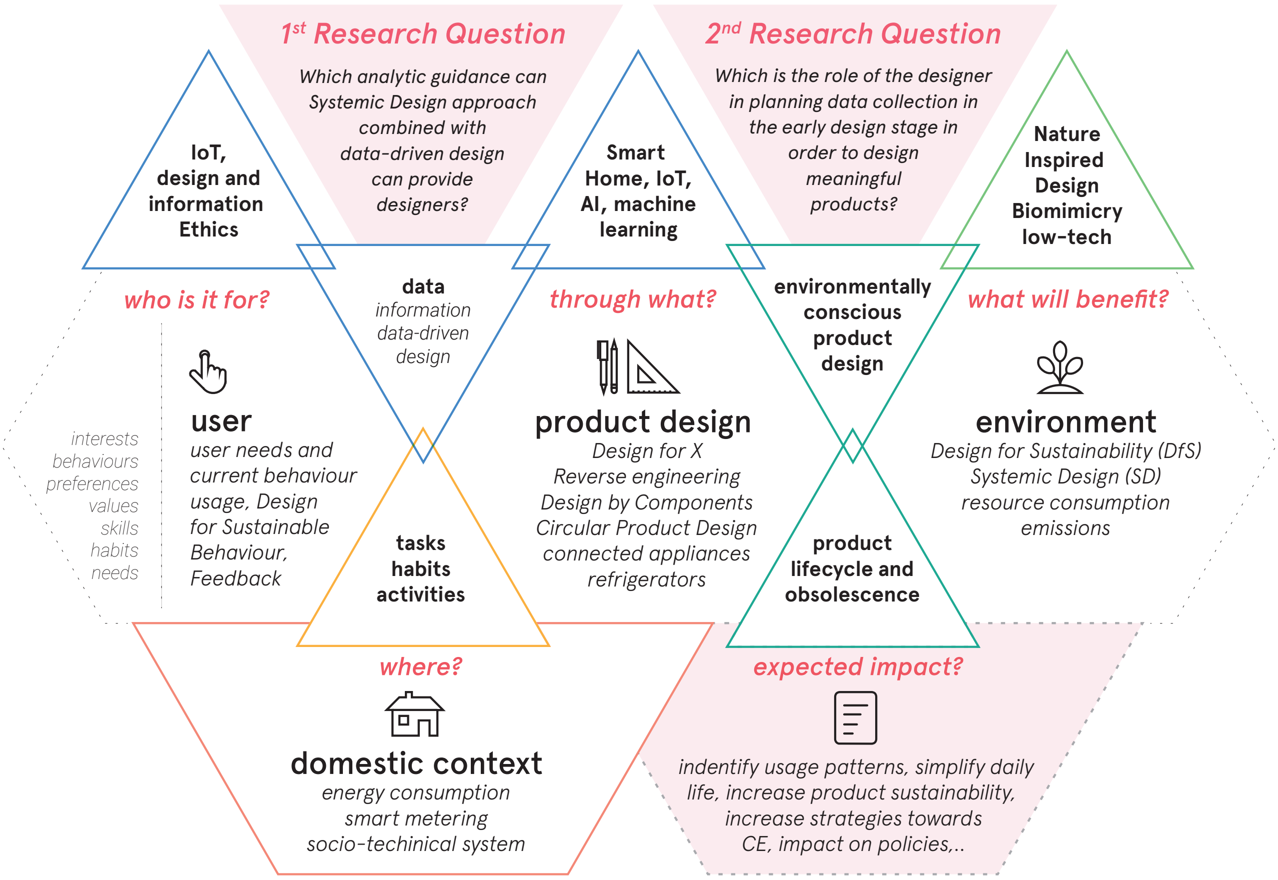


Fig. 6 - Literature review and expected impacts

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Chapter 2

Design research and studies on requirements

This chapter investigates the design scene, by focusing on the role of requirements in product design. It gathers insights from books such as 'Design Research Now' combined with several essays and papers ('Where are the design methodologists?', 'Research through design as a method for interaction design research in HCI' to name a few) from the design field, but not limited to it ('Design Requirements Engineering'). Moreover, this chapter attempts to introduce the Italian design background that led to the design methodology developed at the Politecnico di Torino, based on needs and requirement. The section about requirements ends with an application of the methodology to the specific case study of homd appliances and continues highlighting the need for participatory design process involving specific stakeholders. The chapter deals with the management of evolving requirements, stakeholders and contexts in the last part, called 'the fluidity of design'.

2.1 Design research

The reasons advanced for structuring the design process were often based on the assumption that modern, industrial design had become too complex for intuitive methods (Cross, 2007), i.e. in simple terms, it rose the needs to 'overcome the increased complexity'. According to Buchanan:

> *The field of Design Research did not emerge in recognisable form until the 20th century, when the problems of design and technology became so complex that their resolution required new thinking* (Buchanan, 2007).

Zimmerman et al. (2007) provided a similar definition, by stating that

> *The emergence of design research as a separate activity from design practice grew out of the need to formally address the increasing complexity of systems designers were being asked to create. The increasing complexity of products such as battleships, airplanes, and rockets created a need for new design methods that were more predictable and more collaborative. The design methods movement grew out of this need, and generated the first cohort of design researchers focusing on the development of knowledge instead of artifacts for consumption* (Zimmerman et al., 2007).

The 1960s was heralded as the 'design science decade' by the radical technologist Richard Buckminster Fuller (Cross 2001; 2007). The Design method movement in the 60's and 70's was represented by John Christopher Jones, Christopher Alexander, Geoffrey Broadbent, Bruce Archer. At the same time, the Design Method group was founded in 1966 in Canada by Gary Moore (Conley, 2004).

Since we noticed a confusing use of the terms **method** and **methodology**, we specifically refer to the definitions Conley provides by extracting them from the American Heritage Dictionary. He defines a method as *"a means or manner of procedure, especially a regular and systematic way of accomplishing something"* and methodology as: *"a body of practices, procedures and rules used by those who work in a discipline or engage in an inquiry; a set of working methods"* (Conley, 2004).

There are many reasons that increase the confusion in the field of design research. As Buchanan notices one is the pluralism of design and design research that characterise the field while it makes it difficult to provide a clear, unified explanation of the advance of design research to those outside the field (Buchanan, 2007). He suggests that design is a field comprised of many fields, each shaped by its own problems and lines of investigation. The design research community has been characterised by an ongoing tension around the relationship between design and science (Zimmerman et al. 2007).

In 1929 Le Corbusier wrote about the house as an objectively designed 'machine for living' (Le Corbusier 1929; Cross, 2007). Almost thirty years later, Buckminster Fuller called for a 'design science revolution' based on science, technology, and rationalism (Cross 2001; 2007). 'Design Science' was a term perhaps first used by Buckminster Fuller. In 1969 Herbert Simons called for the study of 'science of design' to help more liberally educate scientists and engineers, *"a body of intellectually tough, analytic, partly formalisable, partly empirical, teachable doctrine about the design process"* (Simons, 1969, p.58; Zimmerman et al. 2007). While designers usually agree with Simons about the aim of design of turning existing situations into preferred ones" (Simons, 1969; Conley, 2004; Zimmerman et al. 2007), they deeply disagree on the idea of reductionism, rationalism and simplification promoted by this author. According to Krippendorff (2007), Simons reduced design to rational problem-solving. Some of the design methodologists themselves detached from this rigidity in design. By the end of 1970, J.C. Jones reacted against design methods.

> *I dislike the machine language, the behaviourism, the continual attempt to fix the whole of life into a logical framework* (Jones, 1977).

Another opponent was Donald Schön, which criticised Simons' 'science of design' for being based on approaches to solving well-formed problems, whereas professional practice throughout design and technology and elsewhere has to face and deal with 'messy, problematic situations' (Schön, 1983; Cross 2001; 2007). Schön's criticism was formalised by Horst Rittel and Melvin Webber in the concept of 'Wicked Problem'[1], which can be defined as *"a problem that because of the conflicting perspectives of the stakeholders cannot be accurately modelled and cannot be addressed using the reductionist approaches of science and engineering"* (Rittel and Webber, 1973; Zimmerman et al., 2007). A linear step-by-step design process cannot provide relevant solutions when the situation at hand is complex. Although treating problem definition and problem solution as separate activities, and working with them separately, may seem attractive, this cannot work because there *"is no definitive formulation of a wicked problem"* (Rittel and Webber 1973, p.161; Westerlund and Wetter-

1 Wicked problems are a "class of social system problems which are illformulated, where the information is confusing, where there are many clients and decision makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing" (Westerlund and Wetter-Edman, 2017)

Edman, 2017). Rittel and Webber's work pointed to an opportunity for design research to provide complementary knowledge to the contributions made by scientists and engineers through methods unique to design and design processes (Zimmerman et al. 2007).

More recently, according to Zimmerman et al. (2007) and Nelson and Erik Stolterman (2012) design was no longer considered as a 'problem-solving' practice to avoid undesirable states and effects, rather a discipline to frame problems in terms of intentional actions that lead to a desirable and appropriate state of reality. Referring to wicked problems, thus, designers could address massively under-constrained problems that were difficult for traditional engineering approaches to address (Zimmerman et al., 2007). Moreover, designers brought empathy for users as a part of the process, considering their needs and desires from an external observer's perspective and working to embody the people they made things for (Zimmerman et al., 2007).

This brief historical overview of the different positions of designer methodologists and critics introduces and contextualises the methodology for product design developed at Politecnico di Torino (Polito), formalised in 2008 by Claudio Germak and Claudia De Giorgi (2008). This methodology fits into this effort to contribute to design research in the Archer meanings of a *"systematic enquiry performed with the goal of generating knowledge"* (Bonsiepe, 2007, Archer, 1981), i.e. an inquiry focused on producing a contribution of knowledge (Zimmerman et al. 2007).

> *The whole point of doing research is to extract reliable knowledge from either the natural or the artificial world, and to make that knowledge available to others in re-usable form.* (Cross, 2007 p.48)

Polito's methodology attempts to structure the design activity, drawing from the work of Giuseppe Ciribini and Enzo Frateili, considered pioneer of the design methodology while showing a focus on the requirements that is common to other disciplines. Accurate studies on requirements, indeed, emerged within the Requirement Engineering (RE) a branch of Software Engineering (Lyytinen et al., 2009) that investigates what engineers need to make to meet a specific need (Zimmerman et al. 2007).

2.2 Requirement design

> *The information collected in the first phase of the design process will be used to define the problem, to develop requirements and to make design decisions (Mink, 2016). The problem definition and requirements guide the designer throughout the design process, although they might change as new insights are gained. Therefore, designers need to thoroughly analyse and frame both the requirements and the domain* (Mink, 2016).

While studies on the requirements were also developed in other research fields, in 2008 at the Politecnico di Torino Germak and De Giorgi published the 'Exploring Design' methodology, to structure design, decision-making and scenario analysis in the early design stages. This methodology has been taught at Politecnico di Torino to about 15,000 students over thirty years, (Germak and De Giorgi, 2008)[2], representing a methodology which is still valid today, although it has experienced additions over the years. Indeed, a 'metadesign phase' has been added to highlight the scenario definition and context evaluation (Explorer 2 - the scenario designer – Figure 7). Subsequently, increased attention to environmental sustainability lead to structure an MSc degree in Ecodesign[3].

> *A key aspect of this research is the creation of a scenario represented by contextual values [..] related to the social, cultural, ethical, biological, and technological values* (Germak and Bozzola, 2010).

Figure 7 is a free review of this methodology, to be more consistent with the widespread terminology of RE. After the first stage of exploration of both target and context (background), the second phase

2 The story of Industrial Design at the Politecnico di Torino began with the Industrial Design course within the five-year degree course in Architecture. Over the years, this course was held by teachers as Enzo Frateili, Giorgio De Ferrari and Luigi Bistagnino. The Industrial Design BSc at Politecnico di Torino started in 1996 with the introduction of the diploma in Industrial Design, or DUNDIT. In 1999 the diploma becomes a BSc, introducing, in 2000, a BSc in Graphic and Virtual Design. Nowadays the two BScs are grouped under the BSc in Design and Visual Communication.

3 The MSc in Eco-Efficient Product Design was introduced in 2002, then renamed MSc in Ecodesign in 2010 and MSc in Systemic Design in 2015.

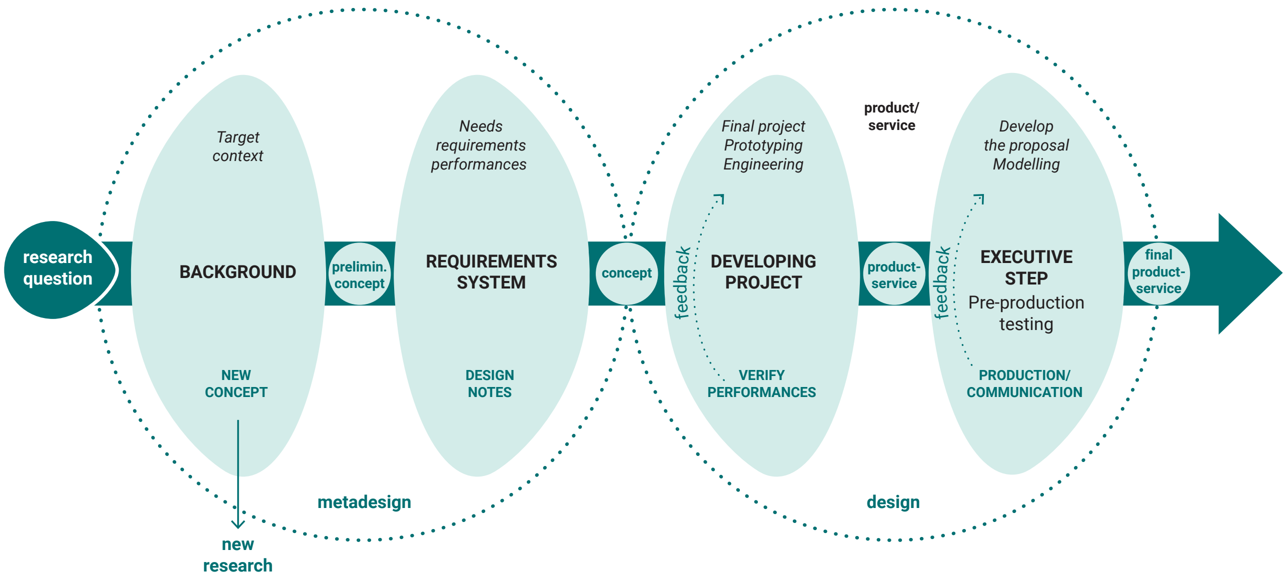

Fig. 7 - Explorer 2 (free review of Germak and De Giorgi, 2008)

(requirements definition) can be assimilated to the requirements elicitation of RE (Cheng and Atlee, 2009; Hansen et al., 2008; Reymen and Romme, 2009). Requirements represent one facet of a broader design effort (Hansen et al., 2008).
Germak and De Giorgi (2008) described different types of designers according to the goal of the project. The Explorer 1 is called the 'conscious' designer. His/her role is to *"seeks a cultural value for his or her product based on the scope [..] with a deductive methodology"*. Referring to a deductive methodology inevitably invokes the attempt to rationalise the design process conducted in the 1960s by the 'design methodologist'.
According to Christopher Alexander (1964) needs can be divided into 'classes of needs' (safety, aesthetics, use, maintenance, to name few, i.e. the third level of the scheme in figure 8), from which specific requirements derive (fourth level of figure 8). These classes are project specific and help the designer to manage the complexity by organising his/her problem, thereby giving it shape, making it easier to handle (Alexander, 1964, p. 62).
Christopher Alexander asks design researchers to examine the context, system of forces, and solutions used to address repeated design problems to extract a set underlying 'design patterns', thereby producing a 'pattern language' (Zimmerman et al., 2007)
In Italy, Giuseppe Ciribini and Enzo Frateili adopted the 'performance design' methodology, a step towards the introduction of standardisation and unification first in architecture and later in design. They were among that group of pioneers in dealing with industrialisation, both involved in teaching at Politecnico di Torino, dealing with the rational aspects of the project, rather than the aesthetics of the artifacts.
Frateili focused on the methodological aspects of functionalism in design, inspired by the Gute-Form of the Ulm School of Design. During the 1980s he was fascinated by the development of electronics and information technologies, from the potential offered by new technologies, moving from a pure "functionalism" towards new expressive languages (Patti, 2017).
In 1972, during a meeting of the International Standards Organisation (ISO), Giuseppe Ciribini proposed the so-called 'Performance Hypothesis' to introduce measurable performance criteria to define standards in both the construction sector and industrial manufacturing (in line with the concept of 'technical requirements' and 'functional performance standards' addressed by Alexander in 1964). Later, it became part of technical regulations for industrial manufacturing to ensure product quality.

> *To respond to human needs, [..] needs must be presented in the form of incoming requirements to which out-going performance must correspond* (Ciribini, 1964).

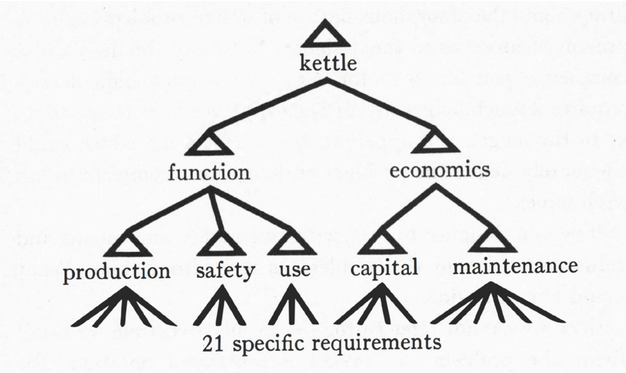

Fig. 8 - Hierarchy of requirements and their classification. Kettle's requirements tree structure (Alexander, 1964, p. 62)-

The 'need-requirement-performance' system observed in the construction field, can be extended to any project that begins with the analysis of requirements. Requirements, in turn, lead to the definition of measurable performances of the component obtained (Germak and De Giorgi, 2008), by providing a technical description of the solution chosen, according to standards about security, ergonomics and so forth. Performances are represented by metrics (i.e. quantifiable variables). 'Expected performances' are assumed during the concept development and, in turn, should be compared with the real ones, when the product is tested (function, efficiency and environmental sustainability have their specific indicators, e.g. KWh/year, CO_2 equivalent).
In this investigation, the interest is focused on identifying, prioritising and managing requirements rather than providing specific solutions (i.e. performances). For this reason, requirements are considered as an expression of the system's values, which then worth to be structured and investigated.
Design requirements are common to different design research areas, such as design methods, software architectures, human-computer interaction, information systems research, industrial design. Despite shared concerns and interests, these research communities have had little exchange of ideas across disciplinary boundaries (Berente et al., 2009), tackling the challenge of managing complexity individually and from many different perspectives, as well as addressing changing requirements, fluidity of design in many ways (through mapping, visualisation, representation, management activities, strategic design models and tools).

2.2.1. Requirements

For the current discussion, we adopt a categorisation which combines the categorisation provided by Cheng and Atlee (2009) with the one provided by Hansen et al. (2008). The goal is to provide a guide to help product designer in managing stakeholders' requirements (going beyond software engineering). The main steps with sub-steps can be listed as follows:

1) **Elicitation/discovery**
   - Understanding the needs of different stakeholders
   - Understanding the current operating context of the product
   - Selecting from collections of proposed requirements
   - Negotiating requirements priorities with the stakeholders
2) **Specification**
   - o *Modelling*
     - Modelling requirements / Setting the system boundaries
     - Setting objective acceptance criteria
   - o *Prioritisation*
     - Documenting and analysing
3) **Validation and verification**
   - Validating that the documented requirements match the negotiated ones
4) **Management**
   - Managing requirements evolution

Requirements elicitation and discovery

It means exploring and learning about the stakeholders' needs and the application domain (context of use), identifying all relevant stakeholders. This process conveys a diffuse position in RE that knowledge about requirements resides with users or stakeholders and must be 'teased out' and clearly articulated by the designers (Hansen et al., 2008). It is commonly seen as the first stage in which designer gain knowledge about the application domain. In this dissertation is considered neither the first nor the only step for the designer to gain this knowledge. Requirements elicitation involves identifying requirements that the system (or a component) should satisfy to achieve a specific goal. The solution could be either conservative or disruptive (from the redesign of the current solution, up to promote new scenarios and paradigm shifts). This academic research deals with typically unconstrained requirements, open to innovation. Technologies can be exploited to improve the precision, accuracy and variety of the requirement details (Cheng and Atlee, 2009).

We consider metaphor and personas definition, ethnographic research, scenarios, brainstorming among the methods that can be used for the requirement elicitation. Very rough prototyping could be effective in establishing a common basis for understanding and communicating (Hansen et al., 2008). These methods tend to be informal and intuitive to facilitate early feedback from the stakeholders (Cheng and Atlee, 2009).

Specification

It consists in both articulating the requirements for the design activity (developing and managing the specification document) and implying the agreement between the stakeholders and the design team.

Specification supports interpretation and understanding among all design stakeholders while laying a technical foundation for the subsequent design effort.

> *Requirements are concerned with what is to be achieved by a design artifact (i.e., the '**what**') without regard to the manner in which it will be designed and implemented (i.e., the '**how**')* (Hansen et al., 2008 p. 52).

Requirement modelling

Modelling refers to the creation of abstracted representations (models) of the worlds (application domain) that leads to requirements specification. In contrast to elicitation models, late-phase requirements models tend to be more precise and unambiguous (Cheng and Atlee, 2009). Modelling activity leads to requirements description, defining lexicon, structures and rules to understand the problem (on the one hand, system boundaries and constraints, on the other hand, assumptions, dynamics, relationships and behaviours). Models seek to identify unstated requirements, predict behaviour, determine inconsistencies between requirements and check for accuracy (Hansen et al., 2008). Eventually, models lead to skim the information, up to record and monitor a single piece of information to answer a specific requirement.

Among the tools used for modelling the requirements for the stakeholder comprehension and subsequent validation, we list scenario-based models[4], animation, prototyping to name a few.

Functional vs non-functional requirements

Functional requirements are measurable requirements that can be validated objectively.

Non-functional requirements (NFR) incorporate the quality expectation for a system, often referred as "ilities" (usability, maintainability, reliability, adaptability) (Mylopoulos et al., 1999), but also security and privacy.

By definition, NFR do not have quantitative satisfaction criteria (Ernst et al., 2008)

Functional requirements are represented as hard goals, while non-functional requirements are represented as soft goals (Ernst et al., 2008).

Requirement prioritisation and negotiation

From being the unique decision maker of the project, the designer is starting to play a role in mediation between stakeholders' conflicting requirements, values, roles and goals, while keeping the system's overview. This strategic role includes performing negotiation, prioritisation evaluation of the requirements in a structured way, to select an optimal combination of requirements to be implemented (Cheng and Atlee, 2009). It can be performed by assigning values to the requirements (numerical assignment), carrying out analytical hierarchy process, cumulative voting, etc. Negotiation involves the identification and resolution of conflict through the exploration of the range of possibilities, such as multi-criteria decision making.

Requirement validation and verification

In this phase, the designer checks whether the reality meets the expectations, i.e. ensuring that models and documentation accurately reflect stakeholders' needs and intentions. Moreover, designers should ensure a high quality of requirements and the lack of inconsistencies or errors. Verification of functional requirements requires the adherence to standards of quality[5], by focusing on the degree to

4 *Scenario-based models have been the focus of much recent research – partly because scenarios are easiest for practitioners and non-technical stakeholders to use, but perhaps also because scenarios are naturally incomplete and thus lend themselves to a plethora of research problems* (Cheng and Atlee, 2009).

which requirements conform to these (Hansen et al., 2008), whether for the NFR this is a qualitative evaluation of informally described or undocumented requirements. It should be performed involving the stakeholders in reviewing the requirements, by providing feedback. Many of the techniques are based on scenario validation (Cheng and Atlee, 2009), while prototyping is often referred to as a key validation technique (Hansen et al., 2008).

Requirement management

It comprises a variety of activities and tasks related to monitoring the relationships between requirements and products. This lead to the promotion of a paradigm shift in considering the evolution of requirements over time, addressed in the next section.

The level of uncertainty

Level of uncertainty derived from the unpredictable behaviour of many systems. Future systems are called to handle uncertainty in many forms; handling the emergent behaviour of the system is one of them.

> *Future systems will need to handle uncertainty in many forms, ranging from unexpected user input, unanticipated environmental conditions (e.g., power outages, security threats, noisy wireless networks, etc.), heterogeneity of devices and the need for interoperability, and on-demand, context-dependent services* (Cheng and Atlee, 2009).

Cheng et Atlee suggested uncertainty could be addressed with three strategies:

> *Uncertainty at run time will make it difficult to apply traditional RE techniques that are typically based on knowledge known at development time. Below we describe three key areas of research that call attention to the challenges posed to the RE research community due to the level of uncertainty of future systems: (i) increasing scale on multiple dimensions, (ii) tight integration between computing systems and the changing physical environment, and (iii) the need for systems to be self-managing and self-configuring, while maintaining assurance constraints* (Cheng and Atlee, 2009).

Complex systems are made of software, hardware and people (socio-technical systems) with complex dependencies and functional-based constraints. Over the last decades, the need to cope with the complexity took different forms, evolving in research activities and new disciplines. Cyber-physical systems (CPSs) to name one, draws its origins from software and mechanical engineering, merging theory of cybernetics, mechatronics, design and process science (Wikipedia). In CPS computing and communication are tightly coupled with the monitoring and control of entities in the physical world (Cheng and Atlee, 2009). The idea behind it is similar to the idea of the Internet of Things (IoT), sharing the same basic architecture. Nevertheless, CPS presents a higher combination and coordination between physical and computational elements (Wikipedia).

Self-managing / self-evolving systems

Creating a system able to accommodate varying, uncertain, incomplete and evolving requirements is quite challenging. For this reason, there is a growing interest in self-managing systems able to adapt to changes in either environments and requirements (Kramer and Magee. 2007)

- Self-healing systems, able to recover dynamically from unexpected errors or attack, system failure, faults, errors, or security breaches (Cheng and Atlee, 2009);
- Self-optimising systems, able to optimise their performance dynamically with respect to changing operational profiles, or adapt at run time to new environmental conditions or to new requirements that were not anticipated during the development (Cheng and Atlee, 2009)

To derive requirements and behaviours at the moment in which users are performing certain operations, new strategies are needed. Some studies in this area were carried out about control-based systems able to support the decision-making in control strategies and biomimetic strategies loops

network of stakeholders is a project-specific operation, and it strictly depends on the product or service to develop. Even in this case, it is not possible to establish a priori what skills will be needed

5 Including consistency with the overall design goal and among requirements, feasibility, i.e. the degree to which a given requirement can be satisfactorily addressed within the design environment, traceability, and the absence of ambiguity Hansen et al., 2008).

in decision making, biomimetic to draw inspiration from biological systems, by simulating the behaviour of a natural organism.
This kind of systems are capable of:

- Identifying and specifying thresholds for when the system should adapt
- Specifying variable sets of requirements
- Identifying correctness criteria for adaptive systems
- Verifying models of adaptive systems and their sets of possible behaviours
- Monitoring the system and environment against the current requirements (Cheng and Atlee, 2009)

2.2.2. Requirements Elicitation/ discovery

Following the categorisation provided in the 'requirements' section, we find it difficult to address the first point *'Understanding the needs of different stakeholders'* because we do not have a clear overview about which are the real stakeholders involved. Before going through the whole process, we need to identify the relevant stakeholders, the direct and indirect actors of our system. Thus, the first question is:

- Who are those stakeholders?

Then, we can ask:

- Which are those needs?
- Who can understand the needs of different stakeholders'?

1) Understanding the needs of different stakeholders'

The stakeholders are peculiar of the system we are considering; they cannot be generalised and their correct identification allows us to proceed with the analysis. If for product design the task of identify stakeholders could be easy to perform, in sociotecnical system the same task can turn to be complex. It depends on the boundaries that we set up in the system itself. Once defined, we may realise that we lack the skills to address the needs of all the stakeholders, and therefore we may have to

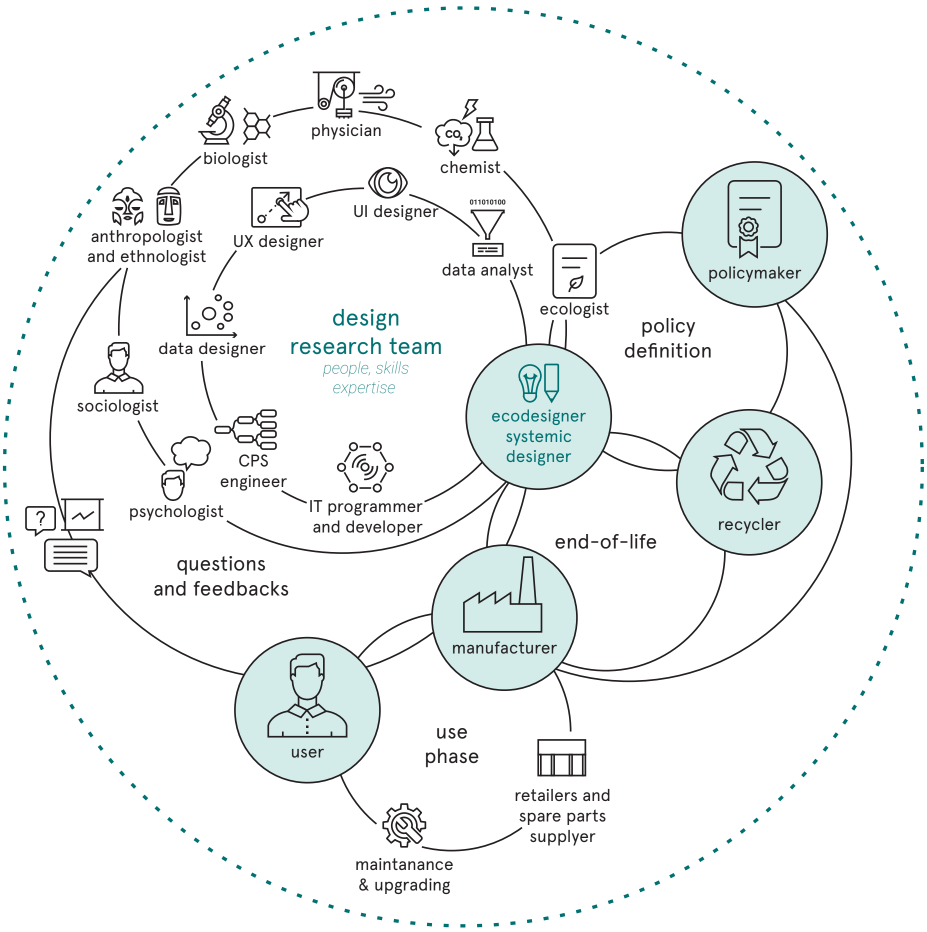

Fig. 9 - A possible definition of the network of stakeholder needed to develop new appliances.

during implement the design team. Fred Brooks indicates complexity as a continuous change in contexts, constraints, functionality, which requires multidisciplinary teams (Berente et al., 2009), with considerable coverage of skills and expertise. We do not longer refer to the work of a single illuminated designer. Complexity goes hand in hand with the segmentation of knowledge to tackle a specific node of the system.

Defining both the design team and the network of stakeholders is a project-specific operation, and it strictly depends on the product or service to develop. Therefore, designers should make assumptions. For example, the design team needed to develop an IoT home appliance (Figure 8) in our opinion should include:

1. UI/UX designers, data designer and analysts, IT programmers and developers, mechanical engineers, CPS engineers, electronic engineers for the product and technological aspects;
2. biologists, physicians, chemists, ecologists and ecodesigner for the environmental aspects;
3. ethnographers, anthropologists, sociologists, psychologists for the social aspects.

The network of stakeholder, instead, should accommodate:

1. the design team defined above, which can indicate user, product and environmental requirements;
2. companies with their supply chain and retailers that define product requirements;
3. anthropologists and social scientists who investigate consumer needs;
4. consumers that provide their needs;
5. recyclers and treatment operators which define product and environmental requirements.

> *Each discipline brings different forms of expertise emphasizing different aspects of the problem. Each discipline has different value systems. In addition, they all are apt to speak different technical languages, where quite often the same terms are used with quite different meanings. These differences can also impact the smooth running of the system.* (Norman and Stappers, 2016 p.87)

The only way to succeed is to set the dialogue combining expertise creatively and effectively, compromising goals and principles for the greater good. The interaction between the actors and effective management of the activities within the system should be finalised to pursue a common goal. This concept works at different scales, from the subsystem to the design team, up to organisations and companies, public sector and municipalities.

Evolving requirements

It is no longer assumed that all requirements will be known in advance of building the system. It is now assumed, instead, that requirements will continue to change as time goes on, that design decision will be made in response to new knowledge and understanding of requirements (Lyytinen et al., 2008). De Risi interpreted the quality as a dynamic aspect (Germak and De Giorgi, 2008), clarifying that:

> *Requirements change over time, caused by (i) technology evolution, which enables new developments, (ii) context and socio-cultural evolution, (iii) industry pushing new requirements over the consumers* (De Risi, 2001)

For this reason, in this first stage, we decided to keep companies out, because their constraints are too binding for this level of analysis. We thus focus on environmental, user and product requirements in the following chapters.

2) Understanding the current operating context of the product' - Object oriented design

> *We must not forget that design knowledge resides in products themselves [..] Much everyday design work entails the use of precedents or previous exemplars – not because of laziness by the designer but because the exemplars actually contain knowledge of what the product should be.* (Jonas, 2007)

From the very beginning, it has been introduced a third vision where objects have the same design agency of user and environment. We refer to chapter 3 for a discussion on this topic. The second step of elicitation 'Understanding the current operating context of the product', however, is addressed in chapters 5, 6 and 7, with a specific case study. Operating context, indeed, can be described and observed by humans, but environments can also be sensed by objects instrumented *ad hoc*.

3) Selecting from collections of proposed requirements

Since requirements definition is an open-ended question, we started the requirements analysis

Needs	
User requirements	1. Safety
	2. Comfort and wellbeing
	3. Aesthetics
Product requirements	4. Functionality
	5. Management and maintenance
	6. Upgradeability
Environmental requirements	7. Environment protection

Table 1 - Requirements (or classes of needs) defined by the UNI 8289 standard translated and freely adapted from the Italian standard)

from listing the classes of needs according to UNI 8289 Italian standard, which identifies and define seven basic classes of needs (Table 1). We translated, adapted and grouped them as follows (Fiore et al., 2017).

Although the terms 'need', 'classes of needs' and 'requirement' may seem to be used with the same meaning, (i) needs give a general idea of necessity; (ii) classes of needs collect and unify needs with a similar purpose, assigning a unique name, while (iii) requirements are the structured way to define those needs to be translated into design features (performances). The evolution and implementation of this 'basic structure' are addressed in chapter 3 (user), 4 (sustainability) and 7 (product).

4) Negotiating requirements priorities with the stakeholders

Multi stakeholder's decision making, processes and solutions require collaboration and agreements of multiple actors. Moreover, during the process, every actor may change (idea, behaviour, status, way of doing things). As for the system itself, the result of bringing together different experts and skills results in an emerging, unpredictable behaviour that differs from those of individuals. For large scale systems, design can be considered an 'interdisciplinary negotiation' rather than planning a perfectly stable system.

How are multiple requirements from multiple stakeholders to be negotiated and evolved? (Lyytinen et al., 2008). It is time to rethink the role of requirements and design product systems which permeate all aspects of our lives and everyday activities. These systems entail requirements that are richer, more complex and more elusive than ever and designing to meet these requirements in our evolving socio-technical environment poses a plethora of new challenges.

> *It is an iterative, spiral-like process, during which the designer goes through reductive and deductive steps and often need to return to earlier phases to re-evaluate previous decisions* (Mink, 2016)

2.3 Democratising the design process through co-design

As predicted in 1972 by Robert Junk, a futurist and social inventor talking about participation in design (Sanders and Stappers, 2008):

> *We can begin the preparation for this radical change. As a prognostician, I don't think this change will take place before the end of the century. [..] something radically different can come, but it won't come on its own: it has to be prepared.*

While some innovations come from a stroke of genius, most innovations result from a "conscious, purposeful search for innovation opportunities. Breakthrough thinking is almost always preceded by extensive preparation (Mink, 2016).

Participatory design advocates the participation of potential users throughout the design process, as a specific form of user involvement which gives citizens or workers a voice in design decisions that influence their lives (de Bront et al., 2013). This practice gives users an active role in product design, preferably from the early stages of the design process. In the early stages, user involvement is most efficient and influential, because their input forms an important point of reference throughout the design process and changes made at the beginning of the process are less costly than those made later on (Mink, 2016). The use of special tools and techniques enables users to take an active role in designing and experiencing product concepts revealing covert or subconscious user needs. In this way, users can

apply their practical knowledge, and complex use situations can become more concrete (de Bront et al., 2013). The designer that starts the design process based on his/her abstracted knowledge, thus, could receive insights also on users' tacit knowledge and practical knowledge (i.e. about how things are currently done and about use problems) and into the use of a product (situated knowledge, see chapter 4). According to Beat Schneider (2008), participatory research is a qualitative research method. According to Sanders and Stappers (2008), the application of participatory design practices (both at the moment of idea generation and continuing throughout the design process at all key moments of the decision) to very large scale problems will change design and may change the world.
This method evolves in **co-design**,

> *which aim to work in close collaboration with a range of stakeholders (Sanders and Stappers 2008). This requires a new set of skills for the design professional who is becoming closer to a facilitator than translating insights into designs appropriate to the relevant technologies of production, a move from 'gatekeeper to innkeeper'* (Cruickshank and Trivedi, 2017)

There is a very broad range of participatory design approaches where participants are welcomed into the heart of the design process rather than being the subject of insight gathering from designers as seen in conventional HCD (Cruickshank and Trivedi, 2017). These are typical bottom-up approaches, and the integration of people in the innovation process depends on their participation and collaboration, made possible through information technologies. The opening of the innovation process to society (de Arruda Torresa, 2017) certainly brings benefits but involves some risks that we will see below. The most recent democratisation took place with the advent of crowdfunding (addressed in Chapter 3), in which people are invited to participate in the process of creating innovation (de Arruda Torresa, 2017).

2.3.1 Expected impacts of involving the user

Combining Mink (2016) and de Bont et al. (2013) considerations, involving potential users in the design process could result in valuable benefits regarding the outcomes of design.

1. leads to generate design requirements, providing access to tacit user knowledge that would otherwise not be available to designers, as well as to practical user knowledge, enabling participants to explain issues and opportunities for product concepts about their own practical knowledge and use situation. This, in turn, should lead to less frustration during decision making.
2. gains user commitment. Involving users in product development, such as in crowdfunding campaigns, can create a positive bonding of (future) customers with a company or a brand.
3. improves the accessibility, applicability acceptance and adoption of the designed product or services.
4. leads to more flexibility and robustness in product use and enhanced user satisfaction.
5. reduce the number of design iterations and thereby the time and cost of development

> *The insights gained from consulting users, guide designers to go beyond their own assumptions, resulting in bottom-up solutions with high impact* (Mink, 2016)

Users can be actively involved at various stages of the design process, including analysis, design and evaluation activities, allowing designers to tap into users' tacit – and practical knowledge. User involvement is especially useful for complex use situations and designing for unfamiliar or specialist target groups (de Bont et al. 2013).

2.3.2 Addressing the reason of the poor application of participatory approaches

Companies' perspective

Sanders and Stappers (2008) already noticed this approach as opposed to consumerism, in which personal happiness is equated with purchasing and consuming material goods. For this reason, this paradigm shift is not welcomed from most of 'traditional' companies. However, some companies found a way to benefit (even economically) from this method, differentiating the services and benefiting from all the phases of the product. The renewed interest in sustainable practices is also helping to fight consumerism and the rampant consumption, fueling this fire (Sanders and Stappers, 2008).

> *In many parts of the world, the needs that capitalism has worked so hard to meet have been met and so new needs are now being invented. Meanwhile, in other parts of the world, basic human needs (e.g., clean water) are not met* (Sanders and Stappers, 2008).

Another reason for the poor application of participatory approaches is that it has been seen as an academic exercise with little or no commercial relevance. Investing in user studies a big and expensive step, and user participation a radical step into the unknown. This is beginning to change now as product development becomes increasingly knowledge-intensive, and industries and universities look to each other for collaborative explorations in innovation (Sanders and Stappers, 2008).

Designers' perspective

Among the other limits to the diffusion of this method, we can list many 'practical issues', by taking them from de work of Bont et al. (2013).

1. **Time** - Preparation of prototypes and the organisation of involvement sessions can be time consuming. To execute user involvement sessions, a single organiser or a small team is needed. The organisers need expertise in facilitation and observation techniques. Once defined, however, a single set-up can usually be re-used for several sessions (de Bont et al. 2013). Involving the user requires time end efforts and does not result in clear-cut decisions because preferences and opinions differ (Mink, 2016).
2. **User selection** - Finding 'the right' users can be difficult. In some cases, any participant will do, but usually, 'open-minded' participants are preferable. Some researchers argue the advantages of involving 'lead-users'[6] in product development
3. **Finding willing users** - In design projects without a predefined group of actual future product users, it can be difficult to find willing participants.
4. **A dispute over rewards** - the researcher probably has to decide on whether and how to compensate participants for their engagement. If participants are actual future users, they will profit simply by improving the product, and sometimes the experience of participating itself is set up to make it worthwhile. Otherwise, some kind of reward might be necessary. However, when rewarding participants with gifts, their motivation might change towards extrinsic motivation, and thus the extent of their engagement might suffer.
5. **User's knowledge and attitude** - Another challenge is to anticipate the users' point of departure concerning their knowledge and state of mind. It is necessary to know what they know about a project, product or possibilities in order to create a situation of meaningful involvement. This becomes even more crucial when participants have aversions against a brand, a product or change in general. While it is not always possible or desirable to resolve these conflicts, being aware of them is important.
6. **Match the purpose of the study** - Depending on the anticipated type of product innovation (i.e. incremental innovation, platform-based innovation or break-through innovation), we can expect a different degree of feasibility of the solutions proposed. If every possibility is left open, this might result in unfeasible concepts. On the other hand, too many constraints hinder the development of innovative concepts. Skilled session moderator must pursue the purpose and 'enforced' by the method (i.e. by specifying or restricting the type of tools or prototypes used in the method).
7. **Confidentiality** - Including external participants in product development bears the danger of leaking confidential information about the company's developments and innovations to the competitors. If design information is confidential, we should carefully consider whether to involve users in the design process. Contracts with the involved users can prevent Information-leaks. Alternatively, product substitutes or simplified versions of products could be used when involving users.

6 According to de Bront et al., 2013)., lead users are people who face needs of a target group earlier than the remainder of the group, and who are independently able to contribute to finding solutions to these needs.

(de Bront et al., 2013).

<u>*The other way round. Refrain from engaging with the users*</u>

> *A lot of times, people don't' know what they want until you show it to them". Apple's products are often used as examples to illustrate that user insights are not required to develop successful products. Moreover, product design can be driven by a firm's vision alone. Involving user does not ensure that all the relevant insights are identified* (Mink, 2016)

A completely different approach comes from Norman, the pioneer of UCD, who provocatively suggests designers refrain from engaging with their users, with his Activity Centred Design (ACD).

> *Sometimes what is needed is a design dictator who says' "ignore what users say: I know what's best for them"* (Norman 2005).

This is a move to (sometimes) free designers to use their intuition instead of engaging with external (Cruickshank and Trivedi, 2017).

We propose an approach where the design team guides the design process involving stakeholders to shape new valuable products.

2.3.3 The evolving role of designers in co-design

Despite the unlikely vision in which everyone can become a designer, designers (and thus systemic designers) make the difference in the co-design processes, since they can work with the parts/details and the whole, simultaneously as well as separately (Westerlund and Wetter-Edman, 2017), bringing highly developed skills that are relevant at larger levels of scope and complexity (Sanders and Stappers, 2008).

We can simplistically state that designers provide another way of thinking, they are 'good at' problem setting and problem definition and have the mental structure for dealing with incomplete information without getting stuck. By selection and training, most designers are good at visual thinking, conducting creative processes, finding missing information, and being able to make necessary decisions in the absence of complete information (Sanders and Stappers, 2008). According to Sanders and Stappers (2008), and then witnessed by the growing number of designers in start-ups that do not deal with design at all,

> *In the near future, designers will find themselves involved not only in the design of stand-alone products but in the design of environments and systems for delivering healthcare, for example* (Sanders and Stappers, 2008)

As we already noticed for the design team, we are witnessing a progressive change in the role of the designer, which cannot longer aspire to a monopoly in the design activity (de Arruda Torresa, 2017). Zimmerman et al. (2007) add that design researcher is a critic and able to study design process and analyse artifacts to discover patterns. However, when people become co-creators, designer-researchers' role is "to support participants, stimulating creativity and the ability to preview and explicit unexpected needs through the availability of knowledge, views and tools for stimulating ideation, expression and visualisation" (de Arruda Torresa, 2017). Sanders and Stappers (2008) present the idea of designer as a creative facilitator, mediating projective interactions to be established between people with different levels of knowledge, skills and creativity. By this way, designers must lead, manage, guide, support and assist participants in the task of creating and implementing solutions to their everyday problems. The authors highlight the importance of designer as a domain expert in project development, creating new tools to develop co-design process to support collective creativity (de Arruda Torresa, 2017). The role of designers and researchers according to Manzini (2007) and de Arruda Torresa, 2017 is contributing to this far-reaching innovation process by organising their capabilities in four steps:

1. **providing guidance and visibility to promising cases** - highlighting their most interesting aspects;
2. **building scenarios of potential futures,** demonstrating what could happen if these cases were to spread and consolidate, becoming mainstream ways of doing;
3. **developing enabling systems** - designing specific solutions to increase the efficiency and accessibility of promising cases;
4. **promoting creative contexts** - collaborating in the development of new creativity management tools (de Arruda Torresa, 2017).

2.4 The Fluidity of Design

> *A point that I want to emphasize is that we do not usually know what the goal is. The hardest part in designing complex systems is not knowing how to design them* (Berente et al., 2009).

Requirements research seeks to articulate user needs (and then requirements) through methods like ethnographic analysis of user activity, bringing relevant functionality into future designs. A new challenge to design is that products can be identified in designing artifacts with a level of malleability, or fluidity, in mind (see chapter 4 for a discussion on Ethics). This concept was introduced by Berente and colleagues:

> *This could involve practices such as co-design with users or developing toolkits for user customization, but can also involve intelligent agents that learn from usage, dynamically evolving artifacts, or user WWgenerated artifacts. The requirements community will be required to increasingly attend to post-development fluidity in a way that is notably different from the evolutionary discourses of the past. This attention should not only focus on the requirements themselves, but the meta-requirements associated with how adaptable requirements should be [..]* (Berente et al., 2009).

The fluidity of the design requirements accommodates the continuous evolution of the artifact after implementation (Hansen et al., 2008). Designers usually consider projects as ‘complete’ at some point. In the same way, before the introduction of WEEE waste regulation, manufacturers paid scant attention to their products, once the product has been sold and the warranty has been expired. Besides the regulatory aspects, this aspect has led some companies to change their goals and business models towards the CE (Bocken et al., 2016). This should be accompanied by the fluidity of design. Software updates are just an example of a product that evolves over time, changing and adapting to technological changes. What if the same concept would be extended to every part of the product? In this scenario, the user purchases/rent a basic product and then he/she could transform and shape it according to his/her needs with components and functions that can be integrated. What if the product would change its behaviour according to contextual factors, usage information and the habits of those who use it? In this scenario, the user purchases/rents a product, he/she start using it and after a while his/her expectations will be delivered, because the product evolves to meet user’s requirements. These are two non-inclusive examples of exploring new scenarios in this area, to empower the user to personalise the artifacts.

2.4.1 The importance of problem framing/setting

Despite the apparent focus on the solution, one of the most important competencies of design researchers is undertaking ‘problem framing or ‘problem setting’ (Westerlund and Wetter-Edman, 2017). According to Sanders and Stappers (2008) the first phase of the design (pre-design or front end) describes the many activities that take place to inform and inspire the exploration of open-ended questions. This process is growing emphasis, becoming increasingly critical because it involves the ‘understanding of users and contexts of use, exploration and selection of technological opportunities such as new materials and information technologies’ (Sanders and Stappers 2008). During this phase, the actual design challenge is explored and, if required, reformulated. Design failures are often caused by addressing the wrong problems. Therefore, designers need to thoroughly analyse and frame the problem, before starting the actual development of a product of service. They need to obtain insights into technological possibilities, business opportunities, the political and legal system, as well as potential users and other stakeholders (Mink, 2016). As already pointed out at the beginning of this chapter, when dealing with wicked problems, the ‘problem formulation’ is the most difficult phase, since there is no definitive formulation of this kind of problems. As Rittel and Webber (1973) claim *“part of the art of dealing with wicked problems is the art of not knowing too early...”*. Since there is no stable, valid problem definition the issue to be dealt with, it needs to be explored and critically investigated throughout the whole process (Westerlund and Wetter-Edman, 2017). For this reason, greater flexibility throughout the whole design process is required. The front end is often referred to as 'fuzzy' because of the ambiguity and chaotic nature that characterise it. In the fuzzy front end, it is often not known whether the deliverable

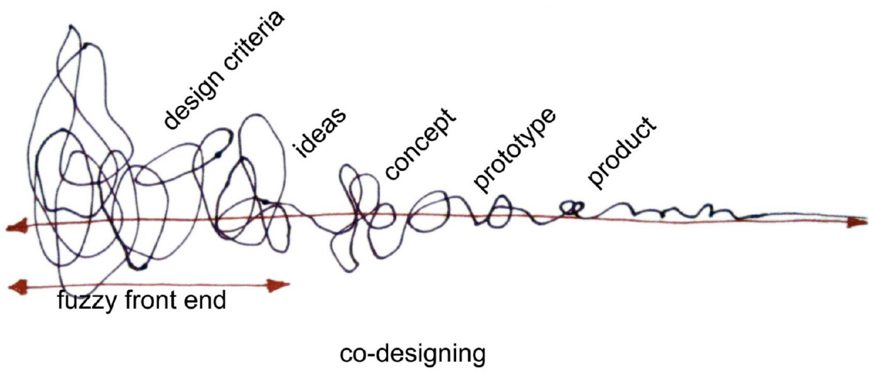

Fig. 10 - Simple representation of the design process, showing the growing importance of the fuzzy front end (Sanders and Stappers, 2008)

of the design process will be a product, a service, an interface, a building, etc. (Sanders and Stappers 2008). Designer should accept that requirements could be 'fuzzy' and 'not defined' at the beginning of the design process, accepting the idea of 'not knowing too early', exploring **open-ended questions** (Sanders and Stappers, 2008), exploring alternative propositions throughout the whole design process (Westerlund and Wetter-Edman, 2017). In this way, the knowledge about the problem and the design outcome increases and they co-evolve together. (Mink, 2016). Westerlund and Wetter-Edman (2017) support this view and emphasise that we should *"shift from a view of objective knowledge to multiple, located, partial perspectives that find their objective character through ongoing processes of debate"*. As shown in figure 10, the fuzzy front end is followed by the traditional design process resulting in ideas for product, service, interface, etc. developed first into concepts, and then into prototypes that are refined based on the feedback of future users (Sanders and Stappers 2008).

After the initial problem-setting, there will be a co-evolution of the 'problem understanding' and the 'design proposal'. They should be seen as two inseparable, intertwined activities that co-constitute each other (Westerlund and Wetter-Edman, 2017). In creative design, indeed, designers continually reframed the problem, constantly questioning the underlying assumptions during the design process (Zimmerman et al., 2007).

2.4.2 The growing role of artifacts, prototypes and physical interfaces

Zimmerman et al. (2007) identify the production of artifacts as vehicles for embodying what "ought to be" and that influence both the research and practice communities. The artifact through which the designer collect information becomes the means for a 'Research through design' (RTD) approach (Frayling, 1993; Findeli,1998; Zimmerman et al., 2007; Jonas, 2007; Schneider, 2008;).

> *Research through design distinguishes itself from the normal design process by the fact that the design is not inspired by the concrete needs of users but by a research question specifically related to research certain circumstances, the research question may be identical with a specific question posed by a user* (Schneider, 2008).

RTD is usually pursued in the form of application oriented research (Zimmerman et al., 2007). As such, it is expected to produce useful – i.e. applicable – knowledge, in line with the growing significance of practice-oriented and application-related knowledge for science and society (Michel, R. 2008 p.16). Objects, indeed, are the means through which transfer knowledge between different domains to facilitate communication between designers and end-users (de Bont et al., 2013). As we address in the following chapter, a prototype helps to set the dialogue between the designer and the user, gaining useful insights into both requirements and 'situated knowledge' (or local knowledge) on how products are used. RTD generates knowledge by designing innovative artefacts, models, prototypes, products, concepts, etc., and evaluates them (validation process) by conducting various experiments (tests, perception experiments, etc.) to answer the research question. Evaluation differs from the simple testing of a prototype since the 'applicability of the knowledge gained' is not restricted to the product on

which research is being conducted (Schneider, 2008). Prototyping is considered an activity for exploring, proposing and creating knowledge. Prototyping is one of the tools used in participatory design (together with scenarios, virtual reality, etc.) which produces a reality that can be aesthetically experienced, providing a representation of a future situation, allowing stakeholders to collaborate and discuss design proposals. (Westerlund and Wetter-Edman, 2017).
To support this, prototyping should allow to:

- imagine other potential realities through experimentation and exploration;
- investigate future uses (Westerlund and Wetter-Edman, 2017).

In evaluating the performance and effect of the artifact situated in the world, design researchers can both discover unanticipated effects and provide a template for bridging the general aspects of the theory to a specific problem space, context of use, and set of target users (Zimmerman et al., 2007). Prototyping should also support the previously mentioned problem-setting, creating knowledge about messy contexts (Westerlund and Wetter-Edman, 2017).

> *Finally, when it comes to prototyping, we suggest that it is important to abandon the idea of THE prototype in favour of an understanding that there is a need for several prototypes in order to support "multiple, located, partial perspectives that find their objective character through ongoing processes of debate". This is similar to design's replacement of THE user with stakeholders in order to account for the many effects that a product in use has* (Westerlund and Wetter-Edman, 2017).

2.4.3 Platform of interaction 'designer-user'

Since heterogeneous and rapidly changing environments demand new approaches and tools, we decided to plan this research with the idea of using a digital platform of interaction (see chapter 8) between the designer and the user (first step), then extending the platform to other stakeholders. This could be useful to set an interaction among the actors inside the system and an interaction with other systems (services, policies) (de Arruda Torresa, 2017), as shown in Figure 9. The replacement of THE user with a network of stakeholders (Westerlund and Wetter-Edman, 2017) should help the designer to address different perspectives and requirements that derive from different phases of the product lifetime (concept/production/use/end-of-life). Moreover, the platform should enable to keep the requirements at hand in every step of design, validating, testing allowing running changes, thus providing the fluidity needed in dealing with sociotechnical systems, as well as providing a platform on which to share concepts and models. Indeed, the platform could help the designer during the immersion phase (de Arruda Torresa, 2017), i.e. when designer (or more often, design team) goes into the field and observe in loco how people live, how they perform their daily activities, identifying their aspirations, behaviors, dreams, difficulties, frustrations, experiences and stories. According to de Arruda Torresa (2017) establishing and maintaining meaningful relationships with people is the best way to understand and improve their reality (de Arruda Torresa, 2017). In this way, the investigation can rely on feeling, intuition and inspiration combined with rational and analytic activities (Mink, 2016). The use of a platform mitigates some of the problems mentioned above, such performing time and resource-consuming activities, helping to manage roles and purposes.

2.5 Remarks

The aim of this work is, therefore, to develop a designer-friendly approach to efficiently guide product designer to design meaningful and relevant products for the user, with the environmental sustainability in mind.
The lack of perceived benefits in smart objects highlighted in the Field of Investigation (chapter 1) could be now addressed by shifting the focus to both users and environment. The anthropocentric vision of design can evolve into a holistic one, in which multiple aspects are considered simultaneously. By the end of the last century, Aldrich considered "meeting the real user needs" and "improving functionality, ease of use, affordability, reliability, maintainability, flexibility, adaptability upgradability, replicability and ease of installation" (Adrich, 2003 p.23) as possible solutions for the development of smart home. Herein, these considerations are combined

with a design methodology based on needs and requirements described above. Almost twenty years after Aldrich, we decided to include a wider network of stakeholders able to define three levels of requirements[7] that come from the user, the product and the environment.

7 A requirement is the transposition of a need in technical terms. It aims to achieve a purpose adding some features and specifications

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Chapter 3

Design Ethics in socio-technical systems

This chapter addresses many of the issue deriving from both the design activity itself and the introduction of technology in everyday life. Relevant authors like Papanek (1984), Thackara (2005) and Manzini (2006) warned about the risks of the design activity, as well as the consequences of bringing products to the world. Papanek defined design as the second most harmful profession one can practice, while Thackara claims that design is the cause of many troubling situations in our world (Mink, 2016). Manzini advocates an imminent need for a paradigm shift towards both a more sustainable design and way of living. In "design for the real world", Papanek pointed out that designers have a social and moral responsibility for the consequences of their innovations (Mink, 2016). For this reason, firstly we cannot ignore the advice, but also, we genuinely believe that designers should include ethical principles in their education. This chapter seeks to address design ethics focusing on socio-technical systems and the new challenges introduced by the Internet of things and Artificial Intelligence. It investigates some issues that affect designers as professionals, together with technological and environmental issues that have not received much attention from ethicists. The methodological framework combines the Value-Sensitive Design (VSD) developed in HCI and computer ethics with the methodology based on need, requirements and performances developed in architecture, addressed in the previous chapter. This approach is applied to the development of connected appliances, to conduct our reflections on an applied case study. Some guidelines are drawn at the end of this chapter to guide designers in achieving a greater understanding of ethical implications involved in the design process, establishing responsibilities and limits of the designer.

3.1 Ethics

Despite the variety of perspectives to address the ethical issue, most of the literature focuses on the theoretical dimension of ethics, follows three traditional approaches:

- Deontology, based on obligation and duty, i.e. the knowledge of what is right and proper;
- Teleology, which maximizes the utility, based on principles and goals;
- Virtue ethics, which considers the role of the character and his/her virtue, (i.e. the worth living).

Even design ethics literature tends to frame ethics according to those approaches (Anjou, 2010a and 2010b). From a philosophical and theoretical debate, in the mid-twentieth century, it raises the need for an applied dimension of ethics (Albrechtslund, 2007; Fiore, 2016), which led to its fragmentation into many disciplines with overlapping boundaries, including Computer Engineering, Business and Design, to name a few. The bulleted list that follows provides some categories:

- Economics and business ethics
- Bioethics
- Organizational ethics
- Environmental ethics
- Social ethics
- Ethics of technology
- Professional ethics (all the disciplines)

In the design field, a more structured approach about ethics has been noticed in HCI (Human Computer Interaction) i.e. in Human Centred Design (Sellen et al., 2009; Friedman and Kahn, 2003), but less structured work has been done, for example, in the field of product design or Design for Sustainability.

This section seeks to address the last three categories mentioned above: social ethics, ethics of technology and professional ethics. Social ethics is addressed by choosing Value Sensitive Design as methodological framework. Among the Ethics of technology, (i) Technoethics, (ii) Cyberethics, (iii) Internet Ethics and (iv) Information Ethics are listed here (Fiore, 2016), although providing an exhaustive analysis of them is out of the scope of this chapter. I choose to analyze more in deep the implication of the Internet of Things and Artificial Intelligence. Referring to the professional ethics, this work focuses on design (d'Anjou, 2010b; Devon and van de Poel, 2004; Manzini, 2006). However, design ethics concerns a vast area, overlapping many independent fields of applied ethics (Chan, 2016), making it necessary to define the boundaries of the role of the designer.

3.2 Social Ethics

Traditionally, ethics has been studied related to individual human conduct. According to Devon and van de Poel, these traditional approaches to ethics have been focused on individuals, their actions and consequences (Devon and van de Poel, 2004). Floridi has defined this approach as 'anthropocentric' (Floridi, 1999), since the individual constitutes the focus, while there are other applied dimensions of ethics that has been extended to non-human living things (biocentric), and ultimately to inanimate things (infocentric and object-oriented). As opposed to moral theory, which relates to the goodness or rightness of relations codified for social order and allowing moral frameworks, ethics relate to relationships and situations. In this way, Social Ethics rather than focusing on the single individual, his/her morality and values, considers the social arrangements for decision-making in an iterative design process and stands among the others in being more focused on the project management and on the design process in general – as a reflective action of choosing between different possibilities (Manzini, 2006). However Social Ethics should not be mistaken for a form of collective decision making. Rather, it deals with how people (from now on we call these people involved "stakeholders") collectively make decisions and thus it could be successful extended to address a more systemic design approach. In our applied case study, Social Ethics seems to embrace the socio-technical complexity of the home system.

Products or services are defined by several choices occurring throughout the design process, made by different stakeholders in different contexts. In consolidated socio-technical systems (such as healthcare, work environments,..), these decisions have been taken by someone in explicit or implicit ways (incremental). When designing systems from scratch or planning on how to change consolidated systems,

Classes of needs			**VSD values** *(Friedman et Kahn., 2003)*
User requirements	1. Safety	Safety: Health	-
		Security: Information	Privacy Freedom from bias Trust Autonomy Informed consent Accountability
	2. Comfort and wellbeing		Human welfare[1] Calmness
	3. Aesthetics		Identity
Product requirements	4. Functionality		Universal usability
	5. Management and maintenance		Ownership and property
	6. Upgradeability		-
Environmental requirements	7. Environment protection		Environmental sustainability[2]

Table 2 - Classes of needs defined by the UNI 8289 standard, integrated with VSD values

a structured decision making should be guaranteed for the whole project and different stakeholders with their needs, values and expectations should be considered from the early design stage.

Many authors pointed out a lack of a formalized approach (Cummings 2006; Devon and Van de Poel, 2004; Chan, 2016) to provide specific guidance for including ethics in design. Value Sensitive Design (VSD) approach (Friedman et al., 2002, Friedman et Kahn., 2003, Cummings 2006; Albrechrslud, 2007) is developed in human-computer interaction (HCI) research to support decision-making in the design of technology and bridge the gap between technical design and ethical concerns expressed through human values. VSD indeed places ‘human values with ethical import’ (Friedman et Kahn., 2003) as key values to be considered during technological products' development.

> *VSD is a theoretically grounded approach to the design of technology that accounts for human values in a principled and comprehensive manner, throughout the design process* (Friedman et al., 2002).

Herein, VSD deals with the design of technologies. What happens when the designer is called to design a product that includes these technologies? Which are the boundaries of different professions, from an ethical perspective? We will try to answer this open-ended question throughout this chapter.

Stepping back, VSD can be defined as an iterative tripartite methodology consisting of conceptual, empirical, and technical investigations. As we have already seen, VSD seeks to design technology that accounts from human values (Friedman 1997) and we seek in turn to extend VDS to product design that embedded technology. This methodology partly

8 According to Cross (2000) most of the design processes have a basic three-phase structure of (i) analysis, (ii) synthesis and (iii) evaluation

overlaps with the consolidated methodology based on 'need-requirement-performance' developed in architecture by Frateili, Ciribini, then applied to product design (addressed in the previous chapter). VSD can be easily incorporated into established design processes, which generally falls along the general structure of 'conceiving an idea, designing an artifact and then testing the design'[8]. For this reason, we coupled the three steps of VSD (conceptual, empirical and technical investigations) with needs, requirements and performance of the methodology developed by Frateili and Ciribini.
Before addressing the ethics of technology and the professional ethics, I address in detail the three steps of VSD, in order to understand which values are not negotiable, the level of "agengy" the technology could have and why social ethics should be integrated with a systemic design approach (and viceversa).

3.2.1 Conceptual. Defining needs or values

Defining needs or values requires an inclusive approach to make sure the right stakeholders are included in the decision-making (Devon, 2004).

> *Design may be the best place to study ethics in technology, because design affects us all. However, not all of us are involved in design, and this asymmetry has great importance for the social ethics of technology* (Devon, 2004).

Table 2 combine the classes of needs presented in Table 1 (p.39) of the previous chapter, according to UNI 8289 Italian standard, with twelve specific human values considered in the design of technology by Friedman et Kahn (2003). In doing so, we noticed that the UNI class of needs did not consider the ethical issues about the information. Therefore, we split 'security' into 'health' and 'information', to better address this issue.
The inclusion of the VSD values into the system of needs highlights that Friedman et Kahn (2003) fully fits the information security, leaving other areas uncovered. This is not an unexpected result, since it was clearly stated the focus on the ethics of technology. Below we reported the definition of conceptual investigation according to the University of Washington (UW)

> *Conceptual investigations [..] comprise philosophically informed analyses of the central constructs and issues under investigation. For example: What values have standing? How should we engage in trade-offs among competing values (e.g., access vs. privacy, or security vs. trust)?* (University of Washington, 2011)

This approach requires prioritising requirements according to the stakeholders and then iterating the process. After that, some human values are taken into consideration and integrated into and throughout the design process. Designers should choose some relevant values *"that could be viewed as a common thread throughout the project"* (Cummings, 2006 p. 703) and iterate the process through the other two phases, that can add or remove values. This approach should be brought to the next stage, in which we detail these hermetic values by explaining what we mean. For example, if we want to develop a system that prevents user from being tracked, the key value would be *"safety and security - privacy"*, the requirement that should be discussed with relevant stakeholder would be *"how can we avoid user profiling, tracking and stalking?"* and the performance to answer could be, for example, *"a specific software or technical solution able to encrypt user data or, if any solution is safe enough, avoid collecting those data that can put the user in danger"*.

3.2.2 Empirical. Identify requirements

The second stage is the empirical investigation focuses on quantitative and qualitative measurements (Cummings, 2006). According to the UW:

> *Empirical investigations focus on the human response to the technical artifact, and on the larger social context in which the technology is situated. The entire range of quantitative and qualitative social science research methods may be applicable (e.g., observations interviews, surveys, focus groups, measurements of user behavior and human physiology, contextual inquiry, and interaction logs)* (University of Washington, 2011)

It represents the mediation between values and technical aspects, between values and feasibility. How to translate those values into practice on a certain artifact? How to translate them to boost the design process? This phase should be based on multi-stakeholder requirements. It provides the means to establish a hierarchy of values, depending on the specific case and prioritising competing values. It allows the designer to support or detract from value conflict. Focusing on the user, we provide a list of

requirements that can be discussed with different stakeholders, without pushing new requirements (Bonino and Corno, 2011; Barbero, 2012b). Detailing the previous categories, we seek to provide a starting point in addressing and forecast possible issues (Figure 11). This quick overview refers to the user, his/her safety, that cannot be negotiated.
The second part of requirements involves comfort and satisfaction (Figure 12). Far from being exhaustive, this list of requirements can be considered as a tool to structure the decision-making process. According to the specific project, the next step should be prioritising the requirements shown in Figure 12 and set the target values of that project. Moreover, requirements can be integrated and, once specifically analysed, they should be investigated directly with the user through surveys and focus groups, since there is the need for research experiment in the real world.

3.2.3 Technical. Define performances

The last phase concerns the investigation of technical issues. According to the UW:

> *Technical investigations focus on the design and performance of the technology itself, involving both retrospective analyses of existing technologies and the design of new technical mechanisms and systems. The conceptual, empirical, and technical investigations are employed iteratively such that the results of one type are integrated with those of the others, which, in turn, influence yet additional investigations of the earlier types.* (University of Washington, 2011)

It evaluates the service or work provided by technical solutions and how they support specific values. It also evaluates how different design possibilities could best support the values identified in the conceptual investigation. Even the third step includes the decision-making, by choosing from several solutions that meet the requirements. This stage serves the dual purpose of having clear in mind the state of the art and predict potential future needs if the solution is currently missing. In this phase, some Multiple Criteria Decision Aid tools (MCDA; Roy, 1990; Doumpos and Zopounidis, 2002) could be used to structure the decision-making, setting some weighted criteria on a decision matrix, to analyse a set of solutions. At the end of the process, these tools can provide a rank of solutions, although it is not

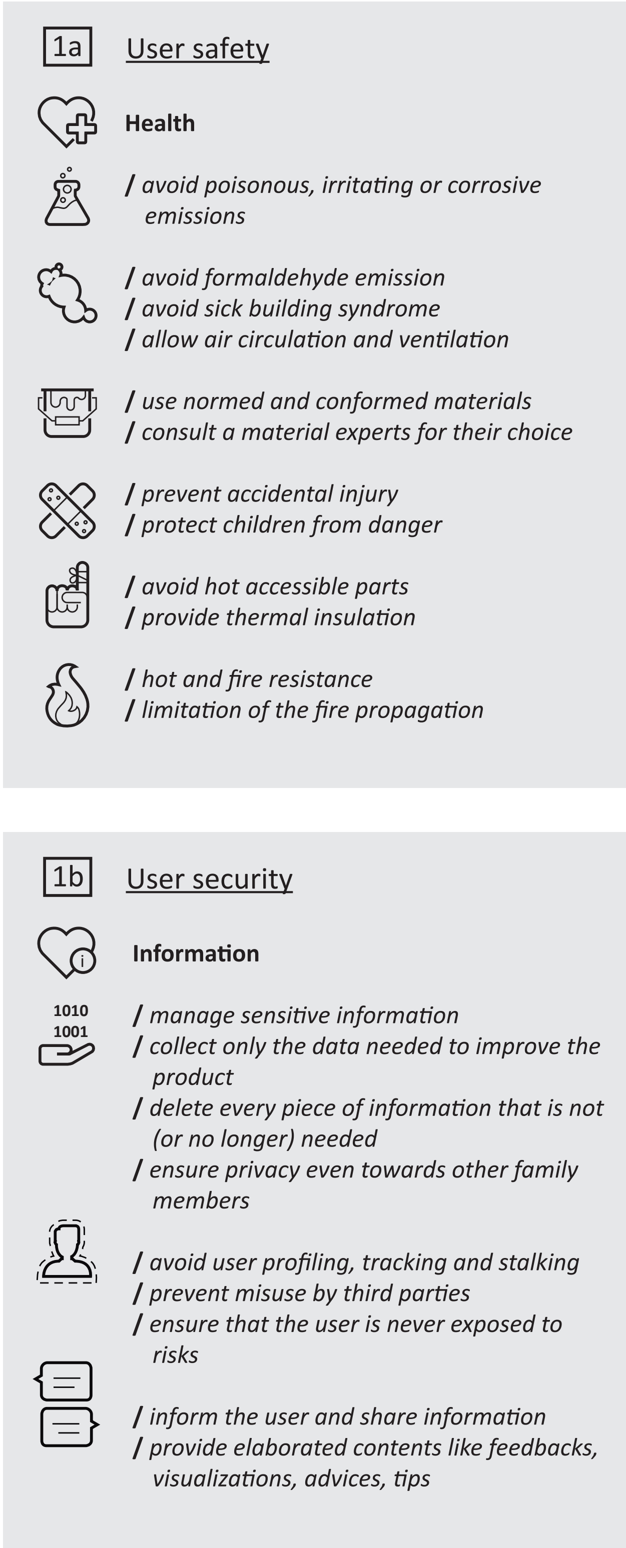

Fig. 11 - User safety and user security

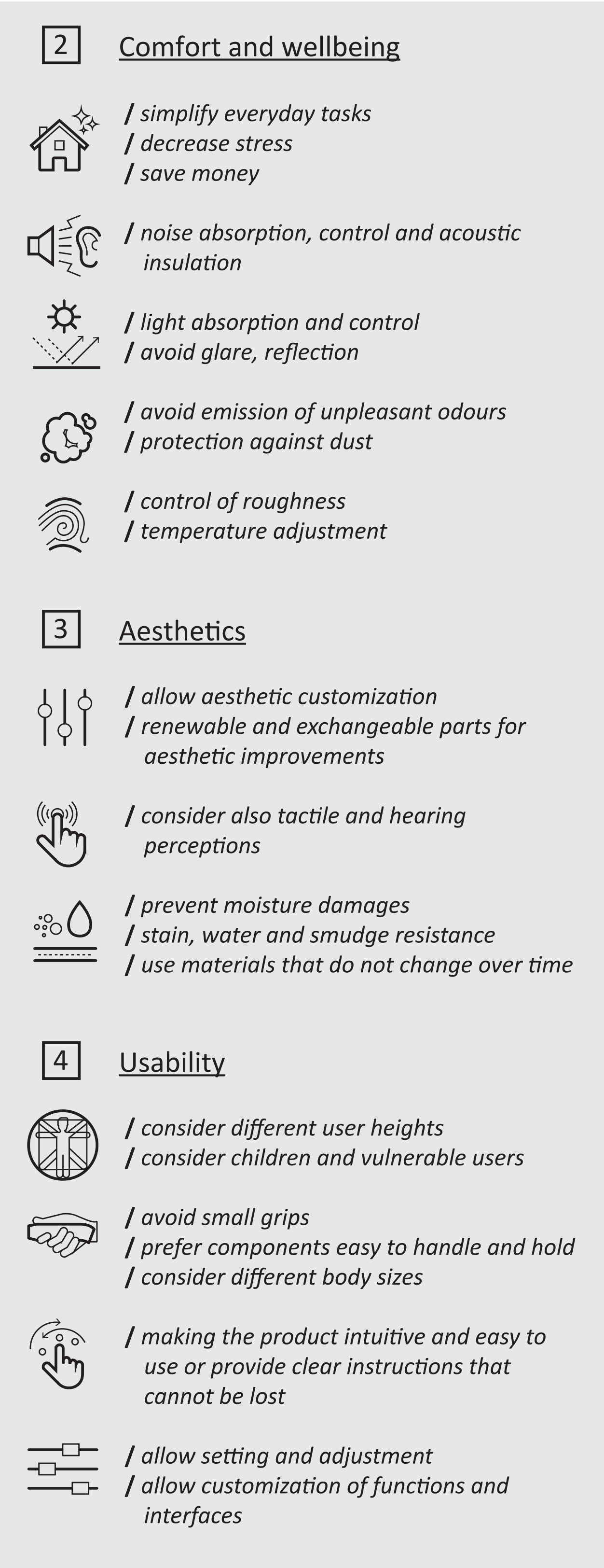

Fig. 12 - Comfort, aesthetics and usability

always necessary

***When values are not negotiable and technology cannot have agency*.**

We want to report the case of Fully Automated Vehicle (AV) and its behaviour in case of accident.
In the case of full AV, the car should have an algorithm that decides what to do in case of accident, because a fully AV provides that the user is not alert and active when moving. While humans take responsibility for what they do, for Artificial Intelligence without intuition, the rules in these situations should be written by AV programmers, humans that in that moment are not in danger and should plan every possible scenario. Although fully AV is not already reached, should we deduce that they are already making choices about whose lives matter? Could thus a car have the agency to do decide who should die? The answer is no.
If such a car needs to be programmed to decide between life and death, then that function should not be developed at all. While other functions that can be automated, the steering must always remain in the driver's hands and the user must be vigilant. The example of AV perfectly fits one of the three types of computing practices that are problematic from the ethical perspective of human agency, i.e. "anthropomorphic computational systems that acts as humans" (Friedman and Kahn, 1992). Another example provided by Cummings (2006) fits the second and third types of issues, i.e. (ii) delegating decision-making to computational system and (ii) delegating instructions to a computational system (Friedman and Kahn, 1992). This case, indeed, is about cruise missile control interfaces and it investigates which is the level of automation that would appropriately support the operator, implying that an automated procedure could give suggestions on how to intervene to cut down lives. Knowing the human tendency towards automated bias, we suggest that no computerized help should be provided in this field and no designer should work for such interfaces, since the definition of ethics is based on the decision making of human agency, humans should keep this agency also in deciding whether an application is right or morally deplorable.

Why do we need to combine social ethics with a systemic design approach?

To this regard, we seek to promote responsible design through a Systemic Design (SD). SD, indeed, provides a more holistic approach that could help designers to keep the stakeholders in the system while considering if a solution has serious consequences on someone. SD helps to manage the scale of detail, from the micro to the macro, while keeping at hand all the relevant aspects and the network of relationships that are established between the stakeholders. When designers do not know if what they are doing is ethically correct, they can ask the question "Is there someone who can suffers from some actions or could be subjected to improper actions?" If the answer is “yes”, “probably” or “maybe” the second question is "could this consequence be avoided or foreseen in any way?". If the answer is “no”, then that action or task should not be developed nor be carried forward. If the answer is “yes” then the process can be reiterated to include a solution that solves the problem, so that the first question can be answered “no”. Design Ethics should question the ethical validity of the existence of the system itself, especially when its intended use includes “military hegemony” or the “decision between life and death”. The systemic effects of VSD should be included. Some values cannot be prioritized in favor of other values that are preferred by the company or the organization for which the designer works, which is just one of the stakeholders. Safety and security, environmental sustainability must be considered as non-negotiable values.

There are various methods grouped by the University of Washington for engaging designers in critical reflection on the functions and futures of designs, such as scenario-based design, value scenarios, future workshops, alternative nows, and design noir (O’Leary et al., 2013). The last one reflects on dystopian effect of design, creating disturbing scenarios for decision makers to better understand ethical choice outcomes. The designer should always question "what if a certain feature would be used by the wrong people? Could one of the stakeholders be endangered?”. Moreover, there cannot be an ethics of sociotechnical systems without individuals although there might be thing-to-things scenarios in which an applied dimension of ethics is extended to inanimate things (object-oriented). In the last case, the implications of these things-to-things interactions must be computational and must not have interactions with the user's life. In this paper, we discuss the ethical design for designing sociotechnical systems, in which we can trace implications between individuals, technologies and systems designed to provide interactions with both and we attribute the sole agency to humans, when important decisions are at stake. I believed that computers can be agents, but cannot be moral agents, i.e. cannot be held morally responsible for a decision. Computers can establish relationships things-to-things, but they cannot make decisions in the real world. Computer can process data, but they cannot take decisions independently, based on them. Computers can be used to collect data and to support operations performed by individuals, but both processes and data collections should be potentially ceased and accessed at any time by the authorised human agent.

3.3 Ethics of technology in connected appliances

> *Design should be a synergy between the abstract knowledge of the expert and the local knowledge of the user. [..] VSD is not simply the accommodation of local values in the designers’ vision of the future, but a process in which designers and citizens depend upon each others’ knowledge in the production of a better world* (Kroes et al., 2008).

In this scenario, a product or a service is considered ‘the medium through which the dialogue between the designer and the user takes place’ (Figure 13). It should help gaining useful insights into both requirements and ‘situated knowledge’ (or local knowledge) on how products are used in the real context of use. The medium could be a smart object or a platform, bringing out the topic of Internet of Things (IoT), which prompted us to undertake this discussion, moving from generic consideration on computational systems to a defined technology (IoT) and a context (domestic environment) with its inhabitants and a network of direct and indirect stakeholders.

3.3.1 Internet of Things

We do now have a plethora of devices with computer technology inside, that are partially connected and with which we interact differently than before

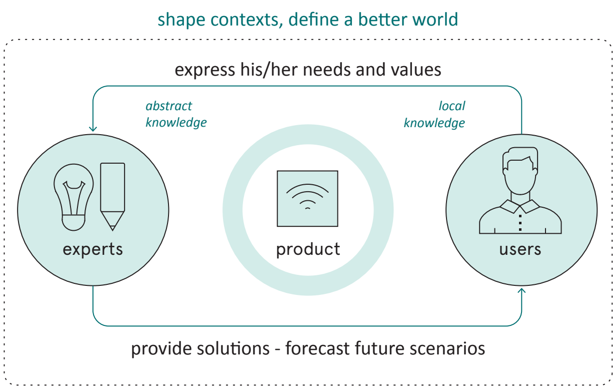

Fig. 13 - Defining the medium of the dialogue between users and experts

(Schurig and Thomas, 2017). The introduction of IoT in people's everyday life is leading to unprecedented opportunities for innovation as well as unprecedented risks and challenges. Collecting different definition, IoT can be defined as:

> *A global network infrastructure of interconnected devices or gadgets [..] able to collect, store, process and communicate information about themselves and their physical environment [..]. IoT indicates a loosely coupled, decentralized system of smart objects* (Kortuem et al., 2010).

According to different definition of smart objects provided by Kortuem et al., (2010), we can define this relatively new category of product as everyday artifacts augmented with computing and communication, enabling them to establish and exchange information about themselves with other artifacts and/or computer applications (Beigl et al., 2001), not only to communicate with people and other smart objects, but also to discover where they are, which other objects are in proximity, and what has happened to them in the past." (Mattern, 2003). Norbert Streitz and colleagues proposed two different approaches to smartness; one is for objects that can take specific actions based the previously collected information; the second is to empower users to make decisions and take responsible actions (Streitz et al., 2005) based on the result provided by smart objects. For Kortuem et al., (2010) a smart object is characterized by three features:

- **Awareness** is a smart object's ability to understand (that is, sense, interpret, and react to) events and human activities occurring in the physical world. An activity-aware object understands the world in terms of event and activity streams, where each event or activity is directly related to the use and handling of the object (pick up, turn on, operate, and so on).
- **Representation** refers to a smart object's application and programming model — in particular, programming abstractions. Its application model consists of aggregation functions for accumulating activities over time.
- **Interaction** denotes the object's ability to converse with the user in terms of input, output, control, and feedback. Activity-aware objects primarily log data and do not provide interactive capabilities.

Therefore, established that smart objects can understand and react to their environment, all the other objects that do not, are just connected or sophisticate objects or systems that do not have a level of understanding built into them (Cruickshank and Trivedi, 2017). However, the true meaningfulness of IoT comes when objects are not considered in isolation.

> *Although smart objects working in isolation create interesting opportunities for novel information services, smart objects' true power arises when multiple objects cooperate to link their respective capabilities* (Kortuem et al., 2010).

The IoT effectiveness increases when the whole system works together (people, objects and technologies). IoT continues to invoke a variety of unique design challenges across a wide range of different application domains.

> *As the IoT pervades more widely, we are becoming increasingly entangled within the heterogeneous network of interconnected objects or things that are readable, recognizable, locatable, addressable, and/or controllable via the Internet* (Lindley et al., 2017 p.2846).

Some legitimate questions arise, regarding the type of data and when they are collected, about who can access them and for what purpose, but also how long they are stored, and so forth.

IoT privacy and security

While users generate data by using the interfaces, services and products, these data are not available to the users, and they cannot perceive their implications

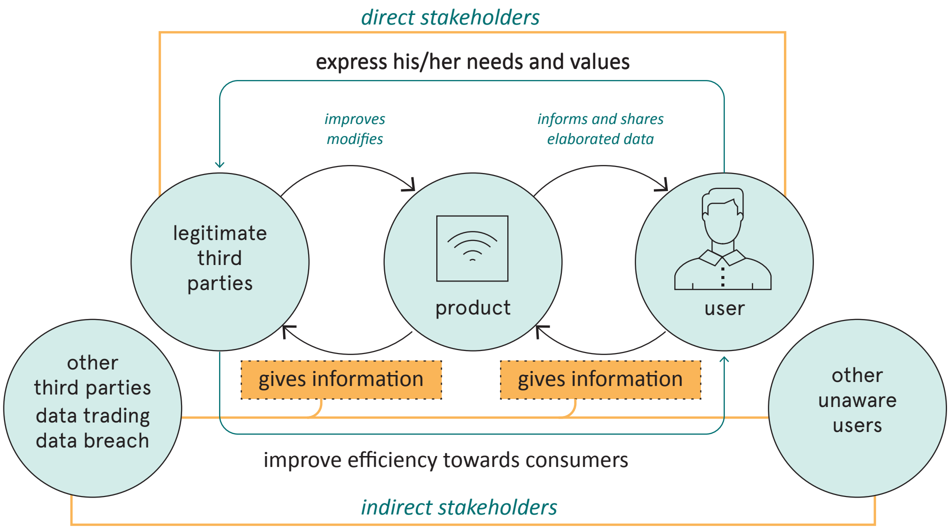

Fig. 14 - Direct and indirect stakeholders and authorised use of information

(Iaconesi, 2017), nor the background data gathering and sharing activities. In fact, *"the visibility of the data shared by these devices today is at best opaque and in worst cases absent"* (Lindley et al., 2017). Users often do not have control over their role within the network of stakeholders surrounding an IoT product (IoT Manifesto, 2015).

Figure 14 shows the flow of information between the stakeholders of a connected devices. In this complex scenario, there are direct and indirect stakeholders (whose analysis is central to a VSD approach), as well as internal and external uses of these data. The internal use of data is the one expected. Providers are among the third parties in a legitimate way, and they could be commercial actors, such as companies, suppliers, home security providers, software and hardware vendors or standardization organisations (Jacobsson et al., 2015). Collected information can be used to reduce costs and improve the efficiency towards consumers because this amount of data enhances the understanding of user characteristics and requirements. How are both direct and indirect stakeholders affected by design? What values are implicated? More pronounced and articulated a technology becomes, the more humanity is exposed to the unanticipated side effects and risks of harnessing technology (Chan, 2016). Along with the consolidation of IoT solutions in different areas, there is increased attention among companies on the value derived from the information made available by connected objects. This could lead to an external use of data by other side stakeholders, which might be interested in profiling clients. The improper use of data should also include illegal computer intrusions, motivated by malicious intentions (Figure 14). Moreover, the privacy of other unaware users, such as children, other family members or those who are visiting relatives and friends, should be ensured.

These concerns, especially when related to privacy, provide an interesting counterpoint to the discussion started in 70's by Nicholas Negroponte about the automation in design. He suggested that a machine that is not able to evolve or self-improve should be considered as unethical (Negroponte, 1970) since it will not be able to adapt to changes and it acts applying simplistic solutions. In his opinion, intelligent machines should be able to learn and understand contexts by interacting with them. It provides us with the opportunity to introduce the concept of artificial intelligence.

3.3.2 Artificial Intelligence

Artificial intelligence (AI) could be deeply connected to IoT. Schurig and Thomas (2017) provide a collection of definitions from different scientists.

> *'The study of the computations that make it possible to perceive, reason and act' [..] 'The branch of computer science that is concerned with the automation of intelligent behavior'[..]* (Schurig and Thomas, 2017).

Although the concept of artificial intelligence dates back to the 1955 with the pioneering work of John McCarthy, with machine learning and deep learnin, we will experience a transition of AI from the theoretical field to the applied one. Platforms like Google and Facebook are making active use of the development of AI (Schurig and Thomas, 2017). Schurig and Thomas (2017) distinguish 6 main fields of application for AI: Artificial Neural Networks (prediction of human-based activities, e.g. election, result of sporting events), Fuzzy Logic (to deal with uncertainty in problems), Software Agents (e.g. Google Now, Netflix, Spotify), Knowledge Based Systems (involved in decision making), Natural Language Processing (capability to understand and generate natural human language, e.g. Amazon's Alexa, Echo, Apple's Siri, Windows' Cortana), Genetic Algorithms and Evolutionary Software (problem-solving systems to find the best solution for a given problem). Some of these types of AI fall into all the ethical problems highlighted above. Can a computational system be considered to have intentional state? Friedman and Kahn (1992) answered "no" many years ago, referring to the impossibility to attach any meaning to symbols. And this position nearly 30 years later is still valid. Computer has no intentionality, which is a necessary condition of moral agency. Computer can monitor, collect, connect and process data, but they do not attach any meaning to those data.

User disempowerment

In her paper Integrating Ethics in Design through the VSD approach (2006), Cummings asked a lot of ethical questions:

> *How much automation is needed for a system and to what degree should humans be in the decision-making loop? How automation can best support human decision makers and what level of automation should be introduced into a decision support system to provide human centered automation support?* (Cummings, 2006, p.705 and p.708).

This paragraph highlights the confusion in this field. These questions seem to assume that technology is there and cannot be questioned.

1. How much automation is needed?...we reply: "Is it really needed?"
2. What degree should humans be in the decision-making loop? ...we reply: "Can be excluded?"
3. How automation can best support human decision makers? ...we reply: "Who are those decision makers"
4. What level of automation should be introduced into a decision support system to provide human centered automation support? ...we reply: "should be introduced?"

These questions evidently conflict with basic human values and it is no longer clear if the technology is the helper or the ultimate goal. We try to replace those questions with another list of questions:

1. "What is the task that the human want to perform?"
2. "Could the task be facilitated by some technology/automations?
3. "Could the use of technology/automation affect human wellbeing or environmental security?
4. "After the implementation of the technology, will the human still be the decision-maker?

Some authors (Manzini, 2006; Friedman and Khan, 1992) pointed out that in many circumstances humans experience a diminished sense of agency. The Level of Automation (LOAs) reached from an automated system has been classified, and it ranges from a minimal level of automation to fully automated systems (Cummings, 2006), as we already pointed out with fully AV. A common risk for designers and user is the lack of system understanding and the loss of situational awareness that full automation can cause. A soft example of that behavior is following the directions of Google Maps to reach a place, without questioning whether they are effective. People are used to rely on it, even though contraindications existed and verification of contradicting information is possible (Skitka et al., 1999). Another example is the introduction of time-saving technologies (Aldrich, 2003) that led to the concept of "wellbeing as the minimization of personal involvement".

> *The best strategy seems to be the one which requires the least physical effort, attention and time and, consequently, the least need for ability and skills* (Manzini, 2006).

This has progressively lead to disengage and disempower the user in everyday tasks, leading to disabling solutions, i.e. "systems of products and services that seek to reduce user involvement and sequester formerly widespread knowledge and skills to integrate them into technical devices" (Manzini, 2006). In the meantime, technologies have filled the time they saved, which was initially intended for leisure. This scenario is 'not-so-hypothetical' and it promotes passive user, disabled to understand how things work that will accept automatic and hyper-technological devices, losing interest in "what they do", because they cannot understand it. This increases the distance between the user and the object. Disengagement may also come from other factors, such as an excessive technology obfuscation. If it is true that "obfuscation contributes towards some "notion of HCD-inspired usability", on the other side it *"disempowers the user and unintentionally reduces the acceptability of IoT devices [and resulted in a] lack of trust in the device"* (Lindley et al., 2017). Another source of disempowerment is attributable to an ever-increasing number of connected devices, that brings humans to daily friction in interacting with them. As the friction increases, the user feels more frustrated about the overall experience, perceiving a diminished usefulness of the connected object (Streitz et al., 2005). Moreover, all these factors deeply hinder the attachment dynamics, leading to increasing product obsolescence.

<u>*Other undesired effects*</u>

If the relationship between technology and user is often controversial, sometimes their interaction is different from the designed or expected one, making some issues challenging to anticipate and prevent. Some authors sought to explain these unpredicted effects as follows:+

> *People learn to manipulate the systems to do completely new activities, ones not contemplated in the design. [..] Sometimes people discover how to take advantage of the system design, deliberately misusing the systems when they discover that by doing so, they get beneficial results* (Norman and Stappers, 2016, p.89).
>
> *The unpredictable nature of user behaviour may result in rebound effects such as increased consumption, the bypassing of technology, or its ignorance and unintended use* (Wilson et al., 2016, p.91; Pettersen and Boks, 2008).

Manipulation, safety issues, rebound effects, unintended uses are some of the side effects of the interaction between people and technology, but undesired effects are not limited to the interaction with the user. They can be extended to societies and environment, undermining different areas.

> *Over the years, CSE (Cognitive Systems Engineering) has learned from many examples in which technologies that were designed to improve performance actually introduced new unintended problems, sometimes making things worse. Wiener coined the term "clumsy automation" to describe a recurring pattern where technological innovations solved the easy problems, but made solving the hard problems more difficult. The potential for clumsy automation typically arises when the designers of the automation lose sight of either (1) the work domain, for example by trivializing aspects of a complex problem; or (2) the people using the technology, for example by overloading limited resources* (Flach, 2016, p.95).

To prevent or at least mitigate these effects, the designer should ask him/herself:

- Can the technology be manipulated for other purposes, even by the same user? How?
- Can the technology if misused become a damage to the same goal for which it was intended? How?
- Can I foresee them in the early stages of design? How?

3.3.3 The impact of the ethics of technology on the professional ethics

Many authors pointed out how product innovation could also have unintended consequences on individuals, as well as on the environment (Mink, 2016).

> *Design is, in the Aristotelian sense, a science of correct action. Ethics is an integral part of all aspects of our designs and all our uses of technology* (Devon, 2004).

The separation of technology from its social context (Van de Poel, 2001) and the idea that technological practices are free from any consequences should be considered outdated. Technology should get free from the instrumentalist paradigm, which perceived it as external to moral choices. Ethics of technology associated with this instrumentalist model could ask

> *if the ends justify the means, or whether certain consequences are justifiable and to what extent is the designer virtuous or not in the use of technology* (Chan, 2016).

Design Ethics should bridge the gap between technology and context, considering context-specific, socio-political and cultural values. In doing so, the designer should fully understand the environment and explore future possibilities. Going back to the case study, the connected device is the technical element of a broader system that also contains individuals and social contexts. Technology both shaped society and social factors shape it in turn. Should the designer be considered responsible to produce the material environment, through the existence and use of what is produced for his employers? (Van de Poel, 2001). Are both the design team and the company responsible for the information generated from IoT connected devices? What is the responsibility of design? According to Chan

> *The responsibility of design has so far been problematically understood and defined, and mostly it does not go beyond the obligation for professional due diligence. A first way to consider responsibility is indeed a form of professional ethics or code of conduct towards clients and users; the second way, however, admits to a broader social intention, as social and moral responsibilities of design* (Chan, 2016).

Thus, the first way should lead to write a design ethics code that addresses the implications deriving from new technologies and establish a design ethics community able to judge controversial cases and protects the designer towards the requests coming from companies, as well as penalise designers who behaved in unethical ways. In this way, the designer should feel entitled to act in an ethical way, even more so because if he/she did not, his/her work would be judged. Designers should avoid working on tasks in which they foresee any negative consequences. Giving more emphasis to the second way, however, a social and moral responsibilities of design is included in the design process through the definition of three guidelines. We aim to demonstrate that the designer could act as a promoter of ethical aspects because ‘technical issues’ do not fall upon 'other experts' responsibility.

3.3.4 Guidelines

1) Consider privacy, security and data accessibility

In this specific field, the designer should consider privacy and security issues and current limits to avoid falling into one of the problems described above. This task is even more challenging when designers cannot count on social norms to provide guidance in many matters of new technology and design (Flusser, 1999). In the current state of the art there is a general lack of legislation and policies, which directly leads to the possibility of:

- Wrong/improper use of information;
- User identification, tracking and profiling;
- User limitation of freedom

As mentioned before, these issues should be included in the design process, in the same way in which user needs are considered. The designer should question how to prevent and avoid wrong or bad behavior resulting from the misuse of the products and information. The designer is responsible for determining what to collect, which data are needed (Streitz et al., 2005) and which are unnecessary or even dangerous to collect. According to Streitz et al., 2005 and the IoT Design Manifesto (2015) ‘privacy-by-design’ must be guaranteed in any device and related digital application, trying to identify and foresee potential security threats. This operation involves studying, modelling, and analyzing the environment in which the system will operate (Cheng and Atlee, 2008).

> *This is not the business of hoarding data; we only collect data that serves the utility of the product and service. Therefore, identifying what those data points are must be conscientious and deliberate* (IoT Design Manifesto, 2015).

The designer should draw on the methods presented before to simulate critical reflection with different stakeholders on the possible negative effects of some functions and futures of designs, regarding privacy, security and accessibility, considering possible data leak, data breach and other negative scenarios.

Data should be accessible to users who generated them, promoting accessibility and transparency and users should be empowered to set the boundaries of how their data is accessed and how they are engaged with via the product (IoT Design Manifesto, 2015). Even in this case, focus groups and participative sessions can make designers understand how the user would like to access his/her own data, what does he/she want to see and, consequently, with the help of company and computer experts, designers should understand how to prevent third parties to access data, thus protecting the user.

2) Protect the human agency

Keeping the operator, the designer and the user (stakeholders in general) in the decision-making loop should contrast the tendency to rely upon automated (computer-generated) recommendations. An ethical design should shift from a passive to an active involvement of the user with his active participation in the design process. Moreover, this approach should never let the user think that his/

her freedom and control upon things or systems is failing. We can always check if the human agency is protected through prototyping the solution and asking directly to the stakeholders, but in any step, we should ask ourselves "after the implementation of the technology, will the human still be the decision-maker?" If the answer is no, then we must interpret the reason why it is not, and try to solve the friction between humans and technologies.

If the task is simple, such as "adjust the temperature of the heater", the procedure can be automated. However, individuals should never consider themselves at the mercy of the automation decisions and if one individual feels too cold or too hot, according to the other people in the room, he/she should be able to act to diminish his/her thermal discomfort, even if the HVAC system has complex algorithms to decide which is the right temperature for that environment. On the other hand, when an automated system makes a choice that cannot be changed, the user should at least be informed about the reasons behind choice. The user should be able to ask somehow "why the HVAC system cannot raise the temperature in the office by a few degrees?". If the answer is that "raising a single degree of temperature would bring an increase in energy consumption of 5€/min" or "the system is in a technical failure and cannot be controlled", the user would find at least an intellectual satisfaction, understanding the reason why he/she is experiencing discomfort or should work wearing an extra jacket and, in the case of technical failure, he/she may decide to work from a different place (if possible). The user should not feel any automation as "restrictive" and should always be informed about the reason behind some effects.

3) Promoting physical interfaces

To mitigate the undesired effects reported as the third source of disempowerment, i.e. the daily friction in interacting with dematerialized technologies, one possible solution could be enhancing the importance of physical interface and tangible part of the system. This could be also a way for the product designer to take care of designing tangible objects. Many authors, indeed, agree on the importance of using physical objects and physical interfaces instead of delegating functions to screens, displays and smartphone through apps (digital interfaces). When a digital and immaterial counterpart augments tangible objects, the value of the physical part must be clarified and highlighted (Vitali et al., 2017).

Schurig and Thomas (2017) predict that:

> *The rising complexity will make a digital interaction so unfriendly for the user that the added intelligence will be used to enable designs that focus completely on tangible interfaces and natural interactions between human and objects* (p.3809).

According to Vitali et al., (2017) suggested to experiment:

> *Less intrusive ways of integrating technology into our lives [..] screen-only interaction is not always perceived as rewarding. People are often ashamed of being tethered and dependent on their devices and may feel the need to "disconnect" for a digital detox pause* (p.2594).

Schurig and Thomas suggest that:

1. Design should take the lead over technology in terms of developing physical products.
2. If the application of AI can save resources when applied to an existing object, then it should be done. If not, it should be evaluated before being forced upon an object.
3. Designing fall-backs in a natural, tangible way will be the most important part of the design of future intelligent objects.

3.3.5 The evolving role of the designer

In 1980 User Centred Design (UCD) codified a way for designers to conceive of their relationships with people that will use their designs, structuring the role of the user (or 'human') that matters in design processes, whose understanding of needs, abilities and perspectives should improve the effectiveness of a design. (Cruickshank and Trivedi, 2017). Now we need an inclusive design approach to deal with the new smart objects able to sense and experience the world and collect information from environments and contexts (Cruickshank and Trivedi, 2017). How can we design for this complex system of people and things? Understanding how designers adapt their design practice to deal with the IoT is not enough. Design research probably needs new platforms for performing future design practice (Lindley et al., 2017), able to provide the fluidity needed to address both uncertainty, evolving requirements and things perspective. It can be noticed that many design researchers consider design tools and methods as insufficient to deal with the complexity of sociotechnical systems, evolving requirements and the new challenges of smart technologies. From a practice perspective, crowdfunding platforms can be considered as platforms of interaction between designer and early adopters. On the one hand, designers propose concepts through video, photo, storyboard etc, on the other hand, people provide feedback on the prototype during the whole crowdfunding process, thus impacting the design process (Vitali et al., 2017) and the development of future products. These digital platforms establish a two-way dialogue between users and designers, facilitating co-design initiatives, enabling user innovation (Vitali et al., 2017).

A platform of interaction 'designer-user'
Sociotechnical systems demand for new approaches and more flexible tools. Using a digital platform of interaction between design team and stakeholders seems to be a viable way to cope with this emerging need. Through the platform, the design team could accommodate the evolving requirements of stakeholders (also those connected to other services, policies), helping the designer to address different perspectives and requirements that derive from different actors, including the insights deriving from smart enabling technologies. In this way designer could keep the requirements at hand in every step of design, validating, testing allowing running changes, providing the fluidity needed in dealing with sociotechnical systems, as well as providing a platform on which to share concepts and models. The data that the objects sense could be accommodated in this type of platform helping the designer during the immersion phase (de Arruda Torresa, 2017), i.e. when designer (or more often, the design team) goes into the field and observe on site how people live, how they perform their daily activities, identifying their aspirations, behaviours, dreams, difficulties, frustrations and experiences. In this way, the investigation can rely on feeling, intuition and inspiration of the design team combined with measurable information. The use of a platform mitigates some of the problems generally attributed to participatory activities, such as time and resource consumption, helping to manage roles and purposes.

3.4 Conclusions

In this chapter we provide a guide to the product designers. Designer, as far as possible, should be able to foresee future problems, while addressing current ones. Although designers cannot always foresee all consequences of the usage of their designs (Mink, 2016; Albrechtslund, 2007), they should at least try to anticipate ethical scenarios and possible issues, thinking through the consequences of their innovations and by uncovering the values, motivations and commitments stakeholders bring into the design process (Mink, 2016). Protect the human agency should ensure that the user understand how things work and how to use them properly, understanding also the cause-effect of different actions and modifying his/her future behavior to reach a personal, social or environmental goals. Designers are called to mediate the social/human component with the technological one. Designing socio-technical systems requires the designer to pay attention to several implications, even unexpected, to ensure that the user is not exposed to risks. In STS, the behavior of the agents is generally unpredictable and maybe cannot be controlled (Kroes et al., 2008). The guidelines defined propose a return to the materialization of abstract concepts. The user seems to be frustrated by the lack of contact with tangible supports, the lack of cause-effect, action-reward, action-punishment that could be regarded as antiquated in a hyper-digitalised world. In this paper, we consider a behavior "right" if it produces good consequences, while if it produces bad consequences that can be foreseen it must be avoided. Ethics should investigate the cause-effect that may occur, detaching from the case-specific, looking at the whole picture and consequences/relations that can be triggered by a product or service. What if those consequences/relations cannot be seen or, worse, are not attributable to anyone? This is the paradox that we, as designers, are called to unmask. Design in an ethically responsible manner is an evolutionary process, and we cannot generalise trying to follow step-by-step predefined rules because contexts change, people change and the whole system evolves. The design should try to direct evolution and changes in an ethical and sustainable direction.

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Chapter 4

Design for Sustainability

This chapter addresses many of the issue deriving from the human impact on the environment, investigating the design scene, by focusing on design for sustainability. In this brief overview, different theoretical frameworks evolved over the last decades are addressed, eventually introducing the Systemic Design approach. The section about requirements ends with an application of the methodology to environmental protection.

4.1 Introduction

The first colour image of the whole Earth was taken by DODGE; the satellite was sent into a near-geostationary orbit in July 1967 (Cosmicwatch, 2015). Afterwards, it appeared in 1968 on the Whole Earth Catalog's first edition (Brand, 1968). This is acknowledged to have heightened awareness and shaken the hearts of both limitedness and the fragility of our planet. Sustainability pioneers like Buckminster Fuller (1968) and Victor Papanek (1971) expressed their concerns about both sustainability and human survival back to the '60s. In the 1970s there was an intensification of environmental awareness (McAloone and Pigosso, 2017). However, beyond the early environmental activism, a more systematic involvement in these issues started not before the 1980s, with a general awareness about the Earth's finite resources and the beginning of regulatory actions.
Before the introduction of directives, industrial outputs were disposed directly in the environment leading to a severe pollution and health consequences. Companies had to comply with the enacted legislation, by investing in technologies, which were chiefly intended for the treatment of industrial wastewater, solid waste and gases generated in the production processes, the so-

called 'end-of-pipe' solutions. The strong tendency to understand environmental and sustainability issues as a cost comes from that (McAloone and Pigosso, 2017). 'Our Common Future', also known as the Brundtland Report, from the United Nations World Commission on Environment and Development (WCED) was published in 1987 and provide the quoted definition of 'sustainable development' as:

> *development that meets the needs of the present without compromising the ability of future generations to meet their own needs.* (World Commission on Environment and Development, 1987, p. 44)

Many steps forward have been made since then, not only at the policy level. In the late 1990s, people started to realise that products were at the origin of most of the pollution and resource depletion leading to a transition to a more proactive approach. Thus, companies realised that all products caused some impacts, not only during the manufacturing processes, but also throughout their entire life cycles (McAloone and Pigosso, 2017). According to McAloone and Pigosso (2017) over the 1990–2010 period, companies have significantly evolved their approaches towards the integration of sustainability into their business activities, developing from a passive and reactive stance, towards the adoption of more preventive and proactive approaches (McAloone and Pigosso, 2017). What happened in the field of design research? The so-called Design for Sustainability (DfS) has experienced several phases from the 1990s onwards. From Green Design to Ecodesign, now embracing the CE and more holistic approaches, like Systemic Design (SD) and Product Service Systems (PSS), when expressly directed to environmental sustainability, to cope with both complexity and strategical aspects. In general:

> *Sustainable design is concerned with the creation of new, added value, eco-efficient products or services that can stimulate the economic competitiveness of industries, while contributing to more sustainable forms of consumption and lifestyle scenarios* (Mestre and Cooper, 2017).

Green design is generally considered the pioneer of the DfS strategies, aimed at lowering environmental impact through the replacement of materials (i.e. replacing toxic materials, use recyclable ones) (Ceschin and Gaziulusoy, 2016). Then, the explosion of the 'green' attribute to anything that pretended to be sustainable and the negative meaning of 'green washing' led to a progressive replacement of green in favour of 'ecodesign'. Changing the attribute went along with an evolution of the meaning, introducing improving solutions throughout the product lifecycle (Mestre and Cooper, 2017). Indeed, ecodesign emerged as a promising approach for the integration of environmental considerations in product development processes (McAloone and Pigosso, 2017; den Hollander et al., 2017). Ecodesign aims to minimise environmental impacts across the product's life cycle[9] without compromising other essential criteria such as performance, functionality, aesthetics, quality and cost (Pigosso at al., 2015). Life cycle design emerged in the 1990s as one of the first detailed approaches to ecodesign to increase efficiency throughout the product life cycle (McAloone and Pigosso, 2017). Mestre and Cooper described the eight strategies for product development (Mestre and Cooper, 2017). Many efforts have been made to set and consolidate the field of Ecodesign. Now, it provides product designers with a range of tools and methods according to different product types and industrial sectors (McAloone and Pigosso, 2017), as well as guidelines and strategies (den Hollander et al., 2017; Pigosso et al. 2015). These tools and methods allow to quantify impacts and compare products, concepts and solution with the goal of minimising the consumption of natural resources (Ceschin and Gaziulusoy, 2016). Among these methods for evaluating the environmental performance of products, Life Cycle Assessment (LCA) and similar approaches were widely used also by manufacturers, while designers more welcome simplified LCA and ecodesign guidelines. Moreover, there are indicators to measure the performance of products at their End-of-Life (EoL) (Movilla et al., 2016). They consist in absolute or relative measures that monitor the effective ecodesign implementation (Movilla et al., 2016).

Ecodesign has been accused over time of being a mere decision-making strategy, rather than a disruptive approach. Moreover, this approach was

9 Comprises the stages of a product life, often defined as raw material extraction, manufacturing, use and maintenance, and end-of-life. (Pigosso at al., 2015).

unable to address a radical change in how human society operates, which should go along with a social, cultural/behavioural, institutional and organisational change (Ceschin and Gaziulusoy, 2016).

4.2 New challenges in DfS

Although production processes become more sustainable, the quantity of household waste and resource consumption generated in industrial nations continues to rise. Indeed, ecodesign strategies alone were not enough to deal with the sustainability challenges that our society is facing, due to the ever-increasing production and consumption of products (McAloone and Pigosso (2017). One aspect to consider when addressing DfS is that some dynamics are unpredictable and the environmental benefits gained from increased efficiency are offset by increased consumption (Cooper, 2005). The 'rebound effect', already mentioned in the previous chapter, occurs where 'designed' energy and material savings of a product results in an actual increase in resource and energy consumption. Miles Park (2009) defined this effect as the difference between the projected and actual savings (or losses) due to increased efficiency, involving direct, indirect and macro-economic effects (Park, 2009). This effect could underlie consumer choices, e.g. although the average energy consumption of one item has decreased, the user buys bigger items or increases the purchasing number. Another factor underlying this trend is the life span of household goods (Cooper, 2005), i.e. the time span during which a product is considered 'functional'. Since functionality is not an absolute or measurable criterion, den Hollander et al. (2017) propose to define product lifetime in terms of **obsolescence** which has more declinations. A product becomes obsolete if it is no longer considered useful or significant by its user (Burns 2010, den Hollander et al., 2017). However, while the obsolescence was utilised as a strategy to boost the American economy after the Great Depression, the criticism of obsolescence initiated in the 70s. In 1985 Papanek formalised it and, in more than 30 years, it took a variety of declinations that correspond to different reasons for discarding a product. Among them, den Hollander et al. (2017) listed aesthetic, social, technological, economic, logistical and functional obsolescence (Hollander et al., 2017). Reduced to its essence:

> *all obsolescence ultimately is a loss of perceived value (i.e., desire or affinity) of the product and/or system, triggered, in some instances, by reduced functionality at the product and/or system side [..] The state of obsolescence does not have to be permanent. It can often be reversed, giving a product a new lease of life [..] Products can have one or more use cycles, but only one lifetime.* (den Hollander et al., 2017)

However, the subjective nature of obsolescence can make it difficult for designers to predict and determine the best design approach (den Hollander et al., 2017).

4.2.1 Product Life Extension - Designing for Physical Durability

Increasing product longevity is possible by *"intervening at various points in the lifecycle"*, improving maintenance through careful use, repair, upgrading, and reuse ('product life extension'), but also reusing, reconditioning or recycling products (and their components). Product durability and product life extension were key themes in an early contribution to the debate on sustainable production (Cooper, 2005; Mestre and Cooper, 2017). To this end, Cooper (2000) later advocated design that embraces the principles of (I) durability, (II) reparability, (III) upgradability, (IV) optimised energy and material consumption, and (V) recyclability (Mestre and Cooper, 2017). Durability is a physical property of a product, and design for durability has been researched quite extensively (Schurig and Thomas, 2017; Vezzoli and Manzini 2008).

Among the strategies for increasing product durability, beyond product's intrinsic durability, we can list 'better care and maintenance' through predictive maintenance (Cooper, 2005), as a strategy for postponing obsolesce (den Hollander et al., 2017).

Maintenance

Maintenance can be defined as the *"combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function"* (den Hollander et al., 2017).

In this definition, postponing obsolescence (i.e., retaining a product in a functioning state) and reversing obsolescence (i.e., restoring a product to a functioning state) are both considered maintenance (den Hollander et al., 2017). De Hollander et al. suggested that retaining leads to **preventive** maintenance, while restoring leads to **corrective** maintenance (den Hollander et al., 2017). **Predictive** maintenance, instead, benefits from machine learning algorithms with predictive skills, allowing to schedule corrective maintenance and to prevent unexpected equipment failures. Predictive maintenance differs from preventive maintenance because it relies on the actual condition of equipment, rather than average or expected life statistics, to predict when maintenance will be required (Wikipedia).

4.2.2 Product attachment - Designing for Emotional Durability

A less explored alternative for extending product's useful life is 'Design for Emotional Durability', which is directly linked to the product attachment. Although the field involves subjective and emotional processes that are difficult to explore, according to the product the designer is developing, product attachment and emotional durability can be addressed by the designer in the early design stages (den Hollander et al., 2017). Designing for Emotional Durability (Chapman, 2005), like other behavioural theories (Design for sustainable Behaviour to name one) goes beyond rational decision-making, being characterised by feelings, habits, routine, emotions. It represents an emotional form of decision-making, difficult to control and predict. However, it can be studied through participatory designing with both experts (psychologists, sociologists, anthropologist, ethnographers, ...) and users, to discover attachment dynamics or patterns that can be exploited to extend the useful life of an object. The emotional durability is a field of investigation that addresses both the sustainability and human-related aspects together, without friction. In general, dealing with sustainability usually lower the attention on the human related aspects, increasing the discrepancy between sustainability and user-centeredness.

4.2.3 Focus on the usage phase: Design for Sustainable Behaviour

Another field that integrates issues related to people and environment is Design for Sustainable Behaviour (DfSB), developed at Loughborough University, which according to Ceschin and Gaziulusoy, 2016:

> *Proposes a set of design intervention strategies based on informing, empowering, providing feedback, rewarding and using affordances and constraints* (Ceschin and Gaziulusoy, 2016)

DfSB is an example of a transdisciplinary enquiry which involves HCD, psychology, anthropology, investigating, at various levels, how to influence the sustainability impact of consumers' activities (Daae et al., 2017). It is implicitly related to the growing complexity of environments, but also the growing complexity of addressing two variables (user and environment) into the design process. As Cheng and Atlee suggest:

> *As systems become larger, more complex, and more tightly integrated into consumer products, the role of cognitive science and psychology will be essential to understand how wide ranges of users will interact with those systems* (Cheng and Atlee, 2008).

4.2.4 Addressing planned obsolescence

Beyond the common loss of the perceived value of the user, which occurs for many reasons, there is a business strategy whereby the product is designed to lose value rapidly (Agrawal et al. 2016; Aladeojebi, 2013). This strategy is generally acknowledged as 'planned obsolescence'. It occurs when manufacturers deliberately accelerate product lifecycle by introducing new features or technological improvements and by stimulating fashion changes (Mugge et al. 2005), which in turn negatively affects the experienced attachment to the currently owned product and induces replacement needs. Both object obsolescence and replacement could be fostered when the product shows a deteriorated appearance or aesthetic wear, e.g. when objects could not return to their original appearance even after cleaning. Technological obsolescence could be dictated by manufacturers, especially when new products make the previous incompatible. It may also happen that the object experiences a decline in performances. In this case, the object is felt outdated by a specific target, but it can still be satisfying for other users. The industrial product design should be challenged to address environmental sustainability issues, by elongating life spans of products, developing products adaptable to local and regional resources and conditions, and enabling product maintenance, repair, upgrading, etc. (Bakırlıoğlu and Doğan, 2012). Two issues can be addressed in the early design stage, anticipating and avoiding their occurrence (Fiore and Bourgeois, 2017).

Cost of maintaining higher than product benefits

When the cost for maintaining is higher than product benefits or even unsuitable compared to buying a new product, designers should, therefore, anticipate this undesirable effect, by designing products that can always be updated, disassembled, repaired and maintained. Moreover, in addition to the product, both designer and companies should foresee the spare parts network and consider services related to the upgrading operations. We should necessarily avoid and delay the replacement of a product when it still works and the user still wants to use it (Fiore and Bourgeois, 2017).

Environmental reasons to replace obsolete products

While planned obsolescence is generally considered a negative strategy, in the specific case of durable goods (e.g. main appliances, vehicles, heating systems) extending the product lifetime is not always a sustainable choice (Fiore and Bourgeois, 2017). For some product categories, indeed, extending longevity beyond a certain point might not be environmentally beneficial (e.g. for products whose main impact is in the use phase) (Ceschin and Gaziulusoy, 2016, Vezzoli and Manzini, 2008). Replacement of obsolete products could be motivated by environmental reasons and could be subsidised by tax incentives to speed up the removal of such products from the economy, pushing consumers to replace their old devices in favour of more sustainable or less harmful ones. As Mugge et al. (2005) suggested, a sensible evaluation of the environmental desirability of early replacement compared to extending product longevity can be performed evaluating the interrelations among three parameters: (i) the initial environmental impact of the replacement product, (ii) the possible improvement of energy efficiency, (iii) the expected usage time (Fiore and Bourgeois, 2017). Den Hollander et al., (2017) confirm that extending product lifetimes do not always result in a net reduction of environmental load.

> *Over time, newer versions of products may be developed that incorporate more efficient technologies. From that moment on, the environmental impacts that arise from the prolonged use of a product may become larger than the embedded impacts of a more efficient replacement product* (Bakker et al. 2014).

Once again, the designer can anticipate this issue by doing research in the early design stages, considering the performances of different materials and technologies. Upgradability and modular design could allow the replacement of a harmful or obsolete part, preserving the operation of the product (Fiore and Bourgeois, 2017).

4.2.5. Circular Product Design

A focus on End-of-life (EoL) strategies that goes beyond the waste hierarchy[10] is still very consistent for the Circular Economy, although CE refuses to consider materials as waste (den Hollander et al., 2017). CE is emerging as a promising approach to guide companies in the transition towards a stronger consideration of waste as resources in closed-loop economies (Pigosso et al., 2015). For a detailed analysis, we refer to the work of the research group in Circular Product Design at Delft University of Technology (Industrial Design Engineering) who is shaping this new branch of design (Bocken et al., 2016; Bakker et al., 2014; den Hollander et al., 2017). They consider 'prolonging and extending useful lifetime by preserving embedded economic value' as the most effective way to preserve resources, redefining product lifetime and EoL.

4.3 System Theories

From the General System Theory to Systemic Design approach

To introduce Systemic Design, we need to step back providing a brief overview of the so-called System Theories. Far from being exhaustive since other

10 As den Hollander et al (2017) explain waste hierarchy is described in the European Waste Framework Directive (EC 2009b) and it details a priority order for managing waste, moving from prevention of waste (the preferred option), to reuse, recycling, other recovery (e.g., energy recovery), and disposal (the least preferred option).

relevant authors have dealt with the history of the systems, it could help starting from the progress in other fields such as biology and then link up with the developments in design to deal with complexity. Back to the end of 1960s, Ludwig von Bertalanffy, an Austrian biologist, postulated in his General System Theory that systems could be investigated through abstract, conceptual models or principles, valid for 'systems' in general, whatever was the nature of the component elements and the relations or forces between them (von Bertalanffy, 1968). Thus, this theoretical framework helps to address different phenomena in different disciplines, from biological, behavioural and social sciences, up to cybernetics, architecture and design, highlighting general system properties and structural similarities or isomorphism in different fields. While von Bertalanffy was working on the General System Theory, other theories were developed from very different fields. Generative science, to name one, explores the natural world and its complex behaviours as a generative process, showing how finite parameters in the natural phenomena interact with each other to generate infinite behaviours (Wikipedia). Other scientists attempted to develop self-managed machines, leading to an entirely new field of investigation that contributed to the systemic vision. Cybernetics, indeed, was invented to control communication in both animals and machines. Like many sciences and disciplines, Cybernetics began in the military field funded by the Army to study tailored missile trajectories to follow military target or aircrafts (Capra, 2010). These theories were also applied to artificial systems, such as object and their context of use, productive processes with their organisations and management (Barbero, 2012b). The generative sciences were further unified by Norbert Wiener and the information theory of Claude E. Shannon and Warren Weaver in 1948 (Barbero, 2012b). Later, in 1977 Ilya Prigogine received the Nobel Prize for his works on complex thermodynamic systems, conciliating important systems theory concepts with thermodynamics. It paved the way for the study of Humberto Maturana and Francisco J. Varela on autopoiesis (Maturana and Varela, 1975) and further studies in the 90s by Stuart Kauffman about self-organisation (Kauffman, 1993). Latest and emerging directions in these sciences include the computer simulations of complex social processes and artificial life (i.e. Boids, developed by Craig Reynolds in 1986 to simulate the flocking behaviour of birds) (Barbero 2012b; Reynolds, 1987). These theories led to the definition of self-regulation and later self-organisation, information flow, message, control and feedback, studying how complex entities interact openly with their environments and evolve continually by acquiring new, 'emergent' properties (Heylighen et al., 2000). The Systemic Design (SD) Approach (Bistagnino, 2011) derives from the General System Theory, the Generative Science and Cybernetics, from which it shares a multidisciplinary approach. It also derives from other eco-management theories, such as open living systems (Schrödinger, 1944) and some of the next theories on industrial processes applied that concept also on artificial systems such as Industrial Ecology and Industrial Symbiosis, more focused and applied to production systems and value chains (Barbero, 2012b). SD research team addresses and analyses different complex situations, through the five principles schematized as follows.

Output>input
The output of a system becomes input for another one, i.e. waste becomes resource.

The importance of relationships
Relationships developed within the system generate the system itself.

Autopoiesis
A system is capable of self-supporting itself, evolving over time.

Local actions
Local context and values determines the peculiarity, the complexity and the evolution of the system.

Human centeredness
The value for the user and his relationship with the context is the center of the project.

4.3.1 Combining system theories with design for sustainability

The correlation between design and system theories occurred to face the complexity of the design activities, which could no longer be performed intuitively, but require tools and methods. The more we add variables, the more we need a multidisciplinary approach, different skills and expertise. This process tries to overcome disciplinary barriers, in contrast to a monospecific direction and specialisation typical of the first half of the century needed to dominate the vast expansion of knowledge in the scientific field (Peruccio, 2012).

Strategic theories

DfS has progressively expanded from a technical and product-centric focus towards large-scale evolving systems in which sustainability is addressed as a socio-technical challenge (Ceschin and Gaziulusoy, 2016). Design profession was in the early phases engaging with environmental issues through frameworks like green design and ecodesign, mentioned above. Some scholars in the first half of 1990s (e.g. Ryan et al., 1992, p. 21) signalled the need for more systemic approaches targeting 'cultural change' in the society rather than focussing solely on technological interventions in production-consumption systems (Ceschin and Gaziulusoy, 2016). Design for production optimisation and the need for a systemic approach appeared as main topics from 1996–2000 (Pigosso et al., 2015). The Strategic design for Environmental Sustainability moves from product design to the design of integrated Product Service Systems (PSS) and Systemic Design (SD) (Marseglia, 2017) as useful strategies to address the complexity. As Pigosso et al. highlighted, today there is an increased focus on systems thinking for understanding relations and interactions among elements. Systems thinking is emerging as a promising approach to support the consideration of sustainability into product design and development — *a systems perspective has the potential to enable a better understanding of the effects of decisions taken during product development on the sustainability performance of products, and would enable the complex consideration of user behaviour* (Pigosso et al., 2015). Design researchers have also started to investigate how to design experiments to trigger and support socio-technical changes and the importance of designing a multiplicity of interconnected and diverse experiments to generate changes in large and complex systems (Manzini and Rizzo, 2011). Sustainable design is concerned with the creation of new, added value, eco-efficient products or service.

Systemic Design Approach

The holistic approach that characterises SD makes it adaptable not only to the industrial process with strategies such as Concurrent EcoDesign (CED) developed by Luigi Bistagnino, Gian Federico Micheletti and Carla Lanzavecchia (Micheletti, 1999, Tamborrini and Barbero, 2012), but also to different fields and sectors, from product design to service design (Barbero, 2012a). SD is a strategic design of scenarios that go beyond product innovation as such, by developing broader themes on which other skills and expertise must necessarily converge. SD focuses on the 'product system' rather than developing physical objects, contextualising by placing the object in a precise social, political, economic and cultural context (Peruccio, 2012). SD proposes both wastes as resources and open loops, becoming part of the biomimetic sector that concerns ecosystems (according to the categorisation provided by Ceschin and Gaziulusoy, 2016). From this point, expanding the boundaries of Systemic Design to socio-technical systems has become imperative. In this regard, Systemic Design was recently blamed for focusing exclusively on the production aspects, without addressing the issue of reducing individual consumption (i.e. change consumption behaviours and habits). For this reason, Ceschin and Gaziulusoy (2016) suggested a combination of Systemic Design with other design approaches (e.g. Product-Service System Design or Design for Social Innovation). This thesis aims to demonstrate how SD could successfully address product design in socio-technical systems and the new challenges derived from new technologies.

4.4 Environmental Requirements

As we highlighted in the previous chapter, besides companies, also designers realised the impact of their products on the environment. Thus, Manzini

Requirements		
User	1. Safety	Safety: Health
		Security: Information
	2. Comfort and wellbeing	
	3. Aesthetics	
Product	4. Functionality	
	5. Management and maintenance	
	6. Upgradeability	
Environment	7. Environment protection	Safety
		End of Life
		Systemic

Table 3 - Requirements (or classes of needs) defined in chapter 2, herein focused on environmental protection

highlighted the responsibility intrinsically rooted in design to lead to a transition towards environmental sustainability although this direction is by definition, unforeseeable (Manzini, 2006). As Simon stated:

> *Design should be considered in the broadest sense of "changing existing situations into preferred ones"* (Simon, 1969).

Among the preferred ones, we must list 'reducing the overall impact of the objects that will be produced' and, in general, 'reduce the use of resources'. According to Chan:

> *Sustainable design is at least to reduce the impact of design on the environment and it is nullified when the scale of its realization in material and energy consumption exceeds its aggregate impact reductions.* (Chan, 2016).

Among these impacts, there is the comparison with previous products (e.g. example, introducing sensing and technology should not conflict with the overall goal of improving the environmental sustainability), but also predict undesired effects listed in chapter 3. This makes the design quite a challenging task. According to Ecodesign strategies, some environmental requirements are identified under the macro-theme of Environmental protection (Tab. 3).
The first block (Fig. 15) refers to traditional aspects such as environmental safety (e.g. avoiding hazardous, toxic materials, etc.) and some End-of-Life requirements are provided.
However, environmental requirements do not refer exclusively to regulatory aspects and energy consumption.
What is missing is an overview that considers what tangible and intangible resources are necessary (e.g. flows of water, air and resources), addressed with a holistic approach. In this way, new products might take a new path towards sustainability. This further step towards sustainability involves a change of perspective, focusing on resources and processes, by asking: (i) What resources are involved? (ii) Which resources can be changed, reduced or saved? (iii) Which resources deserve to be enhanced and exploited after their primary use, becoming part of another system (open systems)? (iv) Which connections can be activated (exchange, transfer, share)? (Fiore et al., 2017)
The second block (Fig. 15) therefore refers to systemic design aspects such output that becomes input for a new process, enhancing residual value and characteristics. The systemic design approach considers the product as a system of components, a local system of interrelated and interconnected functions, with relationships with users and context.

Safety

/ *avoid harmful, poisonous, irritating, eutrophic substances to end up in water*
/ *preserve plants and animals, as well as the bacterial equilibrium of water*

/ *do not use CFCs*
/ *right disposal of gases*

End-of-life

/ *design a long lasting structure (frame) with finest materials and finishes*
/ *use of the materials according to the expected duration of the component*
/ *choose materials with higher possibility of recovery*
/ *use more perishable materials for parts frequently replaced or affected by changes in preferences*

/ *use reversible junctions when different materials are used*
/ *avoid rivets and other irreversible joints*
/ *use irreversible single-material junctions when you need high performances*

System

/ *reuse waste streams inside the system*
/ *enhance the quality and residual characteristics*

/ *reach nearly zero waste*
/ *use less energy*

/ *collect the dissipated heat (conduction, convection, radiation) to perform other functions that usually requires it*

/ *collect wastewater and use its residual features for other purposes*

/ *avoid food waste, prevent that food runs out*

/ *create functional units to perform one task*
/ *exploit physical principles before choosing technologies*

Fig. 15 - Environmental protection – safety, EoL and systemic requirements

4.5 Remarks

Some authors cited in this chapter provide us with a vision of possible evolutions of the DfS and new trends in this field. As highlighted in chapter 2, there is a rising need for a holistic approach which would allow designers to understand and cope with complex problems and their dynamics. Ceschin and Gaziulusoy (2016) highlighted the importance of the evolution and adaptation to different contexts combined with value specific user requirements, highlighting a need for more systemic approaches targeting 'cultural change' in the society and the need to overcome cultural, corporate and regulative barriers, thus, again converging many issues together. Sustainability strategies are growing importance, detaching from the idea of duty and becoming more and more strategic aspects. SD is introduced in this chapter, contributing to the definition of environmental requirements. These requirements enrich the discussion started in chapter 2, which was already implemented with the user requirements in chapter 3. In the author's opinion, product designers should provide new paths towards sustainability, changing their mindset and becoming the first to perform a paradigm shift.

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Chapter 5

Application domain and Methodology

Analysing the application domain consists in defining for which context the project is designed, where it is intended to work, for which environment and with which characteristics. It includes which stakeholders are involved and how they interact with that environment, what they take, what they leave, what they change and for what purpose, which stakeholders indirectly influence that application domain and how. The application domain or operating context, indeed, can be described and observed by humans, but also sensed by objects. This chapter narrows the focus of the research on the home environment, providing the domain and defining the methodological framework used in the remaining of this thesis. It begins establishing the importance household activities and tasks, considering this context as a complex system, then it narrows the field on home appliances. Due to the result of a multi-criteria decision-making process, this chapter ends with a focus on food waste and the refrigerator.

5.1 Household, activities and tasks

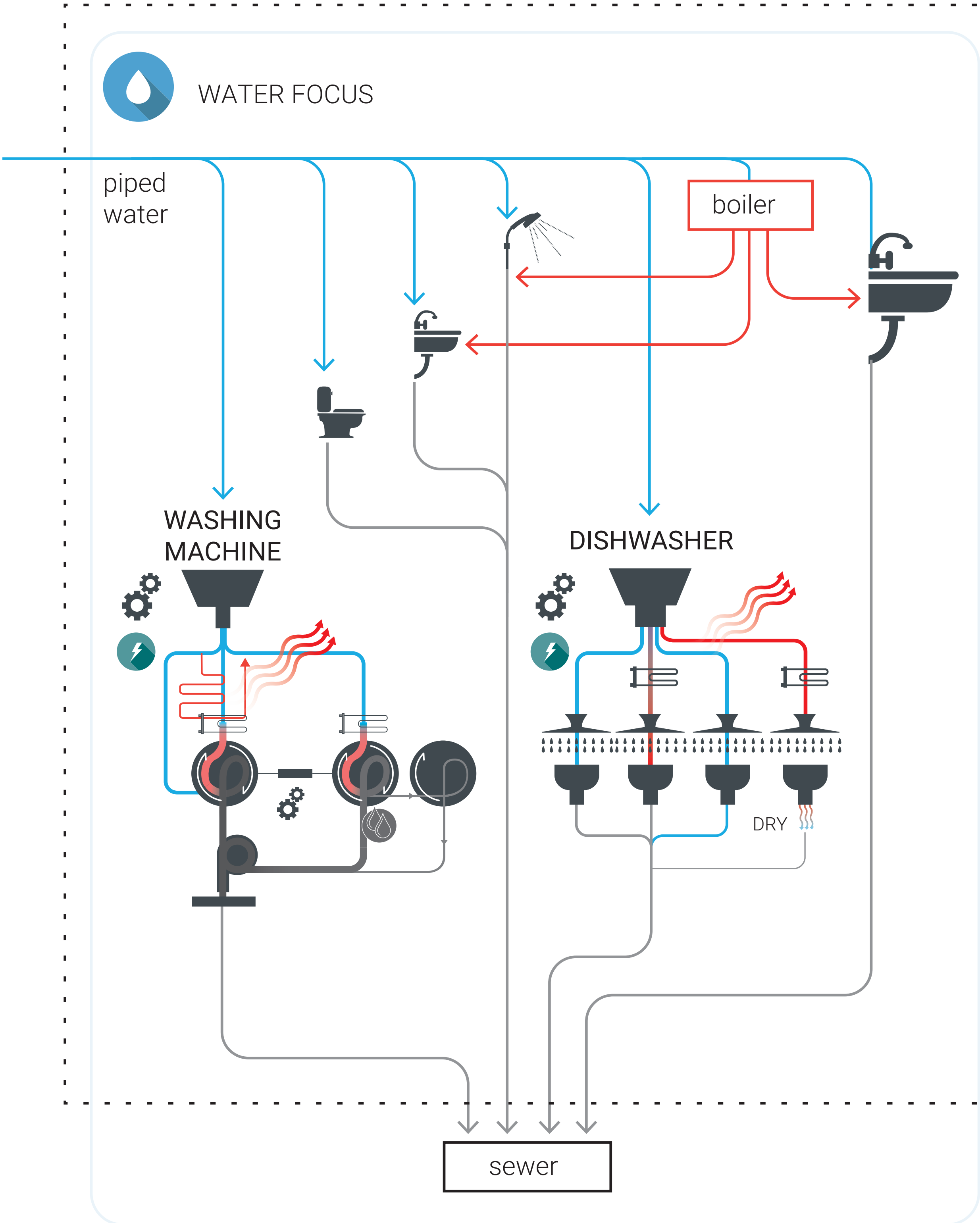
The home environment is a complex context that includes flows of energy, matter, information as well as a social component (made of people, households, guests), a technological one (i.e. appliances, devices). This context causes resource consumption and generates waste (consequences on the environment). In this regard, an extensive body of literature focused either on automation (Ambient Intelligence - Bonino and Corno, 2011) and driving behavioural change to reduce energy consumption (Lilley et al., 2005; Lilley et al., 2009; Darby, 2010; Hawarah et al., 2010). The focus on human-energy interaction encompasses interactions of individuals and households with energy systems (Stern, 2014), through informational strategies (Fréjus and Guibourdenche, 2012; Abrahamse et al., 2005) such as data visualisation (Pierce et al., 2008), in-home displays (Roth and Brodrick, 2008), feedback provision (Wilson et al. 2016; Darby, 2010; Froehlich, 2009) and so forth, suggesting that analysing their user habits, gestures, rituals, needs and aspirations may allow designers to conceive modern solutions and proposals that merge both digital and physical aspects (Vitali et al., 2017). In some of these studies, however, the householder appears as the 'resource man' (Strengers, 2014), thus relieving the individual of responsibilities that are hardly attributable to him/her. One example of this trend consists in transferring the burden and complexity of managing energy to the user. Researchers also pointed out that a better understanding of household dynamics (Stankovic et al., 2015, Bonino and Corno, 2010) such as habitual use behaviour (habits) and routine activities (Tang and Bhamra, 2009) could provide valuable insights to be leveraged in the design stage. Activities are a descriptive term for the common ways people spend their time, including daily routines such as cooking, doing laundry (Stankovic at al., 2015), habits and active behaviours. Habits are defined as routinised action enacted without conscious intention. However, habits are key determinants of the actual enactment of intention to ensuring behaviour (Wilson et al., 2016). Intentions are rational/cognitive decision making, while actions or behaviour are the results of this decision-making process, the active part that can also be affected by what people learned from prior experiences. Focusing on actions and tasks, simplifying them and trying to recognise them in complex patterns could be relevant and a way to reduce consumption. As reported in chapter 4, Design for Sustainable Behaviour (DfSB) studies those behaviours and practices, developed over time and in space (Daae et al., 2017). DfSB literature has proposed several strategies and tools for design intervention, that may help designers to promote changes towards sustainable behaviour through design (Daae et al., 2017). Indeed, DfSB uses a variety of UCD research tools, such as diaries, interviews, surveys, video observation, and generally concludes with suggestions for product-oriented design interventions. As Berg claims in the 1990s, "designers manifest neither interest in nor knowledge of house work" (Berg, 1994). Although nowadays designers are more aware of the relevance of the user, a deeper knowledge of activities and routines should be brought into the redesign process (Bonino and Corno, 2008). Moreover, all the elements that have been designed should positively contribute to the activity that is being performed (Lindley et al., 2017), improving the task. The shape of an object can influence our understanding of its function, and the feedback that provides are important to avoid frustration. Especially when the desired action is not executed in the way the user is expecting it, frustration is usually the result if insufficient feedback is given (Schurig and Thomas, 2017). A data-driven design approach recently appeared for understanding domestic routines and foster design or redesign of products. Data were used as a medium to generate an understanding of home energy consumption (Bourgeois, 2014), by building a personal visualisation of laundry routines, for example.

5.2 Systemic Design applied to the home system

We decided to focus on the home environment to pursue sustainable technological and social innovations. In this context, indeed, we can find products (appliances) whose impacts reside in use phase. For these products, we should investigate both energy consumption and user behaviour (Ceschin and Gaziulusoy, 2016), to lower the impact of consumption, while addressing functional aspects and daily tasks.

5.2.1 The multiscale dimension of the home system

The home system can be analysed at different levels of detail, under different layers. Like every system, we can consider a single component or a group of parts, up to the holistic view, focusing from time to time on different aspects. We can look at the home system switching-on the 'resource level' (air, water, food, waste) and energy flows considering appliances as interfaces through which the user uses and transform those resources. Figure 16 shows the holistic diagnosis on the context (the home enviroment), setting the boundaries of the system inside the house. It analyses the flow of matter


WATER FOCUS
piped water
boiler
WASHING MACHINE
DISHWASHER
DRY
sewer

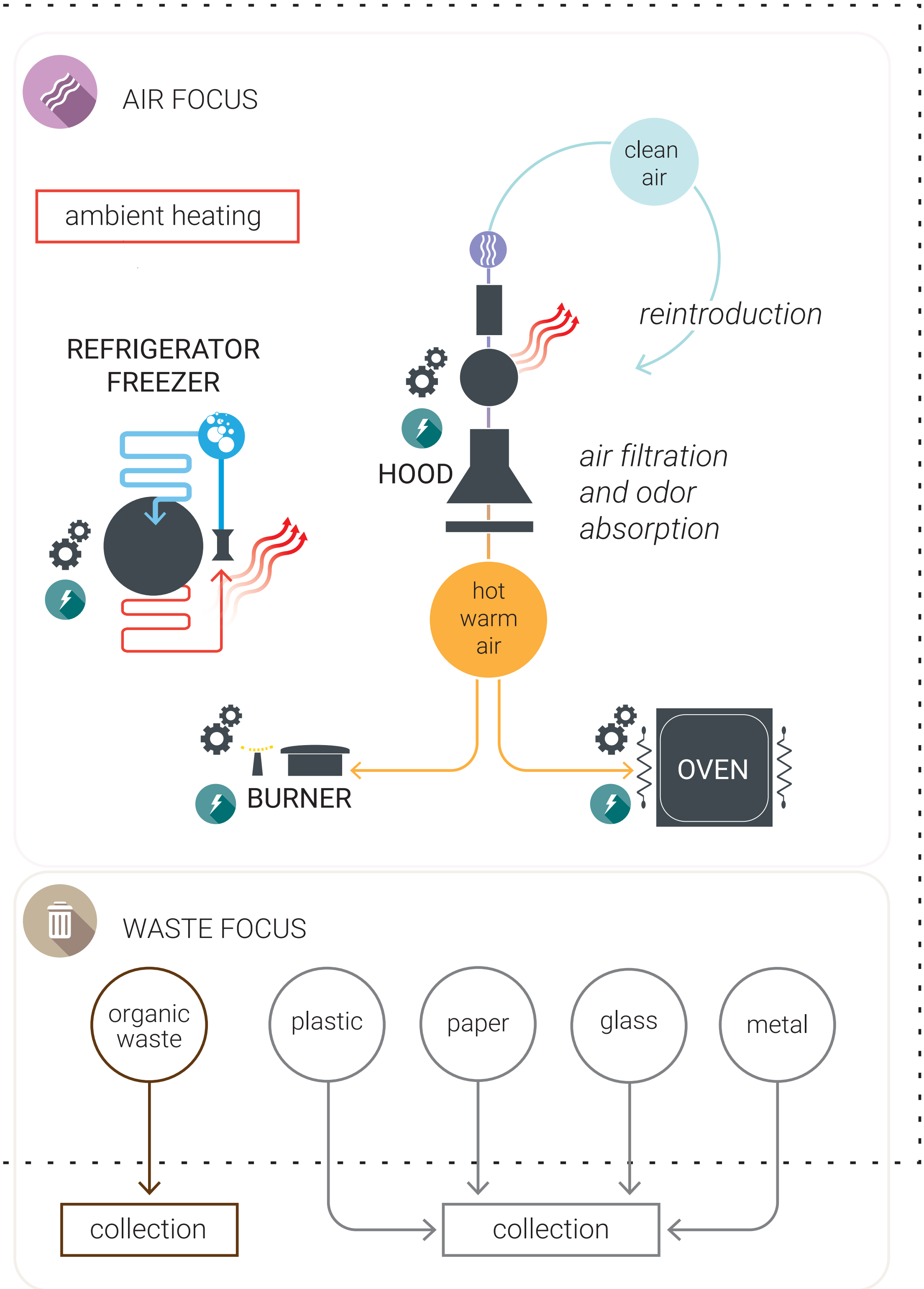


Fig. 16 - Holistic Diagnosis of current household streams

and energy that occur in the home appliances, establishing the relationships with the other parts of the house. Herein, the focus is on water, air, energy and waste. However, as we will see further on, the same analysis could be performed also on food, immaterial flows of information, relationships, workflows and so on.
Considering home as a system, the elements of the system are the following:

- domestic appliances and their components (objects, components and relationships)
- the dynamics of household members and family (individual, family and relationships)
- the interaction of the individual with domestic appliances (objects, individual and relationships)
- the common goal, i.e. the task to be performed (goals)
- habits and other object/services related to the task (objects/services and relationships)

5.2.2 Research focus: home appliances

We look specifically at everyday objects, in which an interaction between people and technology is expected.
Home appliances are considered as the physical objects, the touchpoints through which the user of complex systems experiences the system.

One-Way dependency
Since we could design a system from scratch, we should accurately avoid creating dependencies among the components of the system that lead to complicated situations, especially when two or n-ways dependencies are involved, for example among the user, the appliance, dynamics and technologies. Human behaviour adds complexity to the system, by also adding challenges and opportunities. Therefore, some emerging properties derive from considering the domestic environment as a complex system. Norman and Stappers suggest that a system should not create complex dependency loops. Indeed, two variables should have a one-way dependency (Norman and Stappers, 2016). We can read the following example considering A as the user and B as the appliances to redesign:

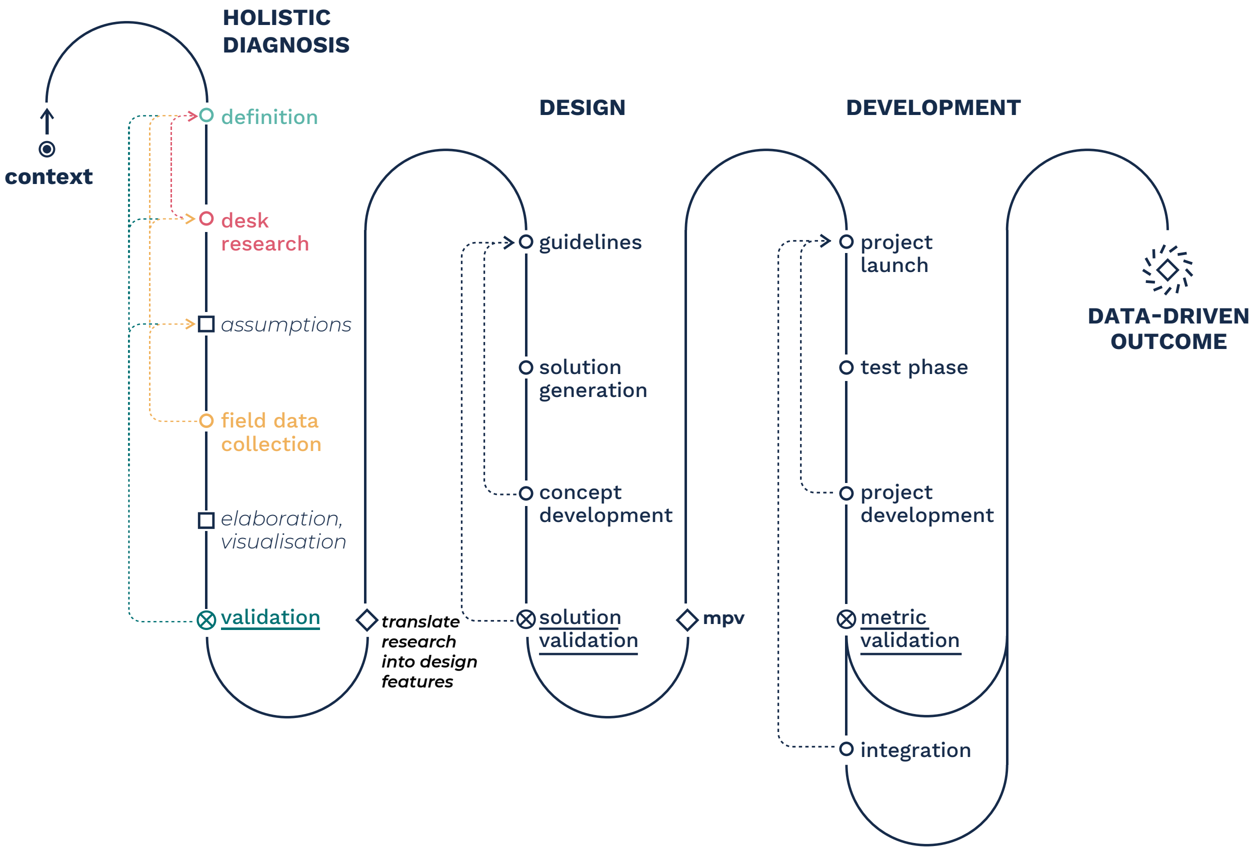
> *The designer should attempt to maximize the independence of stages, and if dependence is required, make it be one-way, not two-way. That is, ideally any two components, A and B, should be independent of one another, but if B depends upon A, even indirectly, ensure that A does not depend upon B, not even indirectly. Two-way dependencies (where A affects B and vice-versa) should be avoided. Most complex physical systems cannot entirely avoid these interdependencies, but minimizing their number and scope is a worthwhile technique* (Norman and Stappers, 2016).

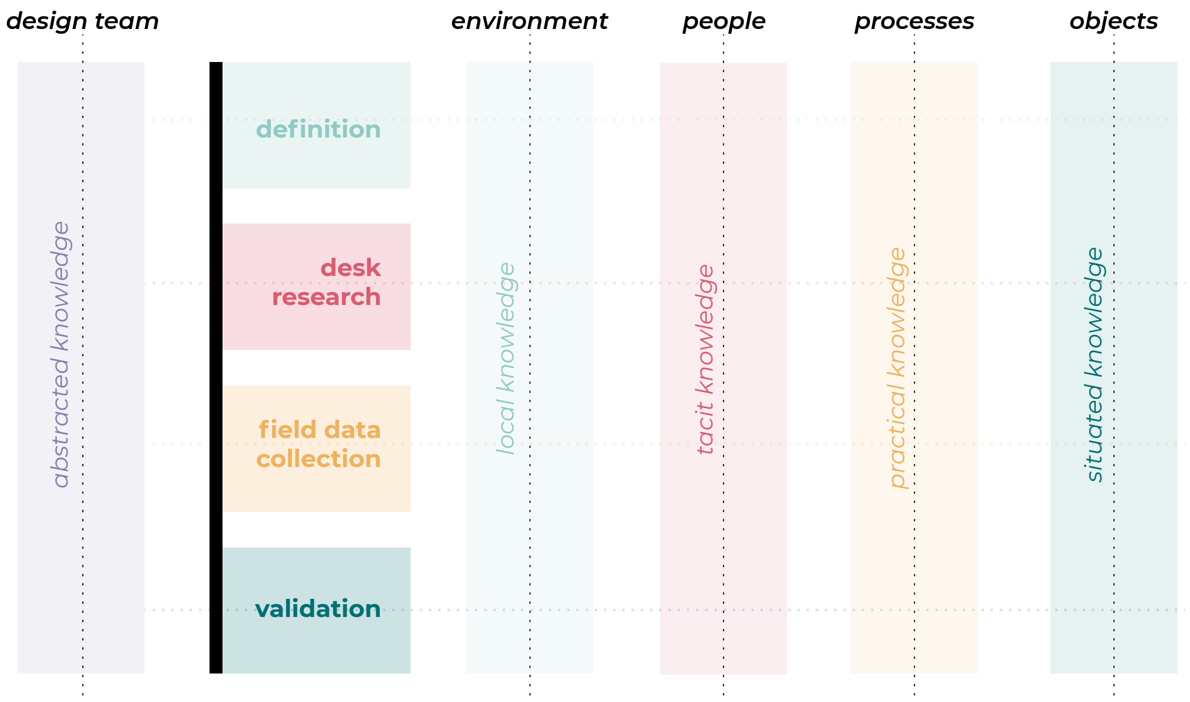
If A is the user and B is the object, it means that in no way the object should rely on the user to perform one task. If we have an automated air conditioning system, we cannot depend on the 'good behaviour' of the user in managing the windows, nor we can rely on a change of behaviour towards a more sustainable one. Experiments carried out in the UK (Wilson et al., 2016) proved that people often ignore feedback when they want to obtain a specific benefit or comfort goal. The unpredictable nature of user behaviour may result in unpredictable effects, increasing, bypassing technologies and unintended use. (Pettersen and Boks, 2008; Wilson et al., 2016)
Many authors argue little attention to the human-related aspects in ecodesign, especially referring to user behaviour in the use phase (Ceschin and Gaziulusoy, 2016; Bhamra et al., 2011). Addressing products that consume energy during the use phase suggests considering different aspects such as ecodesign, user behaviour and resource consumption, since resource conservation is one of the great concerns of the 21st Century (Movilla et al., 2016).

5.3 Methodology

I defined a methodology (Figure 17) that aims to guide the designer in considering complex context and environment characterised by significant impacts in terms of resource consumption. This methodology starts from the context and it goes through a definition phase, desk research, field research and preliminary validation of four different topics: environment, stakeholders, processes and

Fig. 17 - Methodology


HOLISTIC DIAGNOSIS
context
definition
desk research
assumptions
field data collection
elaboration, visualisation
validation
translate research into design features
DESIGN
guidelines
solution generation
concept development
solution validation
mpv
DEVELOPMENT
project launch
test phase
project development
metric validation
integration
DATA-DRIVEN OUTCOME


design team
environment
people
processes
objects
abstracted knowledge
definition
desk research
field data collection
validation
local knowledge
tacit knowledge
practical knowledge
situated knowledge

products It combines systemic design with HCD and data-driven design process performed with smart enabling technology able to provide data and quantified knowledge. It presents a data-driven product design methodology for STS.
It prepares the designer to work in trans-disciplinary research projects on STS, with the final goal of design meaningful and relevant products for the user, with the environmental sustainability in mind. The presented methodology is focused on the pre-design process, that can be followed by the other steps of a traditional design methodology (ideate-prototype-test or design-develop-deploy). We chose to contextualise this pre-design phase (also called fuzzy front-end or holistic diagnosis), within the methodology developed by the Innovation Design Lab (IDL) of the Politecnico di Torino research method applied by the Innovation Design Lab at Politecnico di Torino (Gaiardo and Tamborrini, 2017). I contextualise this methodology in the home environment. The stakeholders have been defined in chapter 2 (Figure 9) and the focus on the appliances has been discussed in chapter 1 (Figure 1). To define the processes involved and the objects, however, the list of appliances is too big and we need to narrow down the focus, by choosing only one appliance.

5.3.1 A multi-criteria decision making

Home appliances are considered as the physical object through which the users consume resources. They are durable goods, which last about 10-14 years, they occupy space in landfills (about 2% of the overall space), although their disposal has been optimised. Their redesign could become a vehicle to deliver a part of the system change towards a more sustainable one. Despite the systemic view, at some point, we cannot address the complexity of the home system as a whole. Thus, we need to focus on a node of this system, shifting from macro to micro. Since no companies nor clients were involved in this study, 'on which factors should I base my decision?'. I decided to perform a multi-criteria analysis based on both sustainable indicators and human-related ones based on the level of interaction with the object. The purpose of this analysis was to investigate which large appliance was the preferred starting point, in order find out both the most unsustainable current product and the one with the highest level of interaction with the user. I have deliberately excluded brown appliances, because their use does not happen on a regular basis and because they do not constitute a homogeneous class of products. Large appliances, instead, show a similar expected useful life (10-14 years) and the same structural constraints, which

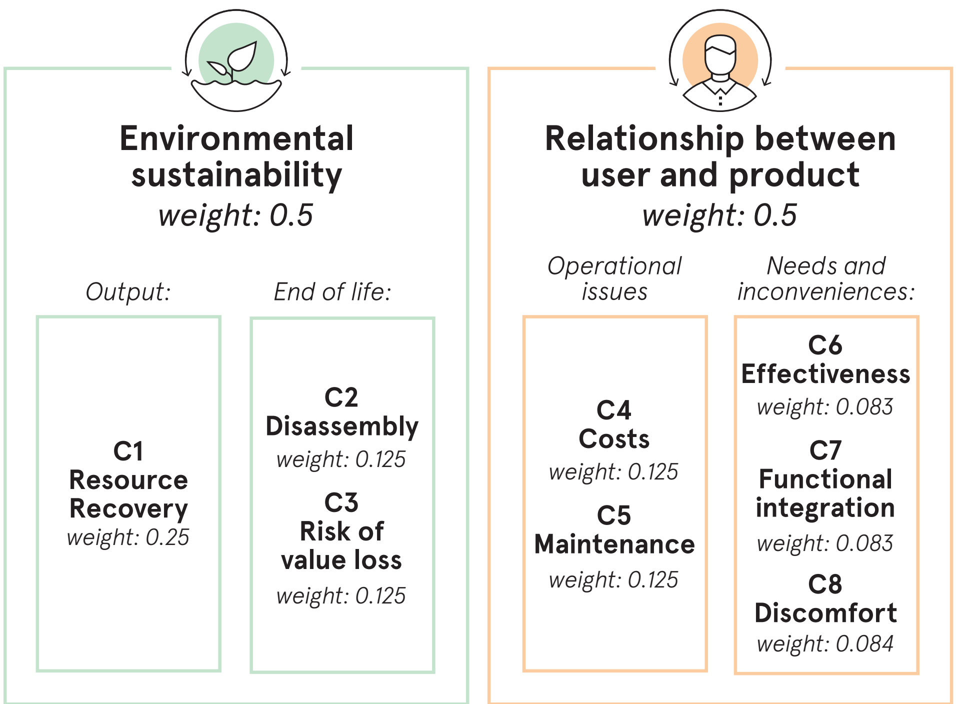
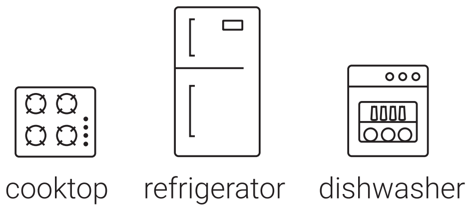


Fig. 18 - Multi-criteria decision aid (MCDA) process

Alternatives	C1 Recovery	C2 Disassembly	C3 Value Loss	C4 Costs	C5 Maintenance	C6 Effectiveness	C7 Funct.Integration	C8 Discomfort
Cooktop	5	4	6	320	1	7	7	2
Oven	2	3	12	65	4	5	5	6
Hood	1	2	7	30	5	6	4	7
Fridge	4	7	10	180	5	3	3	3
Dishwasher	5	4	13	135	3	4	2	4
Washing Machine	3	4	12	170	4	3	1	4



Criteria	Indifference Threshold		Preference Threshold		Veto Threshold	
	α	ß	α	ß	α	ß
C1 Recovery	0	0	0	0	6	0
C2 Disassembly	0	0	0	0	5	0
C3 Value Loss	0.5	0	2	0	7	0
C4 Costs	40	0	80	0	300	0
C5 Maintenance	0	0	0	0	5	0
C6 Effectiveness	0	0	0	0	5	0
C7 Funct.Integration	0	0	0	0	8	0
C8 Discomfort	0	0	0	0	6	0

Fig. 19 - MCDA results

lead them to be placed in a specific part of the house, influencing the dynamics around them
To perform this choice I used a Multi-Criteria Decision Aid (MCDA), a flexible and integrated methodology to address a variety of real-world decision-making situations (Doumpos and Zopounidis, 2002). According to the most common classifications, I divided major appliances into:

1. **hot appliances**: cooktop, oven and hood;
2. **cold appliances**: refrigerator and freezer;
3. **wet appliances**: dishwasher and washing machine.

Each appliance was considered as a design choice, i.e. an 'alternative', which has been evaluated through some criteria. A criterion is a real function that connects a possible decision with its (quantitative or qualitative) performance in relation to a specific aspect (Doumpos and Zopounidis, 2002). The application of a multi-criteria method, to the model and some preferential information on the criteria, activates a pair-wise comparison of the possible decisions (home appliances in this study) on each criterion and synthesises these elements to obtain a ranking of design decisions (Doumpos and Zopounidis, 2002). The criteria chosen are reported in figure 18. They are invented by the author and do not come from literature. They are specific for the task that we want to perform, which is 'choosing between a set of product the one to be addressed in next stage'. This experiment is described more in detail in a conference paper (Fiore et al., 2016).
This combination of criteria led to narrowing the focus on the kitchen appliances, without providing just one best solution, since three appliances were ranked as fair value.
Although this experiment was used to clarify our ideas and give priorities, it proved too rigid to tackle the topic. Providing common criteria and parameters for analysing such different objects was one of the most complex aspects to manage. The result obtained pushed us to reconsider the indicators provided, and thus consider things from another perspective, i.e. in terms of relationships and workflows.

5.3.2 Appliances, activities and relationships between activities

From the results of the previous section, I decided to keep the focus of the study on the kitchen dynamics, by investigating the flows of food within the home system. I investigated food related dynamics, analysing workflows, activities and transitions between activities that somehow are related to food, including food waste. This makes possible highlighting household food streams, cooking/preparation operations and tasks. The refrigerator shows a great number of relationships with the other part of the kitchen (Figure 20) and I started considering to proceed with the analysis of this appliance. This analysis made me reflect on the role of food waste and I realised that this issue deserved more attention. Eventually, I decided to focus on the appliance that more than others contributes to this waste: the refrigerator, the appliance that conserves

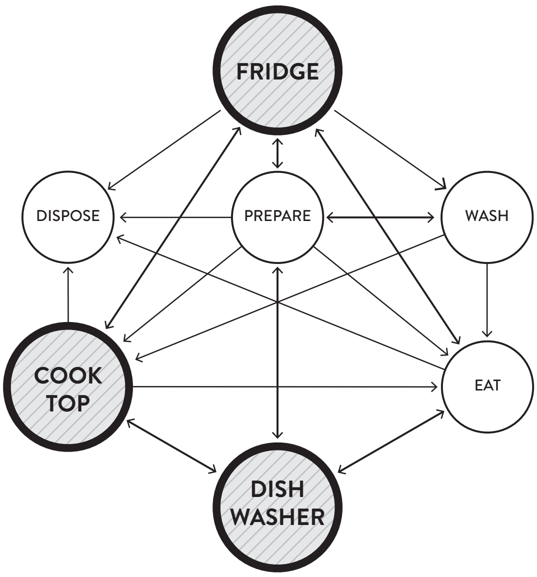


Fig. 20 - Food relationships within the kitchen environment

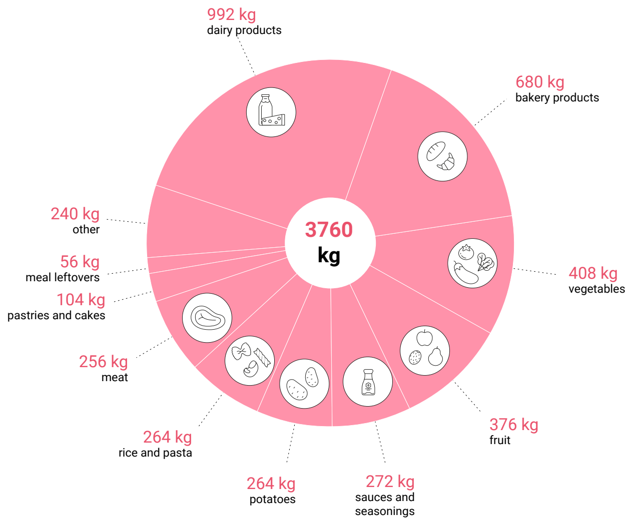


Fig. 21 - Food waste composition in the Netherlands (according to Milieu Centraal, 2012; Ministry of Economic Affairs, 2014)

about 750 kg of food per person every year (Magalini et al., 2018), of which approximately 40-50kg is being trashed. In the next section, we will see what are the reasons for this waste as a first step towards its decrease.

5.4 How households waste food

Wasting food means wasting resources (water and energy consumed along the food chain, but also animal feed, fertilisers, etc.), depleting, occupying the soil and producing greenhouse gases for no reason, as well as wasting money for uneaten food, environmental and economic cost of disposal. Since food becomes more and more pre-packed and over-packed, the impact of food on landfill should also include the environmental and economic cost attributable to the packaging and its disposal. Globally the economic costs of food wastage, based on producer prices, were estimated at about USD 750 billion (FAO, 2013). In the Netherlands, about 52% of the food is wasted in the consumption phase, whereby 38% is wasted in households, 14% wasted by catering industry as cited by the Netherlands Nutrition Centre (2014). Dutch consumers are responsible for 38% of the food wasted in the Netherlands, approximately 8–11% of food purchased equating to 43–60 kg of food waste €270–400 per household per year (Thönissen, 2009). Every year, an Italian family, instead, discards approximately 49 kg of food, wasting 1,19 billion tons of food. In economic terms, this is roughly equivalent to waste €7,65 billion (316 € per household). A typical UK household throws away from £4,80 to £7,70 of edible food every week (250-400 £/year) (WRAP 2012)
American households discarded 211 kg of food per year (about 52 kg per person per year), not including food to drain, home composting or feed to pets, costing a family of four at least $589 annually, Household food waste in the US worth $48.3 billion of food each year (Parfit et al., 2010). Diet composition in developed countries has a high share of animal food items, fruit and vegetables. These products have relatively short durability and therefore are more likely to spoil (Lundqvist et al., 2008). Moreover, food product from livestock like dairy and meat have also a bigger impact on the environment than vegetables. We are referring to avoidable waste, i.e. food and drink thrown away, that was edible at some point before disposal (Parfit et al., 2010). The Netherlands Nutrition Centre (2014) and the Ministry of Economic Affairs (2014) determined the waste of different food segments (waste composition). Dairy, bread and vegetables are the top 3 products wasted in the Netherlands (see Fig. 21). As we can imagine, the waste composition

varies depending on cultural, traditional, territorial features of the household analysed.
In Italy, a Gfk Eurisko study allowed to 'weigh' the annual waste for the different types of food. The main wastes concern vegetables (10.7 kg), fruit (9.9 kg), bread (9.1 kg), and pasta (6.0 kg), while expensive food items are wasted in less quantity: meat (4.5 kg), cheese (2.1 kg), fish (1.8 kg), deep-frozen (1.8 kg) and cured meat such as salami and ham (1.2). Groups that waste more than average in the Netherlands according to Milieu Centraal are single occupancy households, families with young children and people younger than 25 years old. Also in the UK, single occupancy-household waste the most according to WRAP (2008).

5.4.1 User behaviour

People do not want to waste food, but neither do they want to let go of their current routines (Boll, 2016).
A Gfk Eurisko study involved 800 Italian households over a week in September. They ask people to fill in a diary of their food waste in relation to their daily meals. (Fagnani, 2013)

> *Anselmi, vice president of Gfk Eurisko, explains how the study was conducted:*
> *We asked households to keep a careful diary of wastage, referring to the meals of the day. The results show that 90% of consumers consider the problem as severe. Only 54% of respondents, however, daily check the refrigerator and 65% check the pantry once a month. Only 36 out of 100 states to scrupulously adhere to the expiry date indicated on the packaging, while 45% is in favour of selling at discounted prices non-perishable expired food. There is a reconsideration of our lifestyles, evidenced by the fact that 54 percent of people seem to agree that after this crisis, the way to consume will be different in the next future. Among the changes, they recognise that there will be more significant attention to the issue of food waste* (Fagnani, 2013 free translation).

5.4.2 Factors and reasons

Understanding food waste is the first step towards reducing it. The Netherlands National Institute for Public Health and the Environment (Milieu Centraal, 2012), lists among the causes of food waste (Boll, 2016):

- Wrong Planning and travels
- Hygiene
- Lack of knowledge about expiration dates
- Lack of awareness of over-throwing food

Wrong planning

Parfit et al. (2010) gives as the main reason for avoidable food waste that food is not used in time. Not used in time means that it passes the expiry date, has rotted or has got mouldy or looked, tasted or smelled bad. Too much fresh food is bought, and fresh products are purchased too long upfront (Milieu Centraal, 2012). Several reasons could be attributed to this problem, and changes in lifestyle are among them. These changes lead the consumer to have little time during the week for the food shopping and to postpone the purchase of food (especially the fresh one) during the weekend. In most cases, the user is not able to assess the right amount of food to be bought and predict the actual use during the week. Moreover, the consumer can hardly forecast the expiry date of fresh food. Additional reasons are the lack of one-person portions and packs in the supermarkets, which pushes the consumer to buy family-size packages for a small household and the food storage. The consumer does not know how to store food to extend its shelf life. Storing food gives complications when food is stored wrongly or too long (Milieu Centraal, 2012; Boll, 2016). Preparing and cooking processes also produce a considerable quantity of waste, due excessive vegetable discarding, food damage (e.g. burnt food). One-fifth of the people usually cook too much and throws leftovers away. A quarter of the food waste consists of meal leftovers. Shopping behaviour has also changed; Dutch consumers search for specific products with the furthest expiry date. This causes the supermarkets to throw away the products with a close expiry date (Milieu Centraal, 2012; Boll, 2016).

Health and hygiene

According to the Public Waste Agency of Flanders (OVAM), health and hygiene are the main motivation in discarding food. Milieu Centraal and Voedingscentrum, (2011) indicates the fear of eating spoiled food on top of this (Boll, 2016), indicating the presence of mould as a decisive factor. In these studies, however, we do not know what had been asked. The consumer probably considers as food waste only products which have been entirely discarded without consuming them. Consumers usually do not perceive

Reasons	**Causes**
Wrong Planning	- buying too much food
Hygiene Lack of knowledge about expiration dates	- smell - bad taste - food that got mouldy/ old or bad
Lack of awareness of over-throwing food	- satiety (people have eaten enough) - do not want anymore (do not feel like eating it) - not enough to save - that product will not be eaten anymore - accidentally spilt

Table 4 - Reasons for discarding food (Boll 2016)

as food waste some typologies of foodstuffs, such as small leftovers, dry bread, fruit and vegetable peels.

Lack of knowledge about expiration dates
According to van Westerhoven (2013) there is still a lack of knowledge about the meaning of “best before date” and “use by date (“Tenminste Houdbaar Tot” and “Tenminste Goed Tot” in Dutch, “Da consumarsi preferibilmente entro” e “da consumarsi entro” in Italian). People either do not know where the abbreviation on package stand for or they confuse the meaning. Besides, consumers handle food with too much ease when they “do not feel like eating it”, or they prefer fresh food. In this way, food will be thrown away without smelling touching or tasting (Boll, 2016).

Lack of awareness on domestic excess of food waste.
In the Netherlands, 80% of the household say not to waste much food, though research has shown that only 10% of this group throws away less than average. People usually do not realise how much they spill, since they often waste small bits and pieces (Milieu Centraal and Voedingscentrum, 2011). Furthermore, people think they take responsibility for their own waste, but they generally see themselves as a cog in the machine. According to them, the most significant contribution to decreasing food waste should come from providers as farmers and supermarkets instead of individuals. The gathered data gives an insight into food waste, the amount of food wasted and its impact. The reasons why people waste food are heterogeneous and depend on many factors. However, food waste has an impact on both environmental and socio-economic aspects. Buying too much food is one of the consumers’ reasons to waste and understanding the implications directly attributable to food purchase's dynamics (supermarket, work and free time dynamics), and to the method of conservation (fridge) is important for tackle the issue more in depth.
In his master thesis, Boll (2016) asked a sample of consumers the reasons for which they waste food. We try to fit these reason into the Milieu Centraal categories and in the following table (Tab. 4). From these observations, we may understand something more about users and the dynamics related to the storage. And so we went back to talking about the fridge and its placement within these food dynamics. Travels, weekend out, forget thing inside, don’t check the refrigerator frequently are other possible reasons not considered when thinking about the general food waste. Perhaps users consider these reasons as something that ‘happens’ without an attributable responsibility (e.g. do not check the refrigerator brings things to get mouldy, but the user sees the mould without associating it with his failure to control the fridge).
The next chapter focuses on the refrigerator, from its invention to the current usage dynamics and alternative scenarios.

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Chapter 6

Focus on the refrigerator

In the previous chapter, we identified the refrigerator as a good starting point for the subsequent analysis which at this point includes a focus on current products, case studies and best practices (Figure 22).
The refrigerator is a representative example to address the complexity of redesign a home appliance. Nevertheless, compared to the dishwasher or the washing machine, it represents a ‘simplified system’, since it a stand-alone appliance, connected to electricity but not to the water network, thus simplifying the redesign. However, we need to step back and identify which operations the householder should perform and then detect which actions are involved. In this case, the main task we identified is *“storing foods items at the right temperature to fulfil their expected duration”* (goal). As anticipated, ‘refrigerator’ is a design solution. From there, all the other actions such as the door opening derive directly from the solution ‘refrigerator with two front doors’. We should give greater value to the task and the habits related to the task such as food habits and type of food to be stored (food and relationships) rather than considering components and technologies used to perform it. We can look at the refrigerator as a complex system made of components, interactions, feedback, information. By definition, if we remove or add elements to a system, its properties should vary in some way. Parts are interconnected and operated like a 'whole system'. If we modify the elements of the system, it changes the configuration. In fact, in the case of the refrigerator, if an interaction occurs, for example introducing food at different temperatures, opening the door preparing for the meal, the energy consumption, temperature and humidity patterns should vary, showing an alteration. To understand when and how this alteration takes place, we use

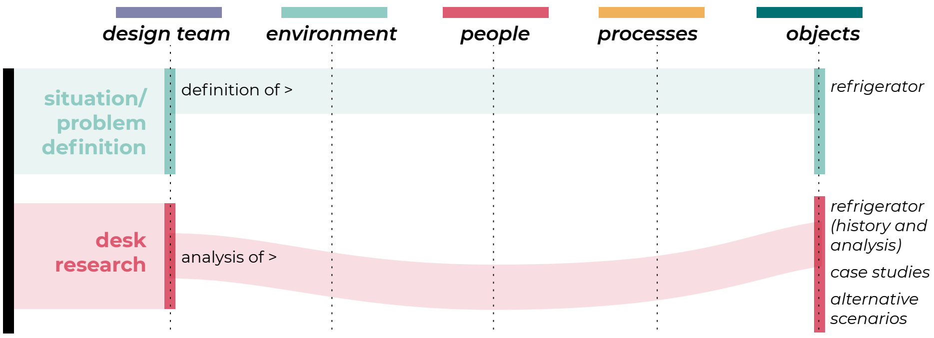

Fig. 22 - Methodology with a focus on the refrigerator

Wagner's parallel between the variation of the operating conditions and the chess game.

> *If I replace pieces of wood with pieces of ivory, the change is indifferent to the system; but if I diminish or increase the number of pieces, this change reaches deep into the grammar of the game.* (Wagner, 1971)

If we replace an appliance with another of the same type, we are just replacing ivory with wood, without promoting any paradigm shift or change in system structure. There is no significant variation concerning the tasks, routines and dynamics that revolve around the appliance.

However, if the system differs (e.g. introducing a pot-in-pot refrigerator instead of a current refrigerator), then the dynamics of the house, the habits, the relationships with the object change. For this reason, keeping the same technology is convenient, and it is equally convenient to build all the dynamics (inside and outside the home with supermarket and work dynamics) on the reliability and existence of this object. Therefore, considering and focusing only on that object prevents the designer from questioning on whether the refrigerator is really needed and 'the growing role of refrigeration in today's Western food system' (Kuijer and Bekker, 2015), not considering other agents of change and assuming the availability of that appliance. Indeed, 'requirements' reside primarily in the investigation space, while 'products' reside primarily in the solution spaces (Bergman, 2009). Products are current solution to specific tasks, issue and contexts. Together with a case studies analysis, we investigated current products to understand the room for intervention for designers (Fiore and Bourgeois, 2017).

6.1 Background information on refrigerators

6.1.1 Back to the original task: food preservation

Before the development of artificial refrigeration techniques during the 1800s, people utilised a variety of means to chill and preserve foodstuffs. For centuries, ice served as the principal refrigerant (Marton, 2006). The idea of using a low-temperature environment to prevent food spoilage has been around for centuries. The first cellars were holes dug into the ground and lined with wood or straw and packed with snow and ice: this was the only means of refrigeration for most of history (Bellis, 2017a). To preserve the ice itself, people stored it in pits or caves insulated with straw and wood, by which means they could maintain a supply of ice for months (Marton, 2006). Human cultures have long known that cold temperatures can protect valuable foodstuffs from bacteria and other factors that may render them inedible. Preservative methods such as salting and drying were also effective, but these were not well suited to all kinds of food. Before mechanical refrigeration was widely available, many cultures used well-insulated buildings called icehouses for food storage, using winter ice and snow as natural coolants (Rauè, 2010). These structures date to the second millennium BC in Europe and Asia, and the names of the engineers who designed them have been lost to history (Bellis, 2017a). However, ice houses are still commonly used in rural areas where electricity and appliances were expensive or unavailable. Even today, in many developing nations, ice remains the only available refrigerant (Marton, 2006) In many areas, a local delivery person, colloquially known as an "iceman" in the U.S., would bring fresh ice blocks to neighbourhoods (Conjecture Corporation, 2009).

6.1.2 History of refrigerator

The invention of the typical home appliance resulted from a series of innovations by chemists, engineers, and inventors over 18th and 19th centuries, most of whom were Americans. In 1748, at the University of Glasgow, the Scottish physicist William Cullen discovered that some chemical reactions would draw heat away from one place, cooling it. However, he did not use his discovery for any practical purpose (Bellis, 2017a) nor application and did not realise he had found the basis for modern refrigeration (Conjecture Corporation, 2009). In the early 1800s, the American engineer Thomas Moore built a portable insulated chamber cooled by block ice. Moore coined the term "refrigerator" to describe his invention, although it came to be more commonly known as the "icebox." Iceboxes had the same general shape and function as modern-day refrigerators (Conjecture Corporation, 2009). At the same time (in 1805) an American inventor, Oliver Evans designed but did not build, a machine to make use of Cullen's chemical process. The first practical refrigerating machine was built and patented by the scientist Jacob Perkins, in 1834 (Bellis, 2017a). That was considered the first functioning refrigerator, and it used ether in a vapour compression cycle. Perkins, a major figure in American engineering, also tinkered with heating and cooling systems for the home and he is sometimes called the father of refrigeration (Conjecture Corporation, 2009). An American physician, John Gorrie was seeking a steady source of ice to lower the body temperature of patients suffering from yellow fever. The ice delivery methods common at the time were insufficient for his purposes so, working from Evans' original design, he built a refrigeration unit that was more practical and efficient than the one created by Perkins (Conjecture Corporation, 2009, Bellis, 2017a).

These inventors are credited with developing the earliest versions of the modern refrigerator in the early 1800s. Later that century, in 1876 the work of the German engineer Carl von Linden allowed chemical refrigerant to be stored efficiently (Conjecture Corporation, 2009), discovering an improved method of liquefying the gas. He patented not a refrigerator but the process of liquefying gas, paving the way for mass production of refrigerators (Conjecture Corporation, 2009, Bellis, 2017a).

Thomas Elkins of Albany, instead, patented the design for the refrigerator in November 1879[11]. His patent was for an insulated cabinet into which ice is placed to cool the interior. As such, it was a "refrigerator" only in the old sense of the term, which included non-mechanical coolers (Bellis, 2017b). From 1879, the refrigerator evolves; the two patents were combined into an insulated cabinet with a cooling system.

6.1.3 The refrigeration process

Mechanical cooling systems depend on chemicals called refrigerants. In 1984, Jacob Perkins used liquid refrigerants like ether, in 1876, Carl von Linden discovered how to store chemical refrigerant efficiently, with an improved method of liquefying gas, paving the way for the widespread sale of refrigerators and their use in the 20th century (Conjecture Corporation, 2009). Since then, the concept remains quite unchanged. Refrigeration is the process of removing heat from a space or a substance, to lower its temperature. A refrigerator uses the evaporation of a liquid, called refrigerant, to absorb heat (Bellis, 2017a). The refrigerant, thus, performs the 'cooling task' by moving through the appliance inside a coil. It is compressed, raising its temperature, then heat is released from the back of the refrigerator; as the heat is dissipated, the refrigerant condenses, and it is kept at high pressure. The refrigerant then moves through an expansion valve, where the pressure drops, and it turns back into a gas. As it changes from liquid to gas, its temperature falls, cooling the air. Fans and motors circulate this cooled air within an insulated box (Conjecture Corporation, 2009). These components remain the basis of most refrigerators used today (Marton, 2006), although refrigerant varied.

6.1.4 Alternative to vapour compression refrigeration

If this review considers the evolutions of the vapour-

11 Thomas Elkins (11/4/1879 U.S. patent #221,222); John Standard (7/14/1891 U.S. patent #455,891) (Bellis, 2017a)

compression solutions, we should acknowledge that there are several refrigeration techniques. According to Elert (1998):

1. Icebox (or dry icebox);
2. Cold air systems;
3. Vapour-compression: the current standard method of refrigeration used in home refrigerators, home air conditioners and heat pumps (Kelvin's idea, refrigerate the environment in the winter, store "cold" in the ground for use in the summer);
4. Vapour-absorption: the Electrolux refrigerator with no moving parts;
5. Thermoelectric.

The *Icebox* is mentioned at the beginning of this chapter, while we did not stress that both Evans' and Gorrie's inventions were based on rapidly expanding gases, i.e. they were *cold air systems*. Evans's machine was based on a closed cycle of compressed ether, represented the first effort to use simple vapour instead of vaporising a liquid. Gorrie's machine compressed air that was next cooled with water. The cooled air was then routed into an engine and, as it re-expanded, its temperature dropped enough so that ice could be made (Marton, 2006)

Vapour compression refrigeration was extensively addressed before. It requires very specific components such as:

1. compressor
2. condenser
3. expansion valve (throttling valve)
4. evaporator

Vapour absorption refrigeration

Oliver Evans was the first to describe a vapour absorption refrigeration and he proposed, but not built, a refrigerator based on a closed cycle of compressed ether, represented the first effort to use simple vapour instead of vaporising a liquid (Marton, 2006). The first vapour absorption refrigerator was developed by Edmond Carré in 1850, using water and sulfuric acid. His brother, Ferdinand Carré, developed the first ammonia/water refrigeration machine in 1859. His refrigerator operated by means of a cycle in which ammonia was absorbed in a liquid (a mixture of ammonia and water) that was subsequently heated. The heat caused the refrigeration (Marton, 2006). Vapour absorption refrigerators can be powered by any heat source, i.e. natural gas, propane, kerosene, butane and need some different components to operate (Elert, 1998):

1. generator: ammonia-water solution heated to generate bubbles of ammonia gas;
2. separator: ammonia gas bubbles out of solution;
3. condenser: ammonia gas condenses;
4. evaporator: ammonia liquid evaporates;
5. absorber: ammonia gas is absorbed by water.

One of the advantages of this solution is that is noiseless. The greatest advantages, however, is that this system may be designed to use any available source of thermal energy - process steam, exhaust from engines or turbines, solar energy etc. (Bhadauria, 2015). These features open a variety of new possibilities within the home environment, allowing systemic reuse of streams, such hot wastewater.

Thermoelectric refrigeration

The thermoelectric method of cooling the water relies on the Peltier effect to create a heat flux between the junction of two different types of materials. When the electricity passes through the Peltier device (Bhadauria, 2015), it brings heat from one side to the other, so that one side gets cooler while the other gets warmer. The primary advantages of a Peltier cooler compared to a vapour-compression refrigerator are (i) the lack of moving parts or circulating liquid, (ii) very long life, (iii) invulnerability to leaks, (iv) small size, and (v) flexible shape. Its main disadvantages are high cost and poor power efficiency. Many researchers and companies are trying to develop Peltier coolers that are cheaper and more efficient (Wikipedia).

Remarks

Alternative solutions to vapour compression refrigeration present valuable features that open a variety of new possibilities within the home environment, allowing systemic reuse of streams, such as the dishwasher's hot water, cooking water or solar heating to run the refrigerator. We can imagine a management system of hot wastewater, which is not currently considered, to have a source of hot water available, without the need to produce it on purpose. Undoubtedly, this would make the installation more complicated, but it fits the idea of built-in solutions, which is gaining importance.

Fig. 23 - recovery of appliances
source: FEMA Photo Library Greg Henshall FEMA

6.2 Refrigerators in the current scenario

Since the refrigerator is generally considered so essential and instrumental in keeping food fresh and edible, it is the standard appliance in almost every home in industrialised countries (Wilson, 2016). In the U.S. alone, over 8 million refrigerators are purchased each year, with an average lifespan of around 10-14 years. A typical refrigerator costs from $400 to $1500 (Wilson, 2016).

6.2.1 Market and purchase

In this section, some dynamics related to the purchase and disposal of products are reported, to better understand the following parts of this chapter. What drives consumers to purchase? How do they behave with the product and what do they do with an old functioning product?

Appliance replacements and purchases

Price is often the primary consideration when purchasing new appliances. Since users acknowledge that refrigerators are the main contributors to overall energy consumption and relative expenses, they consider energy efficiency as one of the main determining factors when purchasing refrigerators. Consumers are more likely to accept a price increment for the purchase of products that consume less, and they could rely on energy labels to compare different models (NEA, 2017). However, there are many aspects for choosing one product over another, reflecting huge differences among users.

Increasing size and preserving features

According to the general increase in working time and the consequent little time available for everyday tasks such as doing the food shopping, users looks for new features to extend food life, buying cold appliances with increased capacity to keep the food fresh (Haines et al., 2010; Mintel, 2007a). For the same reason, both Haines et al. (2010) and Bakker et al. (2014) reported that although the average size of cold appliances on the market was increased by 15% between 1995 and 2001, the appliances have become more efficient. Over time, products have become larger in net volume and heavier (up to 15%). Weight increase is linked to the total volume of the appliance, but even more to the larger wall thickness to reduce energy consumption (Megalini et al., 2018). This feature allows storing greater quantities of fresh and frozen food, taking advantage of BOGOF offers in supermarkets (Haines et al., 2010).

Refrigerator as a status symbol

It has been noticed that consumers are enthusing about larger and more energy-hungry appliances, such as American style fridge-freezers containing integrated LCDs or ice producers (Haines et al., 2010). According to different purchasing power, users still express their status through everyday objects.

> *Increasing consumer expectation for comfort, convenience, as well as the social and psychological contexts within which cold appliance consumption behaviours exist are challenging the energy gains of technological improvements of reducing the impact of product use* (Tang and Bhamra, 2009).

The refrigerator has become an icon object over time, accompanying the social evolution of the domestic environment. Some refrigerators are regarded as pieces of design (e.g. Fab28 by Smeg) (Ha, 2016), while in general, large, stainless steel or brushed aluminium, two-doors refrigerators with ice-makers and a multitude of functions have become a social status.

Energy efficiency vs bigger appliances
As already mentioned, there is a trend of consumers upgrading to a more energy efficient model, looking for energy efficiency at the time of purchase (Haines et al., 2010), by comparing energy labels. However, over its lifetime, an American style fridge and freezer demands on average 150 kWh per annum more than the typical average sized A-rated appliance, consuming 1800 kWh more than the latter (Tang and Bhamra, 2009; Haines et al., 2010).

Increase ownership of multiple refrigerators
Many authors noticed through surveys a recent phenomenon of households owning more than one refrigerator - one for food, one for drinks or other uses. Whilst there have been improvements in the efficiency of new cold appliances, this has been coupled with an increase in the number of appliances in each home often located away from the kitchen (Haines et al., 2010). This apparently goes against any energy efficiency gains. The study does not actually indicate the reason, so we do not know if the second or third product is working, working correctly, or it is kept inside/nearby the house.
The latter four dynamics lead to the 'rebound effect' (addressed in chapter 3), which reduce half of the gains due to energy efficiency improvements (Tang and Bhamra, 2009)

EoL attitude
E-SCOPE study conducted by Cooper and Kieren (2000) interviewing 802 households, investigated the ownership, purchase, use and disposal of household appliances in the UK, found that

> *15.1% of cold appliances discarded were donated for free to family or friends, 0.8% were donated to charity and a further 6% were sold on (second hand shops, dealers)* (Haines et al., 2010).

Consumers prefer to think their product being reused rather than abandoned in landfills.

6.3. Impacts

Many environmental impacts are hidden throughout the life cycle of these devices, ranging from the use of materials for their productions, the quantity of items produced and purchased, the increase in the size of the refrigerators purchased, the increasing energy consumption of bigger models and then how users use the fridge during its useful life, how they disposed of old products.

6.3.1 Environmental impact. Hazardous component and recovery dynamics

Refrigerators have been responsible for severe impacts as well as serious and irreparable environmental damage; they can still have a tremendous impact on the environment if not disposed of properly. For this reason, treatment processes for cooling and freezing appliances are more complex and costly compared to treatments of other large and small home appliances. Proper disposal of ozone-depleting substances and oil, as well as polyurethane foam, represent substantial recycling costs (Megalini et al., 2018).
Every year, in the U.S alone, about 2.5 million refrigerators are disposed of. According to Haine et al., (2010) the predominant type of refrigerator owned is fridge-freezer, with a median lifespan ranging from 11 years (Cooper, 2005) to 14 years (Wilson, 2016; Wang et al. 2013, Bakker et al., 2014). Oguchi and Daigo (2017) provide us with a useful graph to show the reason for this fluctuation in Japan, that depends on the way it is calculated (Fig. 24).

Refrigerant
Refrigerant fluid is a significant hazard of improper disposal of refrigerators, which determines the greatest impact of this product compared to other appliances (Wilson, 2016). Refrigerants used have changed continuously, whereas chemists and environment experts are not yet satisfied with their characteristics. Ever since the first mechanical refrigeration unit was invented scientists strived to find a suitable refrigerant (Unilever UK Ltd). Early refrigerators, from the late 1800s until 1929, indeed, used highly toxic gases such as ammonia [12]

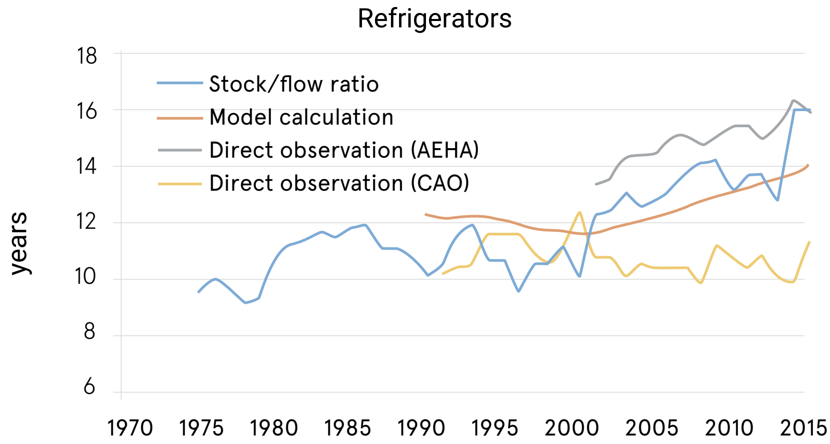

Fig. 24 - Observed or calculated average lifetimes by different approaches[13]. Source: Oguchi and Daigo, 2017

(NH3), methyl chloride (CH3Cl), and sulphur dioxide (SO2) as refrigerants. Several fatal home accidents occurred in the 1920s when methyl chloride leaked out of refrigerators (Bellis, 2017a). Appliance manufacturers then realised that a safer cooling element was needed (Conjecture Corporation, 2009).

CFCs

Three American corporations launched collaborative research to develop a less dangerous method of refrigeration (Bellis, 2017a); their efforts lead to the discovery of synthetic refrigerants called chlorofluorocarbons (CFCs) also known by its brand name Freon®, that was the one patented by Du Pont (Conjecture Corporation, 2009). In just a few years, Freon® would become the standard refrigerant worldwide in the decades that followed for almost all home kitchens. However, Freon® was not a perfect solution either, however. Only decades later, in the 1970s scientists discovered that CFCs contribute to the depletion of the Earth's natural ozone layer, endangered the entire planet. Ozone depletion, which increases the damaging health effects of solar radiation, was soon understood as a major environmental crisis. The discovery that Chlorine from CFCs was depleting the ozone layer is largely attributed to the work of, Frank Sherwood Rowland, Paul J. Crutzen and Mario J. Molina in the early 1970's. They discovered the hole in the ozone layer above the Antarctic pole and linked it with the wide use of CFCs. This lead to the Montreal Protocol which was a treaty to phase out several ozone-depleting substances and became effective in 1989 (Unilever UK Ltd). World governments banned the use of CFCs in the 1980s, although it took decades to remove all the devices from the economy, also due to the average longer life spans of these old devices, up to 35 years (Haines et al., 2010).

HCFCs

Immediately after the Montreal Protocol CFCs were replaced with Hydrochlorofluorocarbons (HCFCs) containing hydrogen, chlorine, fluorine and carbon. They represent a transition phase, an interim measure because they were still depleting the ozone layer but less than CFCs. If CFCs have an ozone depletion index (ODP) of 0.6 – 1, HCFCs have an ODP of 0.01 to 0.5. HCFCs also have a large impact on global warming with a global warming potential (GWP), several thousand times greater than carbon dioxide. The Montreal protocol also introduced measures to dispose of this gas properly. In the UK, this was covered by the duty of care act which ensures that refrigeration units are recycled with the waste brokers WEEE producer compliance scheme, to ensure that refrigerants are not released into the atmosphere (Unilever UK Ltd).

12 Largely abandoned for home use due to its toxicity, ammonia still in widespread use in industrial applications (Wilson, 2016)

13 AEHA stands for Association for Electric Home Appliances of Japan
CAO Cabinet Office of the Japanese government

HFCs
Hydrofluorocarbons (HFCs) which contain hydrogen, fluorine and carbon have replaced both CFCs and HCFCs. They do not deplete the ozone layer as they do not contain chlorine. They are however still known as a 'super' greenhouse gas' having over a thousand times the GWP of carbon dioxide (Wilson, 2016), as they trap large amounts of infrared radiation from the sun which warms the atmosphere. However, use of HFCs is tightly controlled and appliances that contain HFCs are recycled to ensure that the refrigerant does not leak. (Unilever UK Ltd)

Other scenarios
There is an increasing trend back to the origins that sees the use of gases such as carbon dioxide and ammonia, used over 130 years ago. Nowadays, technologies would allow them to be engineered more efficiently. Both are environmentally friendly, economical and energy-efficient. CO2 is non-toxic, non-flammable, non-ozone depleting and has a GWP of just one. Ammonia is non-flammable, non-ozone depleting, with a low GWP, however, it suffers from the disadvantage of being toxic. This prevents the refrigerant being used for domestic and small scale use however it is used in large industrial refrigeration and hockey rinks (Unilever UK Ltd). There is currently much debate about which new refrigerant should be used in the future to completely phase the dependence on HFCs. The chemical industry is incessantly experimenting new refrigerants. The Montreal and Kyoto Protocols are pushing this challenge and we hope to see new safer refrigerants starting to be widely used (Unilever UK Ltd).

Materials and recycling process
Today, people freely replace their consumer durables. Many of the replaced durables end up in the waste stream. As an illustration, in the UK at least 476 kilotons of household appliances, totalling 23 million units, were disposed of annually between 1993 and 1998 (Cooper and Mayers, 2000). With the human need for such appliances growing day by day, the natural resources needed to make them are shrinking (Wilson, 2016). Replacing and (eventually) disposing of products creates an environmental burden because it produces waste and uses up scarce resources needed to produce new consumer durables (Mugge et al., 2005). Proper recycling of refrigerators can allow to reuse metals, help preserving this limited supply of materials, as well as to help reduce the enormous amount of metal volume that enters landfills every year (Wilson, 2016).
'Material Flows of the Home Appliance Industry' (Megalini et al., 2018) gives us an interesting insight into the composition of cooling and freezing appliances, which we have reported in Tab. 5.

Material	**Mt**	**Percentage**
Aluminium	0,02	3,3
Copper	0,01	2,2
Glass	0,01	1,3
Plastics	0,08	15,5
Polyurethane foam	0,01	1,5
Steel	0,34	63,4
Other	0,01	1,2
Material to Energy Recovery	0,06	11,7

Table 5 - Composition of output flow of WEE recovery according to industry take-back scheme, based on real performance recyclers. Assumption of 1,7Mt collected by industry across EU (Megalini et al., 2018).

Metals: aluminium, copper and steel
In general, home appliances have a recovery rate of 57% (Center for Sustainable Systems, 2016) as they are mainly made of metals. For large home appliances, indeed, steel is the predominant material. In terms of weight, 66% of the material is recovered, while regarding economic contribution, 59% is recovered (Megalini et al., 2018). Also for cooling and freezing appliances, steel (with an increase in stainless steel) and non-ferrous metals are major contributors to the total amount of materials recovered (Megalini et al., 2018).

Plastics
Over time, steel has been replaced by plastics. The share of plastic was around 14% in 2000 and

Fig. 25 - Compressor collection
Source: Source Riaz and Sons

increased to nearly 23% today with peeks of 29% in certain cases (Megalini et al., 2018).

Acrylonitrile Butadiene Styrene (ABS)

The plastic share increased from 6,8% up to 23,4% with some products up to 26,7%. One of the main reasons for replacement of metals (steel in particular) with plastics is connected with the increase of flexibility in production, and reduction of the final product price (Megalini et al., 2018)

ABS, like all traditional plastics, is not biodegradable and like a subset of plastics called thermosets, if burned at low temperatures (which is often done during informal or improper disposal), can release dioxins, furans, and polycyclic aromatic hydrocarbons (PAHs). These toxins have a wide range of negative impacts on both wildlife and human health (Wilson, 2016).

Polystyrene (PS)

Inner-liners are made of PS; which share has increased by around 10% (Megalini et al., 2018). PS can be hazardous. It is composed of benzene and styrene, both of which are human carcinogens and can cause multiple neurological problems (Wilson, 2016).

Polyurethane foam (PUR)

The share of PUR used for foam insulation increased over time (from 10 to 12%), as a consequence of the work to improve the energy efficiency of appliances.

Electronics, e-waste

As for many other appliances, compared to the early 2000s, electronic components have increased from 0,5% to 1,5%, and up to 2% for some products (Megalini et al., 2018). Since refrigerators contain electronics, they run the same risk of other electronic product upon disposal and recycling. Indeed, it has been proven that E-waste impacts on air, water, and soil (Wilson, 2016).

6.3.2 Environmental impact. The energy consumption

The residential sector accounts for about 38% of emission associated with economy-wide consumption of electricity (McElroy, 2016). All cold appliances have a high-energy demand within the household (Haines et al., 2010), since are the only pieces of equipment that use energy 24 hours a day 365 days a year, accounting for around one-fifth of domestic energy and from 14 to 25% of the average household bill (Tang and Bhamra, 2008; 2009; NEA, 2017). For this reason, almost all continents or individual countries have taken measures to reduce consumption of electricity in the appliances (Bhabaranjan, 2015). These measures not only result in saving energy but also reducing the impacts from an environmental perspective. EU countries are trying to both reducing EU's oil dependency and cutting greenhouse gas emissions, introducing standards and labelling for appliances, encouraging the removal of obsolete products from the economy, replacing them with energy efficient ones. The efficient use of energy seems to be a relevant issue, and one of the most effective ways of efficient use of energy is its proper use in household appliances (Bhabaranjan, 2015).

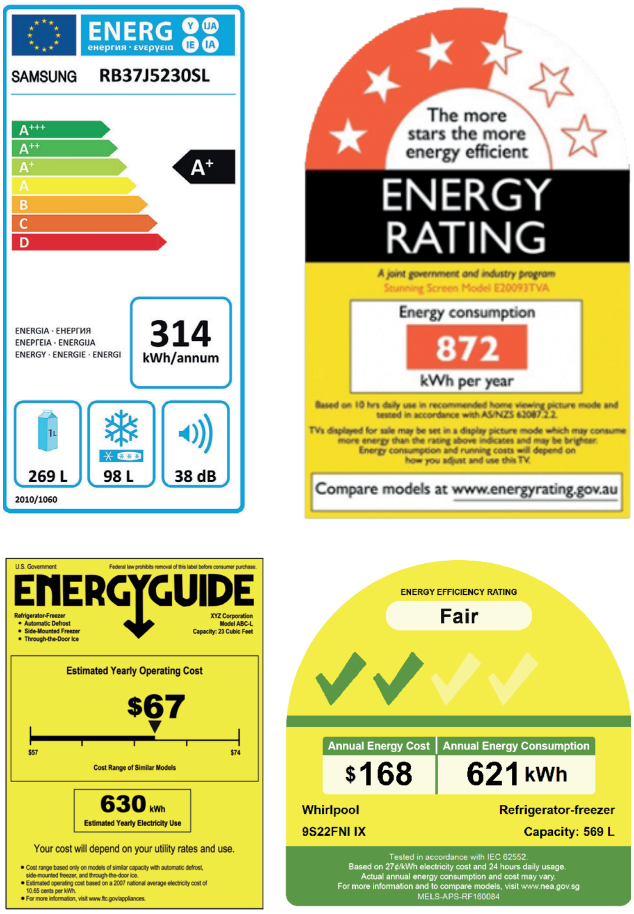

Fig. 26 - Four examples of energy label for a refrigerator.

Policies

Policy measures are very well established for the traditional large domestic appliances, such as fridges. The appliances follow different directives (Table 6; Haines et al., 2010).

Energy Labelling

EU Directive 92/75/EC established a mandatory labelling scheme called EU Energy Label. The directive was implemented by several other directives. The energy efficiency of the appliance is rated in classes from A to G on the label, A being the most energy efficient, G the least efficient. The labels also provide other useful information to the customer to compare and choose among different products.

In the same ways, other countries have their own labelling systems (Figure 26). In Australia and New Zealand, for example, refrigerators and freezers have been required to display an energy label since 1986 and to meet minimum energy efficiency levels since 1999. As a result, refrigerators and freezers are now 70 percent more efficient than they were 30 years ago (Australian Government, 2017). In Asia, since the introduction of mandatory energy labelling in 2008 and MEPS for refrigerators in 2011, the average efficiency of refrigerators has improved by about 26 percent, resulting in more than $18 million in annual energy cost savings for households, or the yearly electricity consumption of around 14,000 homes. These measures have also led to a total carbon abatement of about 0.03 MT - equivalent to the annual carbon emissions of close to 9,000 cars (NEA, 2017).

Towards Circular Economy

Below, Mestre and Cooper (2017) explain the latest updates of the policies in the field of circular economy, beyond the energy labelling:

> *On a policy level, the Ecodesign Directive was first introduced in 2005 by the European Commission (EC). While initially focusing on the energy efficiency of electrical and electronic goods, it was recently revised (EC, 2016) to reflect not only the impact of the use phase and optimisation at end of life (design for disassembly and recycling), but optimisation of the initial lifetime*

Table 6 - Policies and activities affecting domestic appliances categories (Haines et al., 2010)

Appliance Category	Example	EuP[14]	EU Energy Label	Energy Star	CERT/SO	ESR	Building Regs
Cold appliances	Fridge, freezer, fridge&freezer	√	√	√	√	√	

14 Energy using Product (EuP) directive

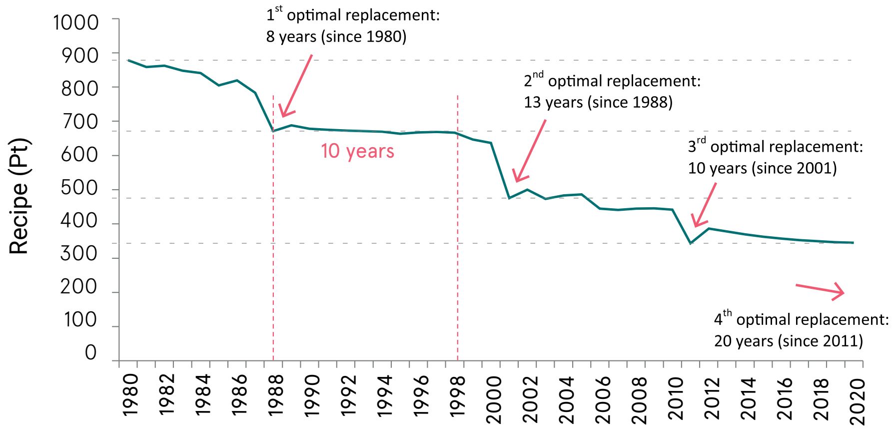

Fig. 27 - Optimal lifespans for a refrigeratorefreezer based on ReCiPe (Pt.) as a measure of environmental impacts.
Source: Bakker et al., 2014)

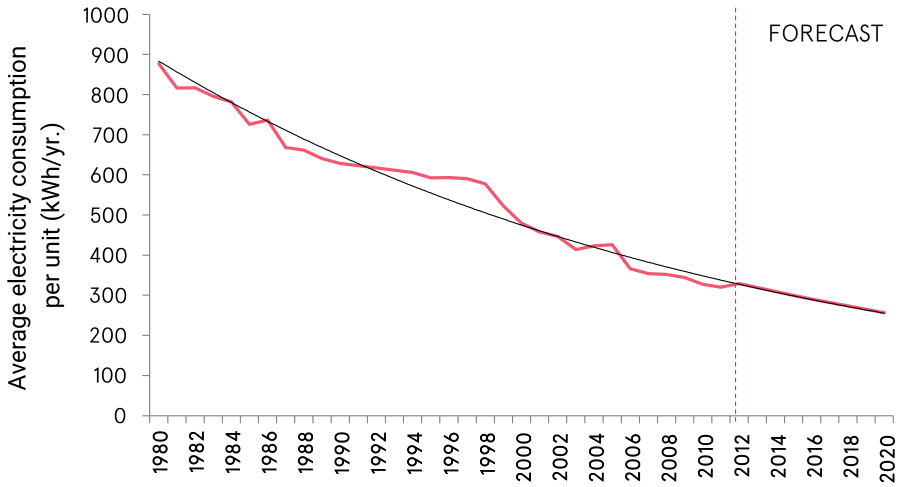

Fig. 28 - Average electricity consumption per unit of refrigerator-freezer (1980-2020).
Source: Bakker et al., 2014)

(design for longevity) through strategies such as repairability and durability. The concept has been reflected in both EU legislative frameworks (e.g. EU waste directives) and the UK waste prevention programme (DEFRA, 2013). More recently, the Circular Economy Package (EC, 2015) intended to bridge the Ecodesign Directive and existing waste management strategies with the concept of the circular economy (Mestre and Cooper, 2017).

European policy initiatives such as the Waste Electrical and Electronic Equipment (WEEE) Directive (European Parliament and Council, 2012) or the Ecodesign Directive (2009) raise the focus of the cooperation needed between different stakeholders, (e.g. between producers and recyclers to support the disassembly) (Movilla et al., 2016). WEEE Directive makes manufacturers responsible for discarded items (Cooper, 2005).

Environmental reasons to replace an obsolete product

From an eco-efficiency standpoint, it is often argued that there will be a point at which the additional performance of a new product will outweigh the benefits of retaining an old product. Such debates are highly relevant in products with a rapid rate of technological improvement, and where there are incentives for users to dispose of older products. The presence of these twin characteristics is discernible in several technology categories including, for example, domestic heating systems, refrigerators, and air conditioning systems (Wells and Nieuwenhuis, 2017)

At present, for products with a relatively high energy-efficient improvement, early replacement is preferred over product longevity (Mugge et al., 2005). Properly replacing refrigerators with high

15 The optimal product lifespan is the point in time where the environmental impacts that arise from using a product equal the embedded impacts of a more energy efficient replacement product (Bakker et al., 2014).

energy demand with modern refrigerators remove the hazards deriving from gas and materials, by reducing electricity usage (Wilson, 2016).
However, some very old appliances are still in use and it is common to own several cold appliances in combination. There is likely to be a reluctance to replace what consumers perceive as a 'perfectly good' refrigerator and the cost savings of a more efficient model are small compared with the initial cost of a new appliance (Haines et al., 2010). According to Bakker at al. (2014) the 'optimal lifespan[15]' of new purchases is now estimated around 20 years, although it should have been shorter in the past (Figure 27). Figure 27 shows flat periods when the efficiency did not improve, followed by sudden jumps in efficiency (Bakker et al., 2014).

Addressing the energy consumption
Fridges are usually left switched-on all the time (8760 hours per year) with an annual energy demand of approximately 350 kWh/year as shown in figure 28. The study conducted by Bakker et al. (2014) shows the electricity consumption from 1980 to 2012 and forecasts the trend until 2020. Figure 28 shows the considerable advances in energy efficiency, showing that refrigerators have become approximately 60% more efficient since 1980 (Bakker et al., 2014).
Refrigerators have become more energy-efficient over time by both developing products which consume less energy and improve the insulation, preventing heat from entering the refrigerator (Bhabaranjan, 2015).
About 32% savings are currently achievable by replacing the compressor with a better-performing one (technological improvement shown in and Figure 29, retrieved from Bhabaranjan, 2015).
As we can notice, between 0 stars and 5 stars there is a marked energy improvement, while between 4 and 5 stars the difference is drastically reduced. This study differs from the previous since it refers to the energy class of the appliance in a real-use context. For this reason, Haier 5 Star Refrigerator consumes 431 KWh/year, which is more than the average indicated by Bakker et al., (2014). However, energy consumption can decrease further by acting on user behaviour or applying corrective measures based on user patterns, for example.

Remarks
Nowadays, many products are replaced while they are still functioning properly: only 22 percent of the products do not function anymore at the time of replacement. Therefore, sustainable consumption demands changes in the behaviour of consumer's replacement (Mugge et al., 2005), but also changes upstream on purchasing attitudes, because strategies to extend product durability can be more successful if applied on valuable products. Miele has indicated a commitment to making household equipment with increased lifespans as a marketing strategy and claims a twenty-year lifespan for some of their relatively expensive household equipment in advertisements (Mugge 2005). This example gives rise to certain design intervention strategies (predictive maintenance, sensors, machine learning, etc.) that perhaps it is not worth introducing into cheap durable goods. Most current products can pursue other strategies like reusing, refurbishing and remanufacturing to meet the demands of another group of consumers. In our opinion, we agree that extending the useful life of an object is a relevant issue, but we would like to avoid forcing the user to use more a product that no longer meets its needs.

6.3.3 Environmental impact. The usage phase

The refrigerator operates within the home environment, a complex context which is driven by household's daily routines. From existing studies, we know that people always make up their own ways of doing things and that their everyday life activities tend to be idiosyncratic. Previous studies found that people improvise and that they are inconsistent in the ways they approach energy-saving in their homes. (Wilson et al., 2014). The use phase of refrigerators has great consequences on both the product life-cycle and energy consumption, in addition to direct consequences on the quality of food stored in it. Consumer behaviour can significantly affect the energy efficiency of cold appliances, for example through door opening practices or by introducing and storing hot or cold items in the refrigerator (Haines et al., 2010). Current energy labels do not reflect actual energy consumption of situated use (Tang and Bhamra, 2008). During routine tests doors are usually kept close, the test load is unrealistic, and temperature recovery derived by introducing warm food and humidity increase with door opening is not examined (Haines et al., 2010). Many researchers

Star rating of Refrigerator	**Power consumption (KWh/year)**
No-Star Refrigerator	1141
No-Star Refrigerator with 5 Star compressor	773
Haier 4 Star Refrigerator	467
Haier 5 Star Refrigerator	431

Table 7 - Comparison of different refrigerators' power consumption (Bhabaranjan, 2015)

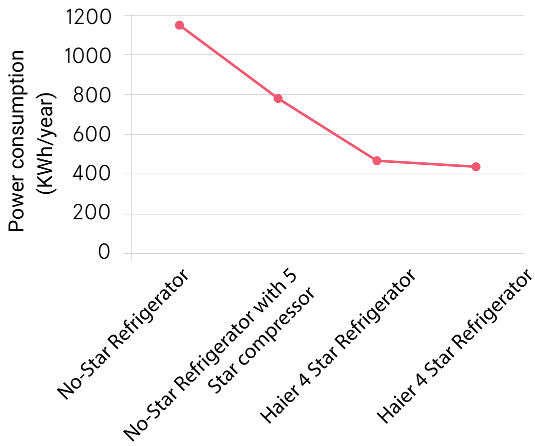

Figure 29 - Representation of power consumption
Source: Bhabaranjan, 2015

complain the lack of real-life usage experiments.

Introducing and storing hot or cold items in the refrigerator

Stamminger et al. (2007) cite two studies that have investigated the impact of inserting and storing hot or cold items inside the refrigerator: the first found that 'introducing food' into the fridge is responsible for 10% of its yearly energy consumption and cooling food with a temperature of 50°C uses three times more energy than cooling food with a temperature of 20°C; the second study found that thawing frozen food in the refrigerator can reduce the energy consumption up to 26% (Haines et al., 2010). Based on these studies, we can easily conclude what good or bad practices in temperature management are.

Effect of door opening

The issues related to door opening are much more controversial. Taking for granted that one of the behaviours that leads increasing energy consumption is the door opening pattern, very few experiments and theoretical studies have been carried out on the analysis of the effect of door-opening on energy consumption, especially in field condition. Bhabaranjan's experiment presents few variables and clear results. The study was conducted by keeping the door of a 5 star marked refrigerator open at different frequency and duration, with the same total overall time. The results showed that frequent opening leads to substantial increase in energy consumption (i.e. frequency and energy consumption are directly proportional variables). The study conducted by Bhabaranjan (2015) demonstrates that opening the door every 3 minutes for just 1 minute is more energy consuming than leaving the door open for 90 minutes every three hours, although the total opening time was steady. We report some graphs and tables of that study (Figure 30 and 31, Tab. 8), acknowledging the author for having increased the knowledge in this field.

The increase is maximum when the door is opened for only 1 minute after every 3 minutes for total 6 hours so that total opening time in 6 hours remains 90 minutes. This happens mainly because the door gets opened before the thermostat reaches its minimum temperature at which the compressor gets 'OFF' (Bhabaranjan, 2015), desynchronising with on-off phases, keeping on running without any break (without any OFF phase).

> *Opening the door for only 1 or 2 minutes will not have much effect on energy consumption if it is not repeated at frequent intervals. In other words, it is important to keep the door closed for sufficient time so that the temperature drops and reaches the set temperature of the thermostat within a reasonable time and the compressor stops. If the door is opened before the temperature drops to thermostat set value, then the temperature will increase again, thereby increasing the running time of the compressor, which results in higher energy consumption* (Bhabaranjan, 2015)

If an increase in the frequency of door opening

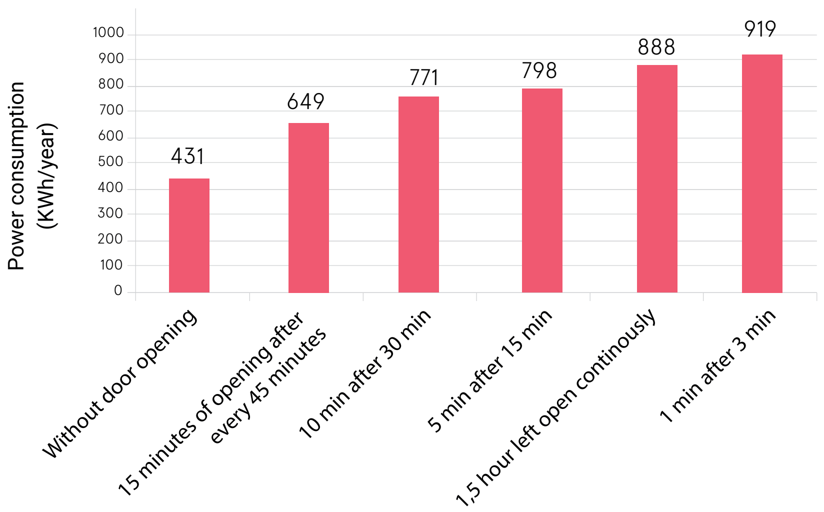

Fig. 30 - Power consumption (KWh/y) related to door opening time
Source: Bhabaranjan, 2015

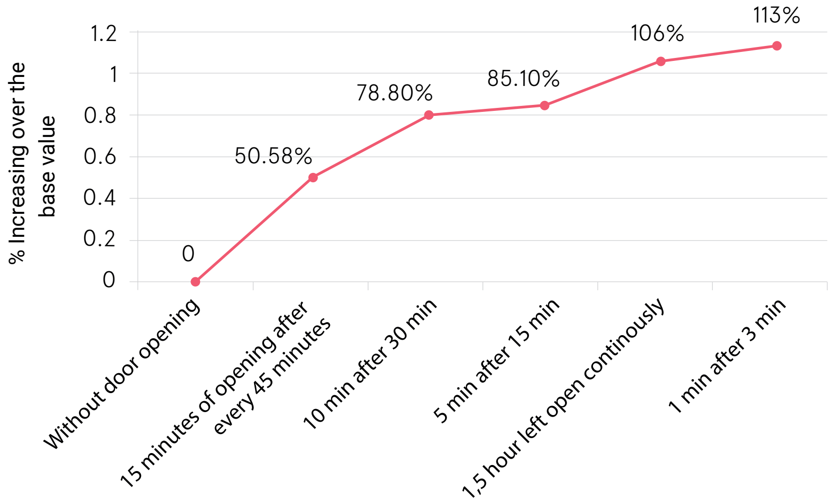

Fig. 31 - Percentage of increasing over the 'base' energy consumption (i.e. when the door is kept close) compared to different opening times
Source: Bhabaranjan, 2015

Table 8 - Effect of door opening on energy consumption. Source: Bhabaranjan, 2015

Door opening time	Power consumption (KWh/year)	Increasing over the base value (percentage)	total opening time in 6 hours
Without door opening	431	--	base value
15 minutes of opening after every 45 minutes	649	50,58	90 min
10 min after 30 min	771	78,8	90 min
5 min after 15 min	798	85,1	90 min
1,5 hour left open continously	888	106	90 min
1 min after 3 min	919	113	90 min

leads to an increase in energy consumption from 50 to 113%, then by maintaining the door opening frequency to the minimum, this amount of electricity could be saved. Since the fridge operation is strictly related also to the temperature decreasing, opening the door too often leads to an increase in temperature that makes the compressor work incessantly. Maybe further studies should consider the increase in temperature in the different usage patterns, according to the ambient temperature. In India, for example, the door opening is expected to impact more than in Norway, since opening causes a lower increase in temperature. Bhabaranjan performed his experiment with an ambient temperature of 32°C, which is hardly achievable in Europe.
According to Haines et al. (2010):

> *A typical range of opening times for fridge doors is between 8-19 seconds. Tang (2008) reported on a video study which included the observation of the behaviour of a young family using the refrigerator at breakfast. In this case study, the fridge was opened a total of 21 times and on three occasions the fridge was left open for a total of 191 seconds. Elias (2009) gives the most frequent opening time of 3 seconds and an average opening time of 7.5 seconds, although the door can be left open for significantly longer periods if food is being searched for or stored after a shopping trip* (Haines et al., 2010).

Haines et al. (2010) found that 20 door openings a day (almost the same number that Tang (2008) observed at breakfast) would generate an increase in electricity consumption of between 1-6%. Other studies defined that consumption increased by 6.4% for 20 door openings a day, with a 12-second opening time, between 6-8% for 24 door openings a day, also with a 12 second opening time. Another study, with similar opening frequency but the reduced opening time of 5 seconds found a similar result of 8% from door openings, in this case, 20 kWh. Saidur (2002) estimated an energy impact of 9Wh-12.4Wh per 12 seconds of door opening and this is also supported by Parker and Stedman (1993), who estimated an impact of 9Wh per opening (Haines et al. 2010).
Eventually, Haines et al. (2010) reported average consumption of 0.68Wh per second in which the door is kept open. Tang and Bhamra (2009) reported in Tab. 9. Some results of other studies related to the door opening, warm/room temperature food introduction and other effects on actual energy consumption.

Remarks

Several studies into calculating energy impact of door opening have been carried out. However, none of these tried to link opening time with the motivation, the frequency and the duration, nor they link the previous parameters with the overall task that the user is carrying out (storing the food shopping, preparing for lunch), during working days or the weekends, across different seasons, according to different lifestyles, routine and cultures. We should investigate the behaviour related to leaving open the door of a refrigerator too long. Nowadays, we can use technologies to monitor long periods and identify usage patterns. Improved understanding of how people use their cold appliances could lead to better future designs and better practice with existing appliances (Haines et al., 2010).

6.4 Investigating alternative scenarios

Since the ‘refrigerator’ is considered the ‘solution’, the commodity that Western society takes for granted, in this section, we record both the progress of the industrial sector, as well as case studies about alternative and low tech solutions provided for ‘conservation’ in general. This approach helps to wider the scenario on more disruptive and experimental solutions, different from those we experience every day.

6.4.1 Companies: the bias of techno-push solutions

In the context of smart home, the refrigerator gives rein to the imagination, with transparent doors (Samsung Food ShowCase Refrigerator; Microsoft, 2011), electronic tablet-like screens on the front (Samsung Family Hub; Microsoft, 2011) allowing keeping track of what enters (Ideo-Ikea, 2015), connected smartphone applications to check and set the inside temperature. The so-called ‘smart fridge’ is a refrigerator which has been programmed to sense what kinds of products are being stored inside it and keep track of the stock through barcode or RFID scanning. This kind of refrigerator is often equipped

Fig. 32 - Fridge arrangement

Table 9 - Effect on actual energy consumption (Haines et al., 2010)

Energy Consumption Research community	Effects on actual energy consumption
Food Refrigeration and Process Engineering Research Centre (FRPERC) report	The effect of door opening is 1-2% The influence of warm food is 4-10%
Mennink et al. (1998) tested 200 litre refrigerator	The effect of door opening is 8% (2.2W) The influence of adding food at room temperature is 11% (3.1W)
Refrigerators and Freezers, product case 5, Methodology Study Eco-Design of Energy-using Products (MEEUP) for European Commission	Ice-up the evaporator deteriorate the efficiency by 10-20% 1°C difference in temperature causes a 4% difference in energy consumption
ECUEL project SAVE (1999) in France used metered appliances in around 98 households for one month between January and July 1998 to monitor	Keeping a cold in a non-heated storeroom rather than a kitchen gives an average energy saving of 3% On average, freezers were operating at 3,1°C colder than the recommended temperature (-18°C), leading to 17,6% more energy use
In Japan, the surveys on Actual Energy Consumption on Top-Runner Refrigerators of Jyukankyo Research Institute (2006) monitored over 100 refrigerators in household for one year	Average annual actual electricity consumption was 65% larger than the JIS test value (Japan Industrial Standards test in 1999)

to determine itself whenever a food item needs to be replenished (Wikipedia). The emerging technology capabilities pushed a list of gadget functionalities falling far from Mennicken and colleagues' definition of a smart home appliance (2012).

6.4.2 The progress of the industrial sector

Nevertheless, consumers are looking for improved functions. In 2013, a market study was conducted by Westgarth (2014) on a panel of almost 2000 Internet users, above the age of 16, who have a fridge/freezer, or intended to buy one in the next 12 months. When asked to select the features they would pay more to have in their fridge/freezer, the consumers revealed they were not as interested in odour or humidity control (16% and 14% respectively) as much as they were in water, drinks, ice dispensers (26%) or freshness monitors/stock control systems (30%) as shown in Figure 33 (Westgarth, 2014; Oliveira, 2015). The technology captures an important fraction of the consumers' interest. The second and third most selected feature is related with technology by the inclusion of a "barcode reader synched to online shopping" (24%) and "intelligent electronic controls" (23%) (Westgarth, 2014; Oliveira, 2004).

> *Intelligence and connectivity enable an entirely new set of product functions and capabilities that allow consumers to interact with products in ways that weren't possible before. [..] Appliances have evolved along with all other consumer products, incorporating electronics and becoming quite sophisticated in their control algorithms and in the sensors incorporated into the [devices]* (Weber, 2016).

Among the main innovations in the field we can list:

1. Adaptability of operation
2. Temperature control
3. Maintenance
4. Flexibility in the space management
5. Customization
6. Visibility of items
7. IoT data for product design

1) Adaptability of operation

Many companies have introduced Digital Inverter Compressor that modulates the operation according to real needs, permitting to minimise consumptions.

2) Temperature control

Beyond the remote control of the temperature, which was the first function introduced with the IoT, other temperature management applications are found in Vertigo refrigerator by KitchenAid which has a separate multitasking drawer or that can be customised according to the various usage needs, changing temperatures according to the function. Miele@Mobile app allows controlling the temperature of the single refrigerator compartments or setting some unique fridge feature (Ha, 2016).

3) Maintenance

SubZero states that they are working on predictive maintenance:

> *enable the service centre to interact with the refrigerator in preventive manner, warning consumers that a problem is arising, for instance involving the fan, and therefore they should replace the spare part before the refrigerator definitively breaks down.* (Ha, 2016)

However, no breakthrough on final products has yet been acknowledged by the author.

4) Flexibility in the space management

LG has what it is called the 'door-in-door', where a section (a door) is isolated from the main one, to allow access regularly needed products (Westgarth, 2014).

Electrolux CustomFlex system (Figure 34) allows the consumers to customise the space on the door, according to their own requirements by using interchangeable containers and shelves. (Ha, 2016).

5) Customization

Miele combi K 20.000 has introduced a writable door BlackBoard (Ha, 2016; Figure 35)

6) Visibility of items

Samsung Family Hub has three cameras (one per shelf) to check the inside content remotely allows, receiving alerts when the registered foods are about to expire and sharing the shopping list on the entire family's devices (Ha, 2016)

7) IoT data for product design

Producers acknowledge that data generated from a smart, connected product have significant implications for design, market segmentation and after-sale service (Weber, 2016).

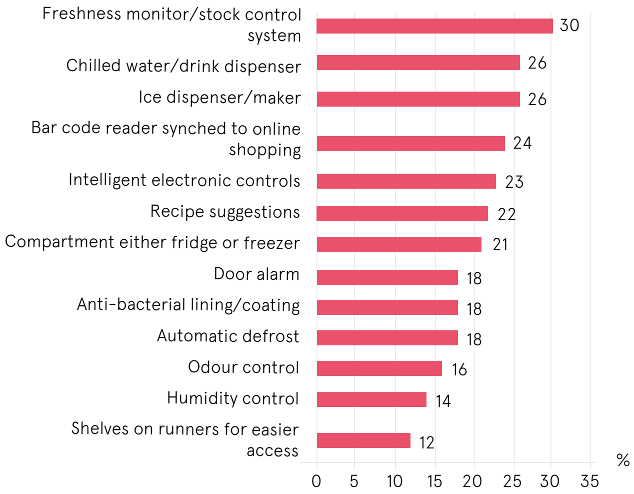

Fig. 33 - Features of fridges and freezers consumers are willing to pay more for in a refrigerator. January 2013. Source: Westgarth, 2014

> *"Having software on the appliance alone does not necessarily make it smart," notes Lamy. "It is the connected aspect that truly brings intelligent features to a product* (Weber, 2016).
> *This technology gives appliance manufacturers unprecedented insight into how the products are actually being used in an objective way," adds Lamy. "Historically, manufacturers had to glean information from customer feedback or support inquiries, which does not provide a complete, unbiased picture* (Weber, 2016).

Remarks

Charles Arthur (2014) suggested that no smart fridge will ever succeed because there is no technology capable of easily scanning the products, knowing the expiration date and seeing inside the fridge in the off light. However, when addressing the IoT applied to a fridge there are many other aspects to consider, especially when your goal is different from incorporating technology into a refrigerator with no other changes. As it has already happened with the additive manufacturing, there is a big difference in printing a 3D objects similar to the current one and designing for additive manufacturing. For the same reason, the object itself should be redesigned to include meaningful features aiming at simplifying certain daily tasks (organisation of food shopping, product visibility, detect the quantities through

Fig. 34- Custom Flex fridge-freezer by Electrolux A) Detachable compartments; B) Compartments in the fridge door. Source: Electrolux, 2015

Fig. 35- K 20.000 fridge-freezer by Miele

weight sensors and so on). However, there are still no tangible, innovative leaps around the refrigerator and broadly domestic food routines (e.g. food shopping unpacking, preparation, consumption, food waste).

6.4.3 Research activities

Some research studies have been carried out in the academic field to investigate refrigerators, focusing on enhancing health and enabling better nutrition (Luo et al., 2009). Other studies dealt with managing item stored (Gangadhar et al., 2011), do preventive shopping (Prapulla et al., 2015), avoid food waste by detecting what is inside with camera recordings (Hsu et al. 2010, Itzkovitch, 2013), barcode scanning (Rouillard, 2012, Itzkovitch, 2013), showing a greater attention and caring about the consumer as an individual. Tang and Bhamra (2009) suggested that the re-design of refrigerator and freezer interior arrangement could facilitate user lifestyle while reducing household energy consumption (redesign). WRAP (2011) studies the effect of ethylene on food preservation (sensing), while other studies investigate low tech solutions for reducing the impact of cold appliances (see case studies below). However, these case studies are mainly R&D or scholarly activities, and little attention is paid to redesign the refrigerator by understanding the environment in which it works nor addressing food waste.

6.4.4 Strategies towards a Circular Economy

These technological advances, however, lack a clear strategy that can lead to lasting results and improvements from an environmental perspective. For this reason, we try to define some strategies to go towards the principles of the circular economy as follows:

1. Improving recycling
2. Extending the product lifetime
3. Work on attachment dynamics
4. Combining IoT data with participatory tools.
5. Object orientated approach

1) Improving recycling

Given the relatively large amount of materials used, the degree of fridge recycling could probably be intensified. Design for recycling might be useful here. (Bakker et al., 2014 p. 14). However, this strategy is the least preferable, because it involves product breakdown in its materials.

2) Extending the product lifetime

Refrigerators have a relatively mature technology, meaning not a lot of breakthrough technological innovation is happening in fridge engineering. Extending a fridge's life to 20 years, therefore, means making it reliable and (emotionally, aesthetically and functionally) durable, and ensuring its energy efficiency does not deteriorate over its lifetime due to ageing insulation foam and leaking door seals. Bakker et al. (2014) suggest that it could be possible to 'sell a fridge with a life-time guarantee' if we identified the likely causes of failure and designed into the original product a simple means to repair them. Working on predictive maintenance might be useful here.

2) Work on attachment dynamics

Another relevant aspect is that home appliances are considered as utilitarian, standardised products, unable to trigger attachment dynamics (Mugge et al., 2005), whose purchase occurs (almost) exclusively for functional reasons. In general, home appliances are a means to do a task faster or easier and user, indeed, seems to want them to last longer, avoiding to waste money in their early replacement unless specified conditions change (Fiore et al., 2017). Bakker et al., confirm this, considering refrigerators as 'low interest products' (Bakker et al., 2014).

> *In the Netherlands, 57% of the 6000 households surveyed keep their fridges until they break down* (Bakker et al., 2014 p. 14)

Product attachment determinants are less relevant for these class of objects (Mugge et al. 2005; Ceschin and Gaziulusoy, 2016), determining a more difficult application of the Designing for Emotional Durability. However, this issue should not necessarily remain unaddressed. Indeed, if the role of design is to change the current situations into preferred ones (Simons, 1969), then we should investigate with both co-design methods and new technologies, which features a refrigerator should have for triggering attachment dynamics. Moreover, IoT technology could provide the right platform to experience both functionality and personalisation in operational features. This could possibly lead establishing new attachment dynamics with users. However, these dynamics are not expected to happen by chance, so if we want to postpone the early replacement of products and address the environmental sustainability by stimulating such dynamics, we should study how to make it possible. Then, there is room for improving performances and useful life in the early design stage, trying to extend their useful life by redesigning meaningful and high-value products (Fiore et al., 2017).

<u>4) Combining IoT data with participatory tools</u>

IoT is suggested by McAloone and Pigosso (2017) as one of the three drivers for the success of Circular Economy, together with sustainable design/eco-design and Business model innovation. Equipping products with intelligence makes them adapt and respond to change and remain fit-for-purpose over longer time periods (McAloone and Pigosso, 2017). IoT data can be used to improve current products, but also for developing virtual services and sharing economy platforms to support the technical lifetime. CE can benefit from this intelligence for up-cycling processes, monitoring the condition of individual components or whole product systems (McAloone and Pigosso, 2017). We reported a research case study in which DfSB has proven to be enhanced by intersecting the use of data with other participatory tools.

leedr
Low Effort Energy Demand Reduction

LEEDR (Low Effort Energy Demand Reduction)
University: Loughborough University, UK
Websites: http://leedr-project.co.uk
LEEDR is a 4-year research project that seeks to situate and understand domestic energy consumption within the context of families' everyday lives and routines. This project investigates how people could make changes in their everyday lives to address the problem of energy demand. The study involves ethnographers, engineers and designers that co-design everyday environments, technologies and activities that help people to consume less energy. They attempt to link perspectives and data from the social sciences, engineering and design, creating new and adapted existing design practices and tools, exploring and designing how people live and how the energy consuming activities are part of their lives. LEEDR addresses complex mesh of activities and routines in which one problem is embedded, rather than focusing on the problem in isolation. The aim was to facilitate new ways of doing things or make old ways of doing things more efficient. They began by studying the intersections of 'people, objects and resources through time and space' (Energy & Digital Living, 2014) as they emerged from detailed ethnographic narratives based on everyday activity visits, and about households' corresponding energy data. This project meshes qualitative data with quantitative ones, to provide new insights from their intersection. Within given narratives, they applied 'freeze frames' to study intersections more in detail, exploring how data became meaningful or relevant within situated moments (Wilson et al., 2014).

<u>5) Object orientated approach</u>

Other approaches investigate using objects and co-ethnographers as a tool for designers. To apply the criteria defined by Giaccardi et al. (2016) described in chapter 3, to the fridge, this device could be regarded as a static object which does not move but contains many products that move from inside to outside, changing environment (outside the fridge) and position (within the fridge) according to the meal, the person who takes the items and puts them. An interesting experiment would be to trace how these objects move, how they move inside the house, where they move when they leave home. On the other hand, refrigerators ‘make time’ only when the user is waiting for something to become cold (desserts, dough, drink). A refrigerator, instead, does not ‘fill time’.

6.4.5 Case studies

The case studies session aims to investigate either conservative or disruptive scenarios (from the redesign of the current solution, up to promote new scenarios and paradigm shifts). In the section case studies, we addressed heterogeneous projects, with the common denominator of being systems for food conservation, who have reinterpreted the concept of fridge detaching from the fridge-totem.

IKEA CONCEPT KITCHEN 2015 - STORING VISUALLY
Companies: IKEA (client), IDEO (coordination)
Designers: Vleer Doing, Vincent van Rheden, Rob van Kasteren Industrial Design, Eindhoven University of Technology
Year: 2016
Country: The Netherlands
Website: www.conceptkitchen2025.com | www.vincentvanrheden.nl

IKEA and the Students at the Eindhoven University of Technology offers a glimpse into the future in which sustainability will become increasingly important. They believe that fridges will become obsolete in the future due to their energy inefficiency. The concept of a modern pantry replaces the fridge-totem making food visible, using materials that are naturally insular, such as cooling ceramic. Groceries could be purchased on a daily basis, delivered on demand by drone. Near-instantaneous food delivery from autonomous vehicles and drones means the end of the weekly shop so that the user will store less, but what is stored will be of better quality.

Fig. 36- Ikea concept kitchen 2015 - Storing visually

ALL ANOTHER FOOD
Studio: Next Design Innovation
Designers: Carola Desi Manzoni, Chiara Gattuso, Ilaria Ventrucci
Year: 2016
Country: Italy
Website: http://www.nextdesigninnovation.it/progetti/all-another-food/

It is a modular food storage cabinet that uses Peltier Cell technology, a small-sized thermoelectric device that acts as a heat pump and, when integrated into a ventilated system, creates cold and warm environments. This new type of product, allows the user to eliminate the refrigerator totem, integrating the functions into the home environment. It should help the user to gain more awareness about food freshness.

Fig. 37- All another food

FRIDAYPROJECT – FOOD STORAGE
Studio: Next Design Innovation
Designers: Valentina Raffaelli, Luca Boscardin
Year: 2013
Country: The Netherlands
Website: http://www.fridayproject.it/FOOD-STORAGE

This project aims to avoid stacking food in the refrigerator. This furniture gives a proper space to the food and organises it with an educational purpose. It is based on the principles of the food guide pyramid: it gives more space to what should be eaten more, and less to other products. It displays the food, pushing people to create recipes with what they see and combine what the user has available at hand. There are appropriate spaces for cereals, pasta and bread, a drawer for the vegetables that need to be in the dark and a terracotta box to conserve products out of the refrigerator. There is additional space for eggs, spices, herbs to dry, legumes, organised with a specific order and logic.

Fig. 38- Fridayproject – Food storage

OLTU
Studio: -
Designers: Fabio Molinas
Year: 2013
Country: Spain
Website: http://www.fabiomolinas.com/oltu/

OLTU takes advantage of the dissipated heat produced from the back of a fridge, which consists in wasted energy, and uses it for cooling the vegetable containers by evaporation. The heat rises and makes evaporate the water contained in the twin-walled terra cotta evaporative cooler, producing a decrease in temperature. Part of its functioning does not depend on energy. This project promotes alternative behaviour than putting everything in the fridge.

Fig. 39- Oltu

SAVE FOOD FROM THE FRIDGE - SHAPING TRADITIONAL ORAL KNOWLEDGE
Studio: Jihyun David
Designers: Jihyun Ryou and David Artuffo
Year: 2012
Country: Korea
Website: http://www.savefoodfromthefridge.com

This project benefits from oral knowledge about vegetables and consists in a set of 'knowledge objects' to keep the fruit and vegetables outside the fridge. Besides being an energy-free storage method, the designer claims this would also enhance food flavour. It invites people to observe their food ingredients, understanding their needs. Ethylene production of apple: since apples emit ethylene gas (which has the effect of speeding up the ripening process of fruits and vegetables kept together with apples) they combine apples with potatoes. This combination is supposed to prevent potatoes from sprouting. Since potatoes last longer when protected from the light, they are kept inside a container that exchanges ethylene with apples. The porosity of eggs: eggs absorb the odour, resulting in bad taste if they are kept in the fridge with other food ingredients. This shelf provides a place for eggs outside the refrigerator, and the user can check their freshness in the water. The fresher they are, the further they sink. Fruit vegetables: peppers, courgettes, and aubergines, for example, are considered as vegetables, while they are biologically fruits which benefit from moist storage, rather than the cold and dry environment in the fridge. This project keeps these vegetables fresh on a shelf outside the refrigerator that integrates a water container. Root vegetables: carrots and leeks last longer when kept upright in the slightly damp sand, mimicking their growing conditions. It allows the organism to save energy and remain fresh longer. Designers translate this feature into a container with sand, that helps to keep the proper humidity and allows the vertical position.

Fig. 40- Save food from the fridge - Shaping Traditional Oral Knowledge

LARDER - MICROBIAL HOME SYSTEM
Company: Philips
Designers: John Arndt and Wonhee Arndt
Year: 2011
Country: The Netherlands
Website: https://www.90yearsofdesign.philips.com/article/67

This project is part of a larger system called Microbial Home, designed by Philips. Larder, ideed, is the sub-system designed to keep fruit and vegetables (i.e. 'living food') fresh, by using natural processes (as opposed to dead food in the refrigerator). Larder consists of an evaporative cooler and vegetable storage system built into a dining table. With a double walled evaporative cooler made of clay at its centre, the compartments and chambers vary in wall thicknesses and volumes and are designed to keep different types of food at different optimal temperatures. The outer surface of the cooler is warmed by hot water pipes, which have been pre-heated by the methane digester in the Microbial Home system.

Fig.41- Larder - Microbial Home System

FLOW 2
Studio: Studio Gorm
Designers: Studio Gorm
Year: 2009
Country: USA
Website: http://www.studiogorm.com/new-gallery-1/

Flow 2 is a living kitchen where nature and technology are integrated into a symbiotic relationship, processes flow into one another in a natural cycle, utilising energy, waste, water and other natural resources. It is a kitchen where food is grown, stored, cooked and composted to grow more food. A vertical dish rack allows water drips from drying dishes to fall onto herb garden. The double walled box keeps food cool through evaporative transpiration of water through the porous clay. These boxes take advantage of the porous properties of clay to help preserve bread, grains and root vegetables. Worms compost food and paper scraps into a nutrient-rich, soil-like, fertilizer (casting), pulling the lever sifts finished compost into the collector tray. Finished castings can be dried and stored until needed

Fig. 42- Flow2

FRIA
Designers: Ursula Tischner
Year: 1994
Country: Germany
Website: --

The refrigerator Fria, designed by Ursula Tischner in 1994, is meant to be installed permanently (Vezzoli and Manzini, 2008). She came up with embedding an adapted fridge into the building design, integrating the pre-designed cooling space (traditional pre-fridge cooling chamber) with the natural ventilation of the northern wall, which cooled the freezer, fridge and cool-storage compartments. It was calculated that in typical German house it could work for about 3-5 months a year without consuming energy (Vezzoli and Manzini, 2008). As soon as the external temperature is low enough, the cold air cools the FRIA, requiring just a small fan to draw air through the filtering system, rather than a complete cooling system. FRIA is also a long-term domestic appliance since every part can be replaced thanks to the fridge's modular design. FRIA is supposed to use at most half the energy of a modern refrigerator. Moreover, there is no CFC usage and energy waste, up to 80% in a standard fridge, is removed through FRIA's integration into the building. This project used alternative sustainable materials such as blown concrete, cork or recycled paper, replacing steels and plastics (Fourth Door, 2013).

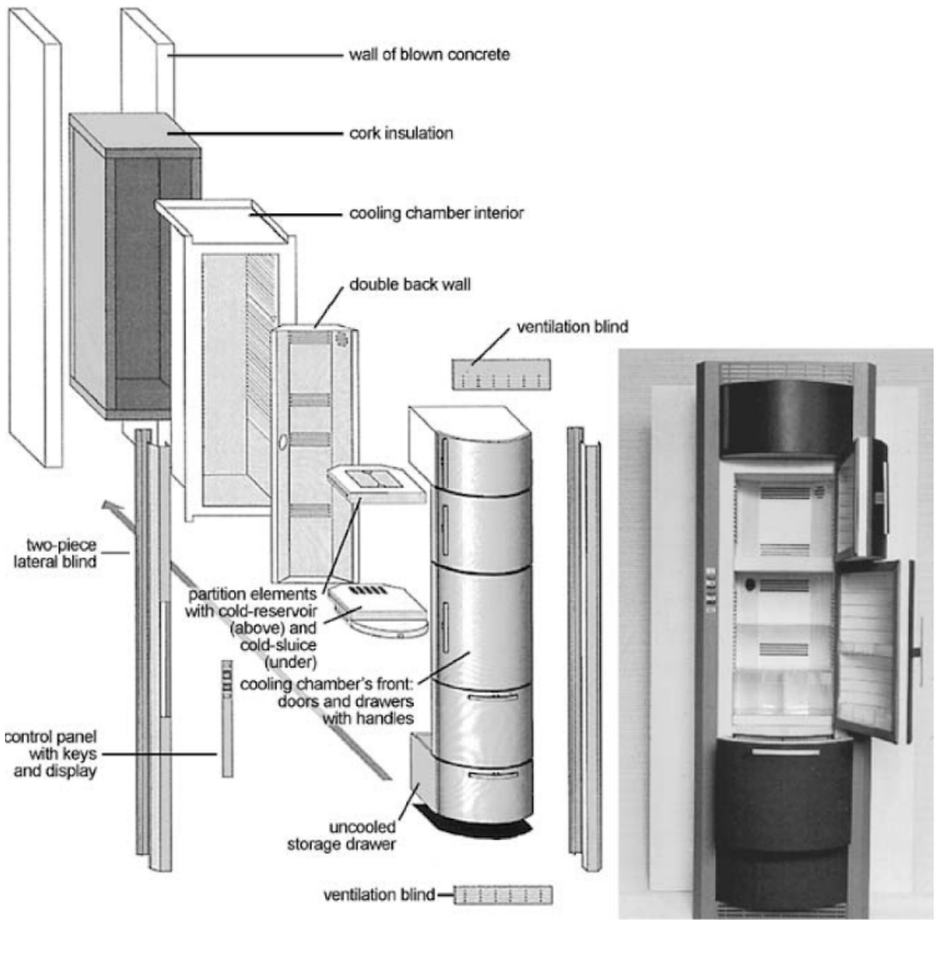

Fig. 43- Fria (Vezzoli and Manzini, 2008)

Remarks
The case studies collected provide us with some interesting guidelines to keep in mind in the design phase, which can be summarised as follows:

FOOD-RELATED

1. Separate food items according to their features, by keeping different types of food at different optimal temperatures.
2. Investigate food properties and specific needs (e.g. keep 'living food' fresh)
3. Investigate other ways of preserving food, that do not need to cool it (growing, drying, processing)

USER-RELATED

4. Make food visible;
5. Change food purchase habits;

PRODUCT-RELATED

6. Consider modularity and upgradeability;
7. Use natural and low-impact materials to perform some functions (e.g. use materials that are naturally insular);
8. Consider built-in solutions;
9. Establish symbiotic relationship with other object, components, systems inside the kitchen, utilising energy, waste, water and other natural resources;
10. Using cold air instead of refrigerants. Consider alternative technologies or low-tech solution to decrease the temperature;
11. Exploit side effects such as heat dissipation from evaporative cooling.

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Chapter 7

Analysis of current products through data gathering

In the previous chapter, we investigated the refrigerator in the current scenario, addressing main issues related to the environmental impact of this object, associated with the use of materials and refrigerants, as well as to the refrigerator operation, or deriving from the usage phase, and therefore in relation with the user. Moreover, we investigate alternative scenarios, through case studies and research projects. In this chapter, instead, we go through the analysis of current products more in detail. As anticipated, the design stage needs timely data related to household habits and behaviour. However, the designer usually does not have a privileged point of view, nor the complete view about the object to design and he/she would require relevant data that are currently not available (Figure 44).
Every design task is characterized by a huge amount of missing information, both unavailable and undeterminable. Part of the design process is spent to obtain this information by doing research in the preliminary design stages. But some pieces of information are user-specific, related to experience, the use of the product, others are expected, assumed, foreseen or random, then they have to be tested and evaluated. (Negroponte, 1970).
In this chapter, we will also discuss the product requirements to complete the

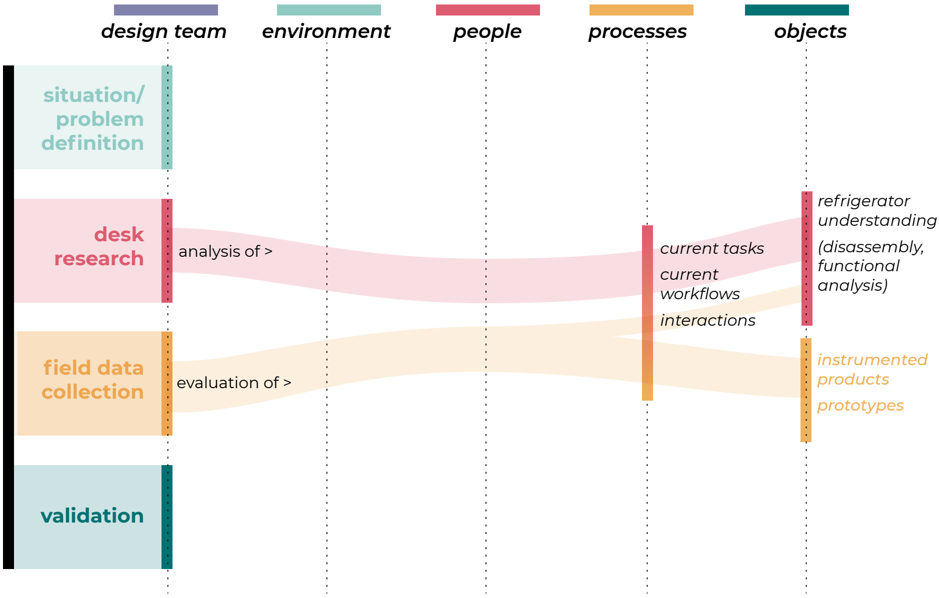


Fig. 44 - Methodology with a focus on current product and processes

picture about pre-requirements, while at the end of the chapter we will see how to leverage the power of IoT data for product design, thus highlighting the need for a platform of interaction between stakeholders, that can put in relation different types of data (feedback, questionnaires, interviews, IoT measurable data, etc.), combining, matching them to derive valuable information.

For simplicity, in this first step, we divided the data into static and dynamic. By static, we mean objective information that can be schematized, calculated and measured at any time. The same process can be carried out on different products, in order to compare these data. The level of complexity of this information is limited and static data are relatively easy to obtain. On the other hand, the information deriving from the operation of the system is catalogued as dynamic data, because they have the same rules that govern the system. If the system is complex, this information is subject to variability, changing over time, evolving as the system evolves. Complexity is also determined by the fact that a human being alone is not able to manage and process them, both in terms of complexity and volume. In the case of introducing sensors inside an object which collects data continuously, even if data collected are not complex at all, the volume collected would prevent a human to process them. The fridge at present is not considered a complex system, while the fridge equipped with sensors, able to gather information, collect and manage user feedback and learn from them becomes a considerably complex system. The first step towards product innovation could be understanding current products and current uses of them. Part of this knowledge has already been acquired in the previous chapter. However, knowledge can be acquired and leveraged by investigating the static and dynamic data of a refrigerator, and this chapter is focused on understanding how. Keeping this in mind, we proceed to the results section, to understand how we can move from considering the refrigerator to addressing a system of objects, contexts, processes, people and their interaction.

7.1 Static data

Many areas of investigation, design tools and methods can be grouped under the definition of product design. This section, however, synthesises some approaches used to build the part of the methodology that investigates current products and how the analysis of the 'static data' was conducted. Therefore, this section takes a step back on lifecycle methods used for redesign activities. For Design for Sustainability and life cycle thinking, we refer to chapter 4.

7.1.1 Design for X

In the last decade of the previous century, some pioneering companies experienced the benefit of

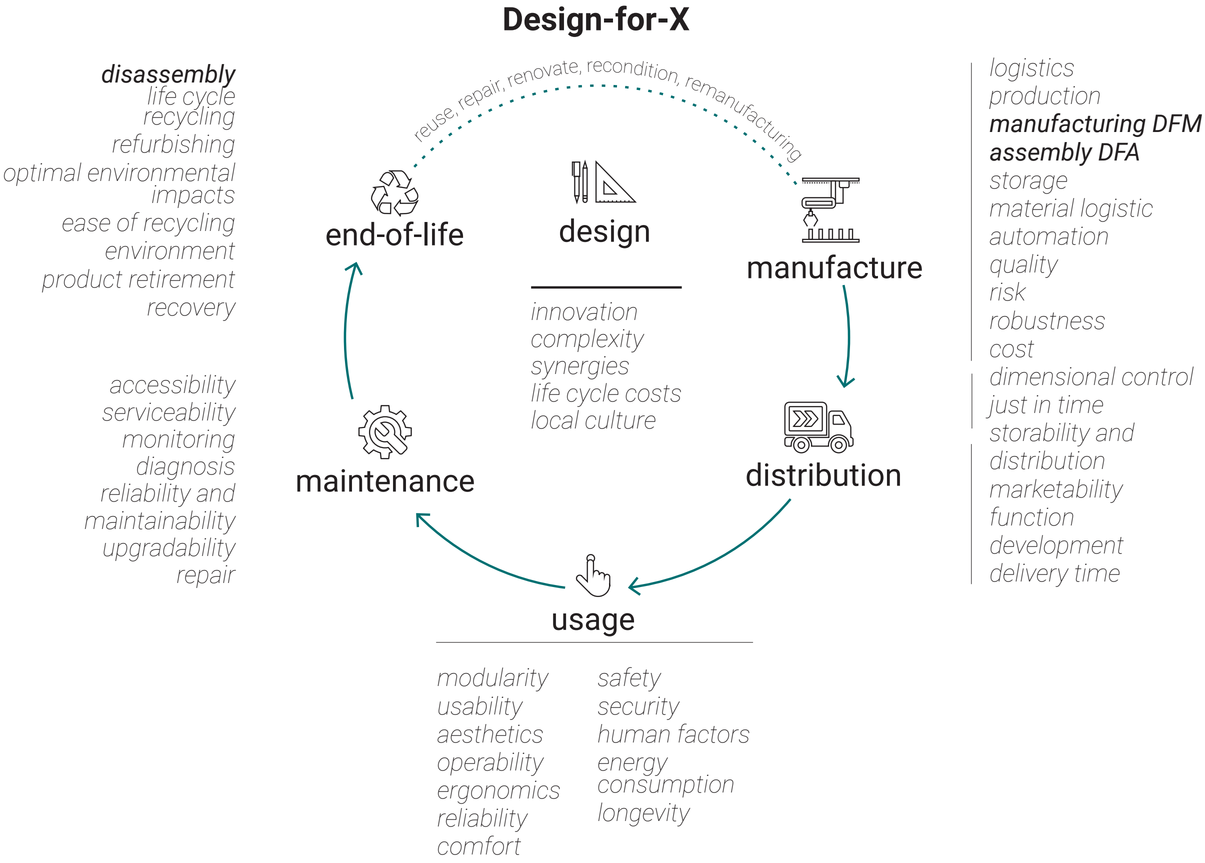


Fig. 45 - DfX methods collected from George G.Q. Huang, 1996 and Udo Lindemann, 2007, placed within the product life-cycle

working in multidisciplinary teams, starting to adopt generic approaches and methodologies that include design requirements such as quality, reliability, environment, and so on (Urrutia et al., 2014). Concurrent engineering is an expression used to define a life-cycle design method to increase design efficiency, optimise costs, reduce development time, and improve product performance. This approach uses several tools that fall under the broader concept of Design-for-X (DfX), where 'X' refers to different properties related to one or more aspects of the process. Despite some companies continued to focus on cost reduction (Urrutia et al., 2014), many others addressed more complex aspects such as production, assembly, maintenance, environment, obsolescence and recyclability (Chiu and Okudan, 2010), supporting their decision-making with tools able to perform analysis and measuring performances, resulting from the design choices made. I decided to place the DfX methods and tools highlighted by George G.Q. Huang (1996) and Udo Lindemann (2007) within the life cycle of a product (Figure 45).

We find that some of the DfX methods about usage, mainenance or end-of-life are currently employed in other approaches, such as Circular Product Design (den Hollander et al., 2017.), e.g. design for longevity (emotional or physical durability), design for maintenance, design for upgrading and EoL (e.g. repair, remanufacture and refurbishment). As Bakker et al. (2014) claim, current 'Design for X' tools and methods should be revitalised and, in general, we should not forget them when we design.

7.1.2 Disassembly methodologies

Design for Disassembly has been a hot topic in academic research since the first studies started more than two decades ago. It has been studied and it is currently studied from different points of view,

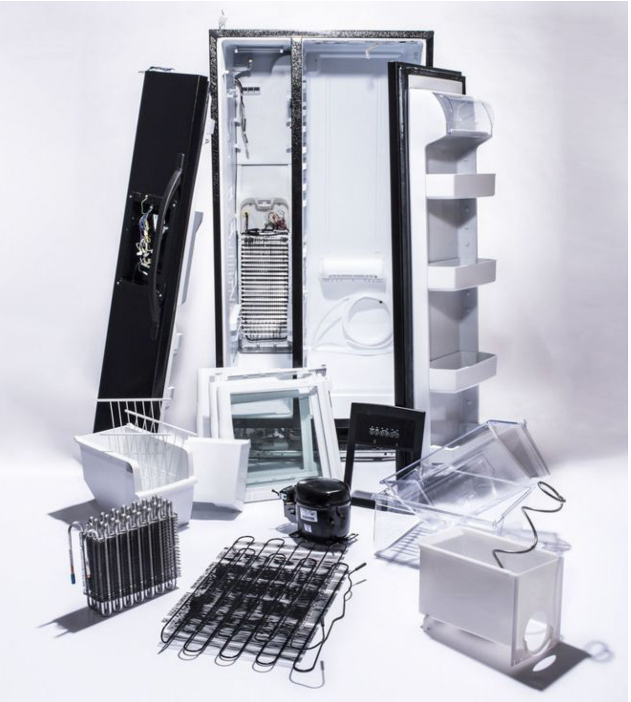


Fig. 46 - Refrigerator components
Source: Josh Scott Photo http://www.joshscottphoto.com

Fig. 47 - Refrigerator minor components
Source: Josh Scott Photo http://www.joshscottphoto.com

such as selective disassembly, disassembly sequence planning or even virtual reality simulation (Movilla et al., 2016).

We should not forget that:

> *design knowledge resides in products themselves [..] Much everyday design work entails the use of precedents or previous exemplars – not because of laziness by the designer but because the exemplars actually contain knowledge of what the product should be.* (Jonas, 2007)

These methods, therefore, serve to extract knowledge from physical objects.

7.1.3 Reverse engineering

If we consider the product analysis, disassembly procedures such as product teardown (Hanft et al., 1996) and reverse engineering (Otto and Wood, 1998) are two common methods to deconstruct an object and understand its functioning through the analysis of its parts. While disassembly procedures are used for end-of-life purposes, reverse engineering is more focused on the redesign of a device or a component, understanding its operation, design and development to redesign or improve it. These two methods are often combined (Otto and Wood, 2001), taking apart components and analysing their operation in detail, usually with the goal of redesign a different product, by learning from competitors (Figure 46 and 47). On the other hand, test and simulations by manufacturers are performed to ensure the reliability of the product or its components.

7.1.4 Design by Component

Design by Component looks at the product as an interconnected and complex system of interrelated components (Bistagnino, 2008). This approach follows some fundamental guidelines such as:

- design products that can be easily disassembled;
- ensure uniform obsolescence of materials and components;
- ensure the possibility to replace parts over time;
- design simplified functional units

In this way, the outer shape should derive directly from the function to perform (form follows function). Moreover, this approach encourages the development of custom products able to meet specific needs.
According to this approach, complex products should be studied at present and then reduced to functional units, redesigned according to the desired activities and functions.

7.1.5 Product requirements

Focusing on the product, herein requirements derived from the approaches addressed above and from Munari's Good Design (Munari, 1997) (Figure 48), highlighting the tight boundary between product and service design. Several requirements are grouped under the broader categories 'resistance' 'management and maintenance' and 'integration and upgradability'.

A first step towards product redesign (and possibly towards innovation) could be understanding current products and the current use of them. To gain more insights, we should investigate how a current refrigerator works, through its disassembly, the study of its components and the functional analysis. Static data comprehend the technical material, such as drawing and model for studying current shapes and dimensions, bill of materials (BoM) to understand how many different materials are involved, the related weights, questioning why designers chose that material (i.e. are there any physical- functional-performance reasons behind one choice?).

7.2 Static Data - refrigerator

7.2.1 Disassembly

Part of this analysis consists in physically disassembling the product into its components (Figure 49)[16], to understand how the product and single components work, the ease of performing the disassembly and the tool needed (Figure 50). Understanding how a refrigerator is made is important not only because of its content on hazardous substances but also because refrigerator contains significant quantities of recoverable materials, such as metals, as addressed in chapter 6. It is considered as a necessary step to retrieve valuable information for both product redesign/optimisation and the design of new products, to orient the design activity towards the minimisation of the environmental impact of products (Movilla et al., 2016). Nowadays the inclusion of disassembly requirements in product design is still more of an exception than usual practice, and no incentives for applying Design for Disassembly approaches are provided. For this reason, policies could turn into good incentives to

Fig. 48 - Product requirements: resistance, management and maintenance, integration and upgradability.

Fig. 49 - Leibherr exploded view of their fridge, with the finished product on the right
Source: http://laundry.reviewed.com

improve product disassembly through the inclusion of 'push' (mandatory) and 'pull' (voluntary) measures (Movilla et al., 2016). Deconstructing and analysing current products is fundamental to understand how they work. Refrigerators today consist of several basic components: an exterior cabinet including the door, an interior cabinet, insulation between the interior and exterior cabinets, the cooling system, the refrigerant, and the fixtures (Wilson, 2016). As we partially mentioned in chapter 6, when we dealt with the environmental impacts of the material used, we can group the components based on their materials and related production processes as follows:

- The **inner** and **outer cabinets**, as well as the door, tend to be made of metal (aluminium or steel, sometimes lacquered or stainless). The metal is generally purchased in a coil that is either fed directly into the manufacturing process or cut to size and fed sheet by sheet. Sometimes the inner cabinet is made of plastic (Marton, 2006).
- The **insulation** consists of fibreglass or poly-foam, made primarily from types of plastic called polystyrene or polyurethane (Wilson, 2016).
- The **fixtures** in refrigerators consist mostly of thermoset plastic, which cannot be recycled (Wilson, 2016). Almost all the large interior fixtures (door and cabinet liners) are made from vacuum-formed plastic; smaller fixtures (butter compartments, egg trays, salad crispers) are purchased as small plastic blanks

16 components are parts or elements of which the object is composed. Obviously, all artificial physical things are made from other things. These other things might be given, or also are composed of components (Ralph and Wand, 2008).

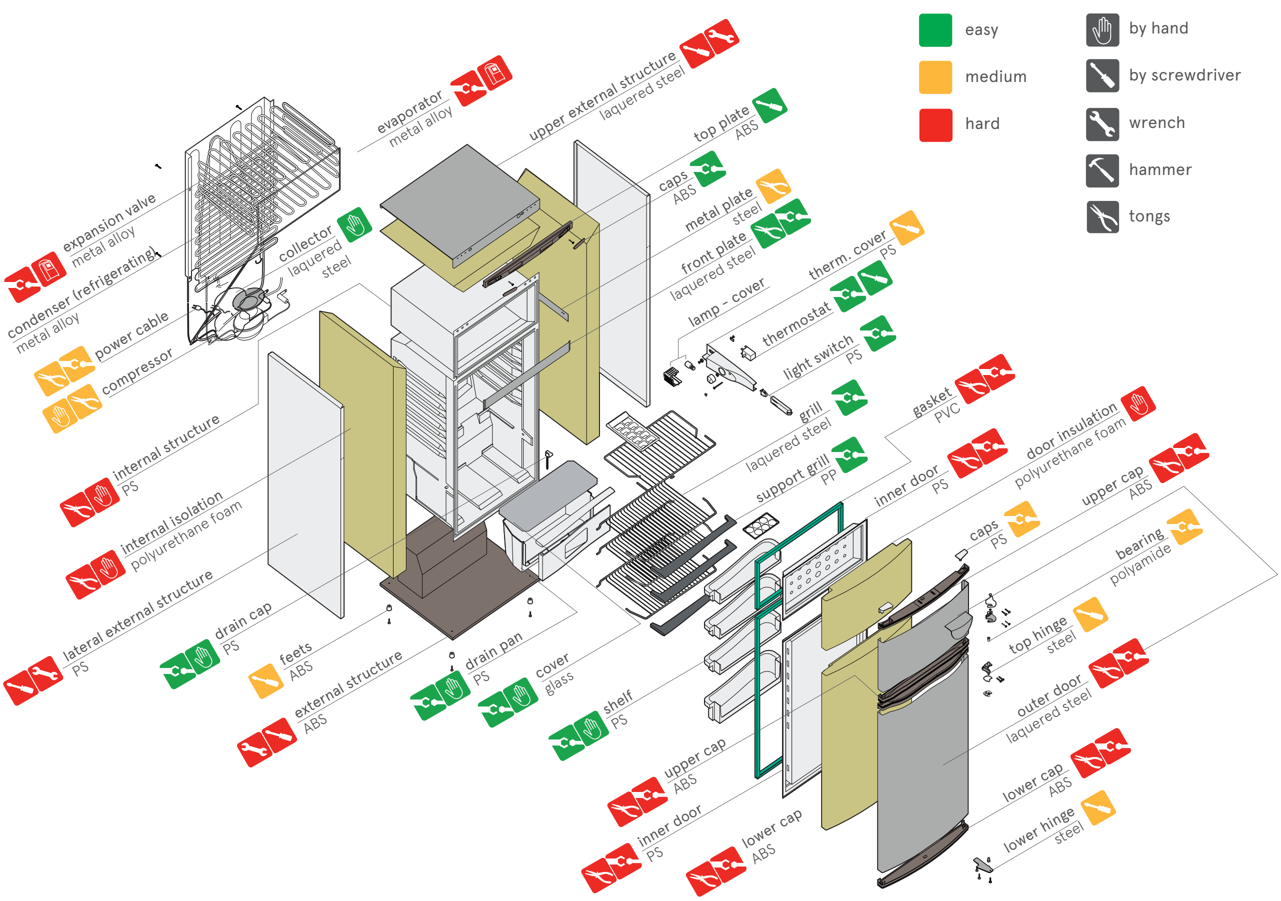


Fig. 50 - A refrigerator disassembly. The product is broken down into its single components.

or in pre-formed pieces (Marton, 2006).

- The components of the **cooling system** (compressor, condenser, coils, fins) are made of aluminium, copper, or an alloy. The tubing is usually copper, because of that metal's ductility—its ability to bend without breaking. Liquid refrigerant under high pressure enters the evaporator (made of aluminium tubes) where it absorbs heat from the inside of the refrigerator (and cools it down in the process). In the process of absorbing heat, the liquid refrigerant evaporates into a gas and then flows into the compressor (made of steel) where it is compressed into a high-pressure gas. The high-pressure refrigerant gas then passes to the condenser (the copper coils outside the refrigerator) and cools back to liquid form. From the condenser, the liquid refrigerant enters the evaporator, and the cooling system cycle starts all over again. (Wilson, 2016)

Figure 51 shows single components coupled with their materials, reporting for each one if its disassembly is easy, medium or difficult to accomplish and the tools needed. Below, instead, the components were grouped by material, establishing how many connections are reversible or not, how and how many components are made of materials that are irreversibly combined. We have also defined parts that are outsourced and not produced by the appliance industry. For a breakdown of weights and percentage of materials, we refer to chapter 6, p.101.

7.2.2 Accessibility

On the same exploded view of the refrigerator, we can perform the accessibility analysis (Figure 52), by considering the ease of accessing each part for maintenance and replacement purposes. Even in this case, the colours indicate if the task was difficult, medium or hard to perform.

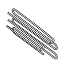
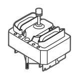
Although shapes and features of refrigerators differ,

COMPONENTS	MATERIAL
evaporator	metal alloy
condenser	metal alloy
expansion valve	metal alloy
cover vegetables	glass
contour grill	PP
metal plate	steel
hinge	steel
bearing	polyamide
mask	laquered steel
collector	laquered steel
door exterior	laquered steel
exterior structure	laquered steel
grill	laquered steel
gasket	PVC
interior door	polyurethane foam
internal isolation	polyurethane foam
mask top	ABS
caps	ABS
external base	ABS
socket mask	ABS
cap	ABS
leg	ABS
cap defrosting	PS
basket bowl	PS
shelf	PS
door interior	PS
big caps	PS
cover thermostat	PS
light switch	PS
internal structure	PS
total weight	70 kg

Fig. 51 - Bill of Materials

Joints	
reversible	16
irreversible	30
Materials	
n. different materials	10
n. assembled materials	4

ENGINE AND CONNECTIONS

	1 bulb 15w
	Cooling gas coil
	1 compressor 270 kWh/annui
	1 m electrical cable 220-240 volt

we could consider that most domestic refrigerators present a similar structure and characteristics and, hence, similar disassembly processes. The goal of the disassembly study is gaining knowledge about current components, relative weight and materials and then perform the functional analysis. Herein, this study is not intended to be exhaustive, nor providing information on the dismantling activity to manufacturers for improving specific products, although it can be implemented in the future for other purposes. The disassembly time needed for performing the operation of different components was not measured since it would require performing this activity in a recycling facility with experienced treatment operators to obtain meaningful data. Moreover, the economic profit of material recovery has not been calculated, and no comparative studies on a bigger sample of refrigerators were performed, being out of the scope of this dissertation. I chose to use a standard refrigerator as a case study of the disassembly tasks, to provide a procedure that can push designers to reflect on how objects are made, divide objects into simple functions that can reconsidered, question whether current objects are functional (not referring to specific performances and measurable indicators, rather in relation to the functions that have been identified). Therefore, this approach is intended for product designers, although studying the indicators listed above may become the object for further investigations, to be carried out with appropriate data setting and collection.

7.2.3 Functional Analysis

The functional analysis comprises activities that enable the understanding of goals. Functional decomposition of a product represents a way of identifying product's major functional aspects (Alexander, 1964). The functional analysis (Figure 52) allows to group components into functional units abstracting from the fridge concept by defining four

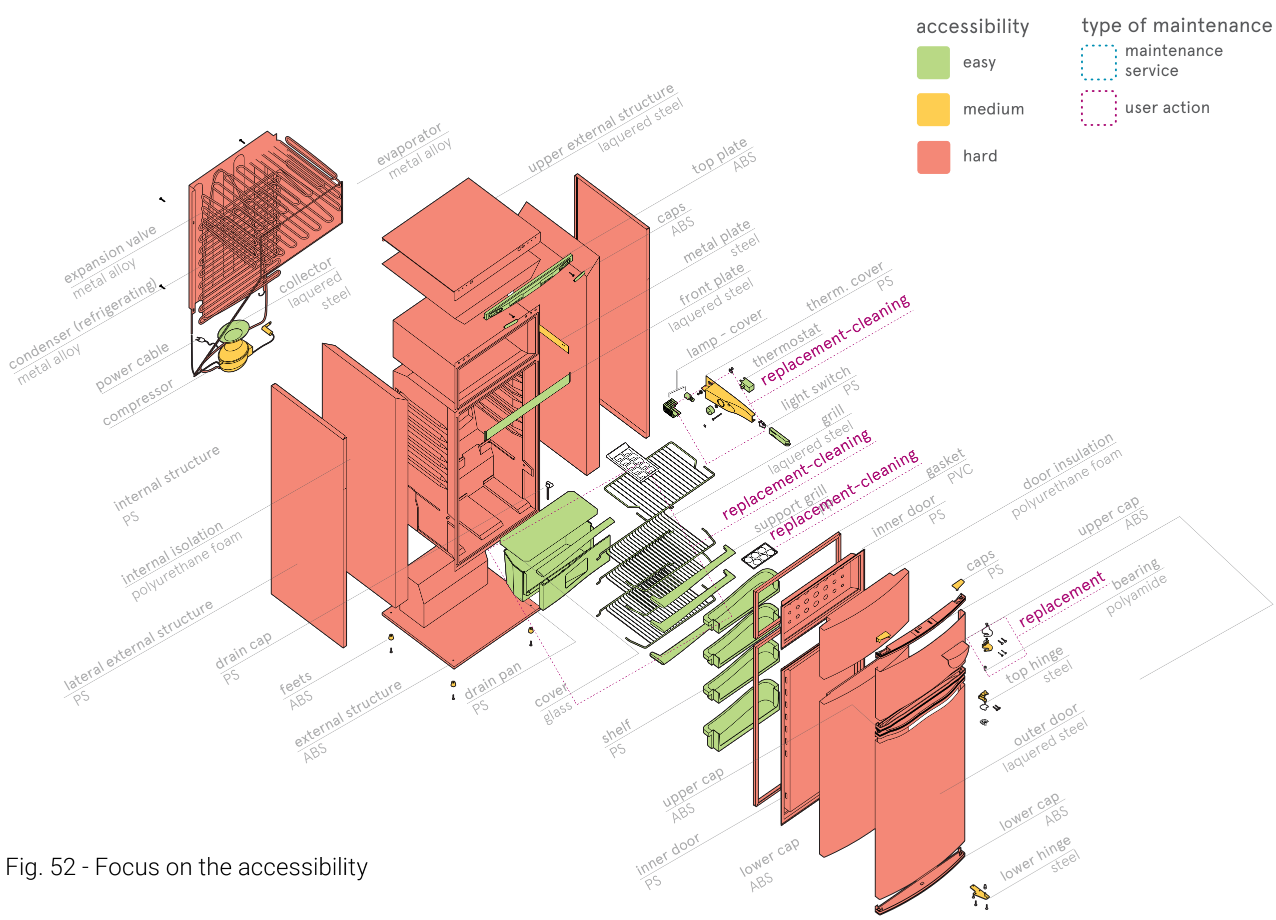


Fig. 52 - Focus on the accessibility

functions which are related to the task *'store the food shopping at the right temperature'*:

1. **Cool down**, through a cooling system or refrigerator unit we need to obtain a temperature drop;
2. **Keep cool**, i.e. maintain the temperature obtained through the insulation system and some components that provide the containment structure.
3. **Organize foodstuffs**, which includes component designed to provide shelves and containers and a structure on which to place them
4. **Access foodstuffs**, e.g. easily pick things from the inside.

This analysis helps to identify specific functions, understanding which parts are needed to perform that function.

Hansen et al. provide an inspiring definition of abstractions referring to:

> *The ability to glean the essence of something from specific instances. In this abstraction enables designers to induce essential elements or processes from specific statements about the application domain and problem space. This helps to ensure that information which enters the specification is essential rather than idiosyncratic, and offers a sound baseline for design* (Hansen et al., 2009).

Herein, the concept expressed is very similar: gleaning the essence of what is essential to shape something new. For each function, there is already a 'current solution' in the current product, but we could provide alternatives for each functional group of the current product to design new and optimised products. For example, to perform the 'cool down' task, we currently use a condenser, a compressor, coils and so on. In this perspective, we would more generally need a 'cooling system or a refrigeration unit', which leaves room to many other solutions for that task (e.g. using Peltier system or traditional pot in pot solution), according to the temperature goal we want to reach, which should not be uniform varying according to the foodstuff we want to store, or integrating different solutions. The second task is 'keep the temperature obtained', through the

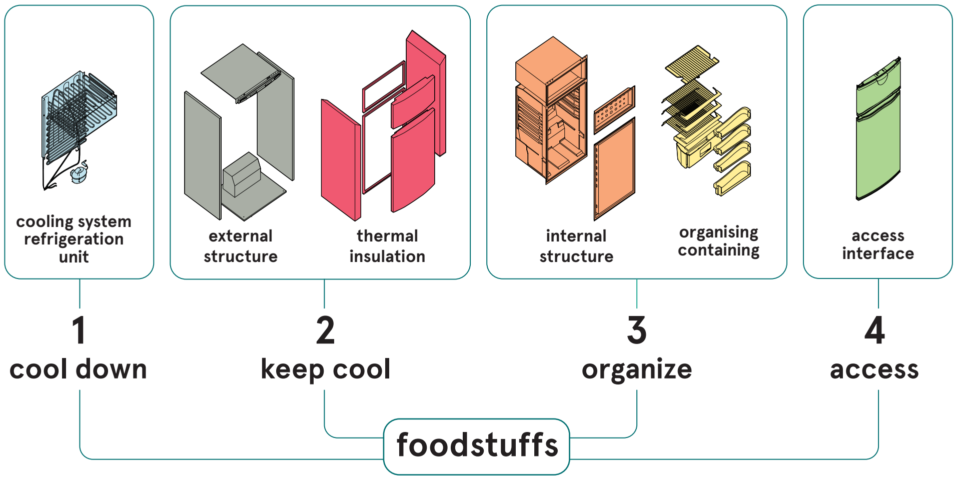


Fig. 53 - Functional analysis

insulation and a box to contain the components, the external structure. Then, 'organize foodstuffs', which includes some components specifically designed to provide shelf, containers and so on and a structure in which to place them. The last function is 'access foodstuffs', in the current product there are two doors.
During this analysis, we do not intend listing all possible current solutions. Rather we seek to provide the maximum simplification and abstraction (essential scheme), able to foster new design ideas.
Further on, in this chapter, we address the importance of building multidisciplinary design teams, combined with the potential for the use of data for design purposes. This approach leaves room for addressing every step of the traditional life-cycle in a more circular way, shifting the focus from the life-cycle centrality of the previous century to a more complex vision about the product. This scenario could radically change by introducing new strategies and business models such as strategies to reduce product ownership through sharing, remanufacturing activities and so forth (Figure 54)

7.2.4 Remarks

Herein, a method for a 'reverse design' is presented. It should guide the designer to extract valuable information from a physical object to redesign it. It can be performed on every object having the possibility to disassemble, measure and observe it. These considerations should help designers to question, understand, reconsider every part (or group of parts) of current objects and their functions, individually or by grouping them. This process leads to define the performances of the product. It also allows members of a design team to focus their efforts on manageable tasks. Moreover, it breaks a large design into its composite subsystems and supports designer's ability to explain and predict outcomes. Decomposition lies at the heart of contemporary advances in modular design (Hansen et al., 2009).

7.3 Dynamic data

Dynamic data are those data which vary over time, deriving from the context of use and interaction with users, which can be acquired by investigating the object in its everyday environment, with quantitative data acquisition (sensors) and qualitative tools (feedback, questionnaires, interviews). The remaining study emphasises the need to base the decision-making process on concrete data, with a clear overview to leverage this knowledge in the design process

7.3.1 Smart objects as a tool

The ability of an object to 'makes sense of' data and other information is a key indicator of IoT development (Cruickshank and Trivedi, 2017). Indeed, smart objects are more than just sensor nodes; they're interactive tools designed to help people accomplish tasks in the real world (Kortuem et al., 2010). Not only record and interpret sensed data but also give users timely information, for example. While the rise of Cyber-Physical Systems (CPS) and the Internet of Things (IoT) offers the opportunity to apply such data-driven processes to physical products only a few steps have been taken towards the real development of meaningful products from data insights. Some pieces of information can be

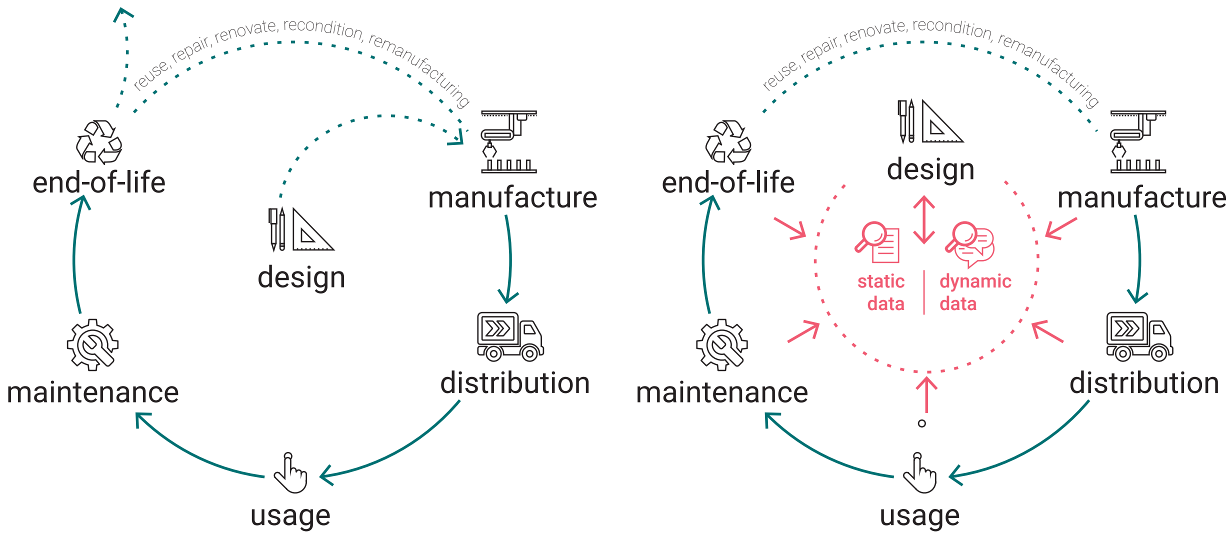


Fig. 54 - From lifecycle to new business models based on the use of data

retrieved from products themselves and their usage data and can be used for predicting whether products are likely to break, or providing feedback to the users. A data-driven approach could lead improving current products and developing new ones, using data as natural part of manufacturer's workflow to better understand products, services and users (Canada, 2015). The IoT diffusion has led, in addition to several other implications, to a renewed interest in data-driven approach fostered by new technologies (e.g. using IoT data in product design). The following step of this analysis is to investigate the refrigerator's behaviour. Beyond question "How does refrigerator work?" is also essential defining what happens when the refrigerator is operating, by monitoring some physical parameters over a continuative period. Understanding the behaviour of the refrigerator as part of household dynamics has been suggested, highlighting a potential innovation at three levels: (i) redesigning the refrigerator, (ii) redesigning a domestic routine in which the refrigerator plays a role such as storing food shopping, preparing, pulling in or taking out food and beverage, eating at home, anticipating meals for the week and (iii) redesigning householders' motivations in its purchase, use and disposal (e.g. savings in energy bill, environmental awareness, etc.). Each level leads to a different set of questions: how can we make an informed improvement? How can the refrigerator anticipate user actions? How do we place the refrigerator within the household dynamics? Which refrigerator behaviours can we leverage to support the householders' lifestyle?

7.4 Investigating the refrigerator's behaviour

Using the refrigerator as a case study, the methodology was implemented through a pilot experiment, highlighting the need for dynamic data related to the real use of refrigerator, i.e. the object in relation to the user. I carried this experiment in cooperation with the Department of Internet of Things at TU Delft, within the Faculty of Industrial Design Engineering, where I spent six months of visiting research. The working team (Figure 55) was therefore represented by me (eco-design background) and a post-doc computer scientist, Jacky Bourgeois. We instrumented two refrigerators[17] over a week with sensors to detect light, energy consumption, inside temperature, humidity and noise, external coil heat dispersion (Figure 56), to understand how these

17 A small and old one (Indesit TFA1 of 2005, 105L, one door and a freezer compartment, Class A) in a Dutch studio (NL experiment) and a large and new refrigerator-freezer (Electrolux RN3453MOX of 2015, 226L, two doors, Class A++) in an Italian apartment (IT experiment). Both refrigerators were in field contexts.

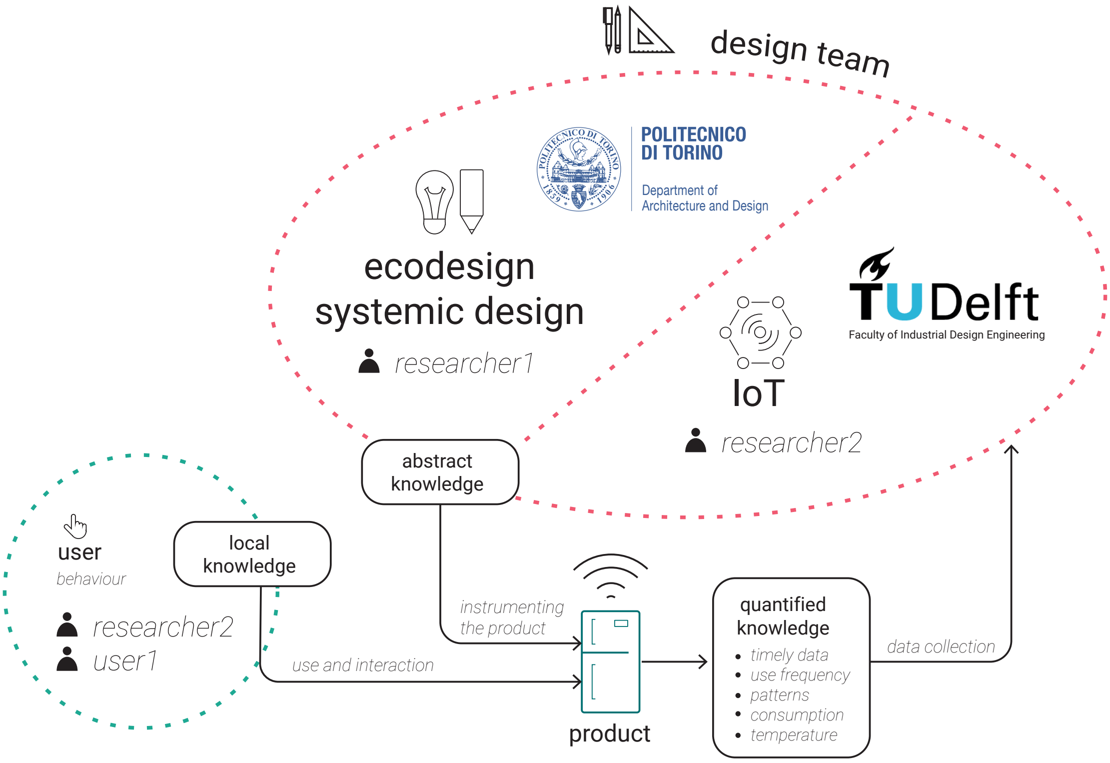


Fig. 55 - Design team for the first experiment

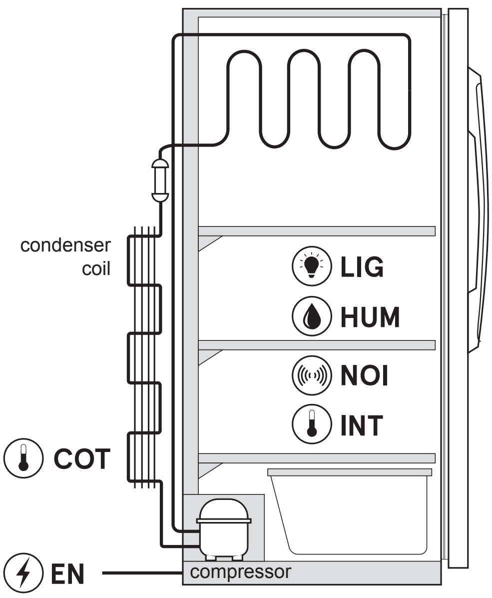


Fig. 56 - Indicators

parameters changed over time and the relationships between them.

7.4.1. Technical information

The set of sensors used consisted of: a NORPS12 light dependent resistor for the inside light (circular sensor), a one wire digital temperature sensor for the coil temperature (black sensor at the end of the wire in Fig. 57), an Electrect Microphone breakout for the inside noise (pink board with the black circle) and a RHT03 humidity and temperature sensor for the insight humidity and temperature (white sensor). After a series of tests on a breadboard, we combined these sensors on a Wireless SD Proto shield plugged on an Arduino Zero (Fig.58). The program deployed on the Arduino collects noise samples every 100 ms and a sample from the other sensors every second, storing data only when a change occurs from the previous recording, thus avoiding redundancy. The shield offers the flexibility to directly solder the sensors, making the prototype easier and faster to develop, while remaining compact and robust enough for the experiment. It also gives the possibility to either store the data on a microSD card or sends them through wireless communication. In these experiments, the prototype was not connected

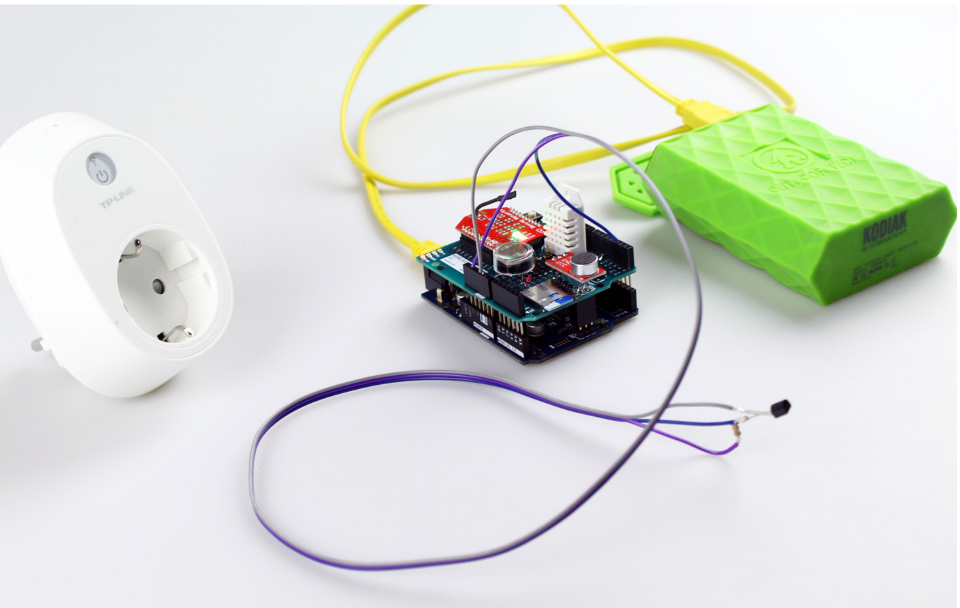


Fig. 57 - Smart plug, prototype with wire for external temperature (coil) and power bank

to the network. We stored data collected from the Arduino into a microSD card. Thus, we needed to carefully note the starting time of each experiment to be able to synchronise the data later on. After each experiment, we extracted the data from the microSD card and used a script to send them into an InfluxDB database with the correct timestamp. We monitored the power consumption with a TP-Link Wi-Fi smart plug HS110 connected between the power socket and the refrigerator. Once connected to a household Wi-Fi network, we used a python script running on a Raspberry Pi to pull the data[18] every second and store them in our InfluxDB database. We used Grafana, a data visualisation tool, to explore the data.

We assumed power consumption as a reflection of the refrigerator's activity and the light as a reflection of user interaction (Figure 59), we combine these two indicators with the other variables and we reflected on the data to extract design insights.

We matched energy and light with several other indicators in two experiments, one in Italy (IT experiment) and one in the Netherlands (NL experiment).

7.4.2 Product-Specific Indicators

The first indicator analysed is the power consumption. It represents the energy footprint of the appliance and its monitoring provides us with useful information.

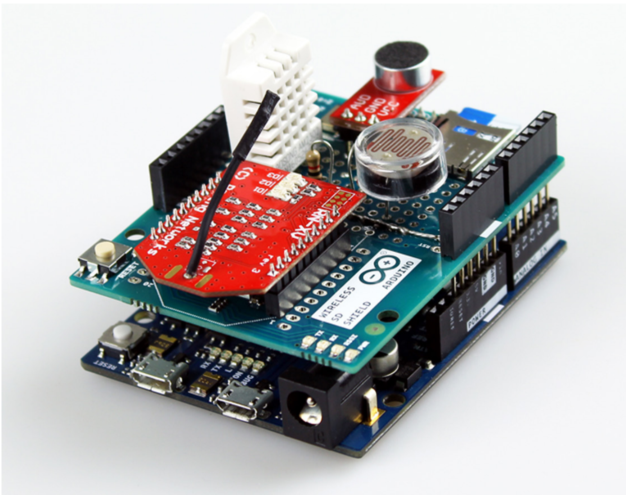


Fig. 58 - Arduino Zero with Wireless SD Proto Shield and sensors

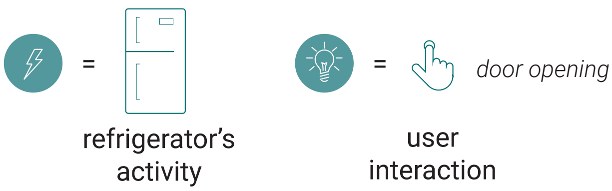


Fig. 59 - Assumptions

18 Script taken from GitHub: https://github.com/softScheck/tplink-smartplug

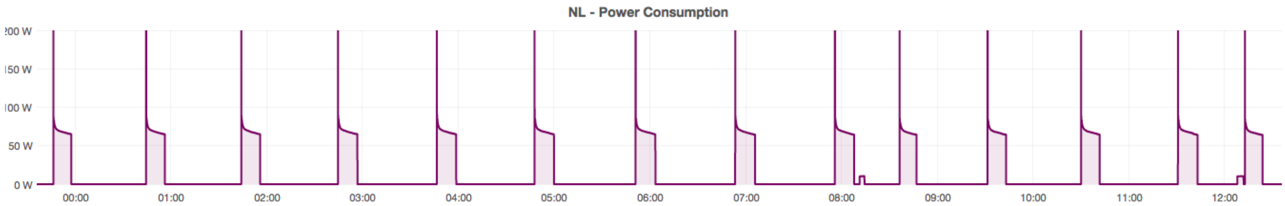


Fig. 60 - Refrigerator’s power consumption over 12 hours. NL experiment (old and small)

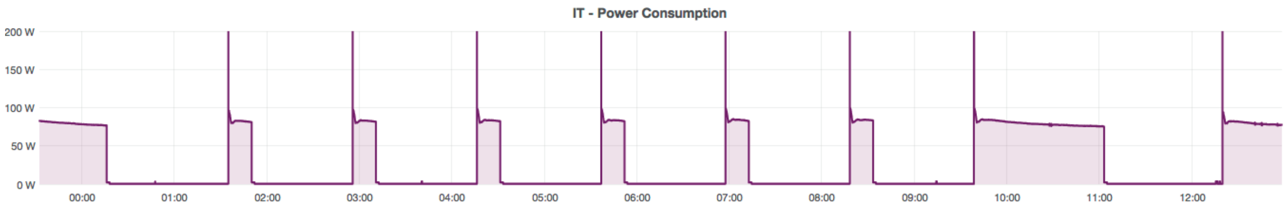


Fig. 61 - Refrigerator’s power consumption over 12 hours. IT experiment (new and large)

Power Consumption and refrigerator behaviour
Figure 60 and 61 clearly indicate the cyclic nature of the energy pattern. Fridge cooling compressor cycles on and off according to the temperature measured inside the appliances, determining a peak in the energy pattern. Pattern varies according to the model of the refrigerator. Older refrigerators like the Indesit TFA1 used in the NL experiment, show shorter operating cycles (Figure 60). Every 50 minutes, the cycle experiences 10 min of activity followed by 40 min of inactivity.
Another refrigerator, the Electrolux RN3453MOX tested in the IT experiment, shows two different types of cycles (short and long ones) less frequent compared to the NL experiment. Short cycles last 80 min (divided into 15 min of activity and 65 min of inactivity,) while long cycles last 120 min (with an ‘on-phase’ of 45 min and an ‘off-phase’ of 75 min) (Figure 61).
The combination of short and long cycles does not follow a defined pattern nor reflect user behaviour. In fact, keeping the refrigerator closed for two consecutive days did not prevent this irregular pattern of short and long cycles.
While the power consumption is a straight indicator of the refrigerator’s activity, other parameters can provide similar or even deeper insights. Figure 62 shows a match between the power consumption and the indicators mentioned above in both IT and NL experiments. We chose to compare these two experiments by setting the same recording time. During 2 hours, the IT refrigerator shows less frequent cycles. We observe that these indicators have a regular and cyclical nature that follows the energy pattern and may provide useful insights. Comparing two refrigerators which differ in age, size and efficiency, raises the attention on how even the other parameters and features vary accordingly.
For instance, the humidity, which is only partially lowered in the NL refrigerator, drastically drops in the second one (35% compared to 50%), when the compressor is working, showing a dehumidifying action or a better sealing. On the other hand, inside temperature experiences a bigger variation in NL fridge, ranging from 8 to 5°C. The delta is lower in the newer refrigerator (from 10 to 9). The cycles are more frequent in the NL fridge, (50 min compared to 80 min of the IT one). Both temperature variation and cycles frequency mean that the temperature in NL refrigerator tends to increase faster, which indicates poor insulation, worse than the IT refrigerator. IT temperatures are overall higher probably because foodstuffs do not benefit from too low temperatures. Instead, removing humidity has been proven to be an efficient way to preserve food. The author believes that these findings contribute to the choice to increase the over-temperature while cutting down the humidity. Considering the noise parameter, it can be noticed that the refrigerators of the past were noisier during the compressor’s ‘on’ phases. While we are sure that old fridges activate the compressor when a critical temperature is reached, we are not sure whether for the new ones is the same, or they record a combination of temperature and humidity which indicates when to activate cooling cycles. Looking at the energy pattern, we can assume that

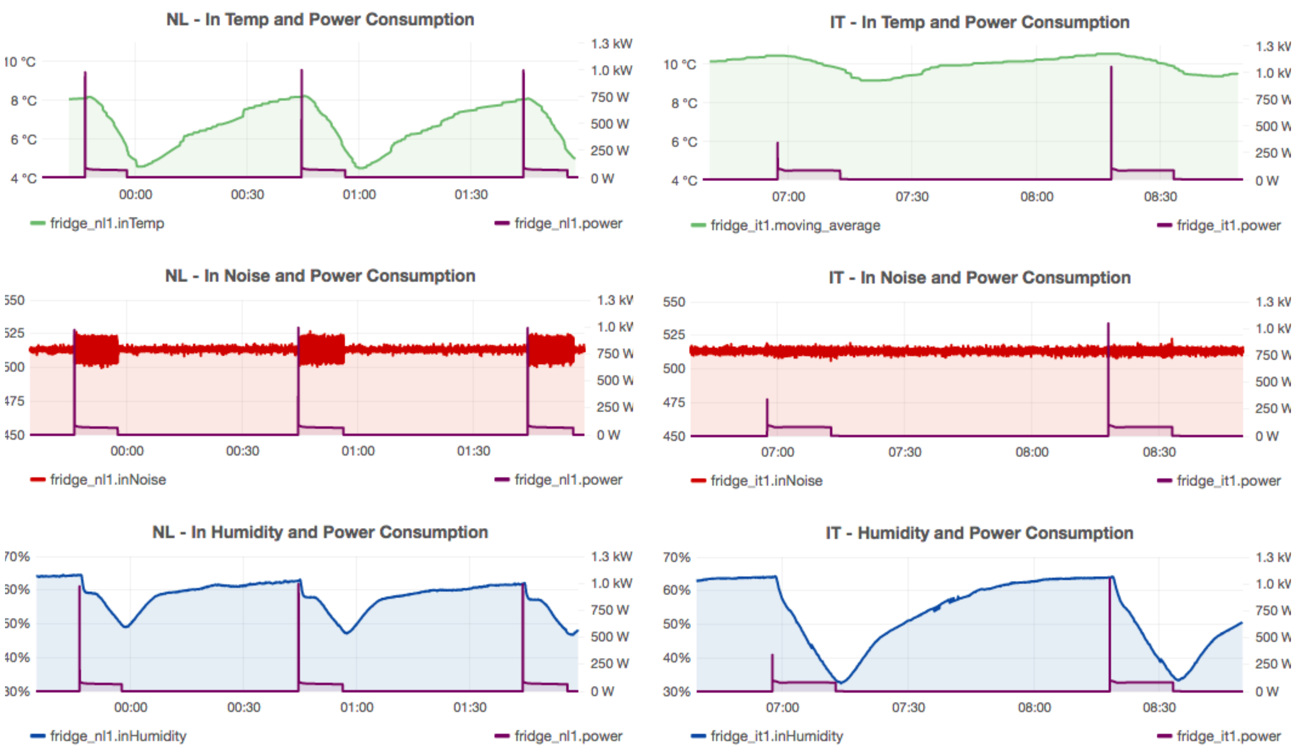


Fig. 62 - Power consumption matched with inside indicators in both NL and IT experiments

the old refrigerator did not have electronics inside, while the new one does since there is a constant consumption of energy even when the compressor is 'off' (Figure 63).

Heat dissipation

Heat dissipation has been identified as a side effect of the refrigerator operation during the analysis of the refrigerator conducted before, as well as in Oltu case study. In general, cooling systems have two common side effects which are completely hidden from user perception. One is heat dissipation since refrigeration is simply 'cooling by removing heat'. Heat is a form of energy that cannot be destroyed. Therefore, to remove heat, we can only transfer from one place to another (VanderGiessen, 2016), where it will be dissipated. The second side effect is water condensation, which is directly connected to the first one. We can experience it in old and small portable refrigerator in which condensate water cannot be removed. During the operation of household refrigerator instead, the level of humidity decreases and the refrigerator performs a dehumidifying activity, as the condensed water is removed from the appliance. Indeed, condensed water drips into a hole in the back of the refrigerator and it is collected into a condensate pan in the back of the appliance. These two side effects work together since the dissipate heat of the compressor makes this water evaporate, and we

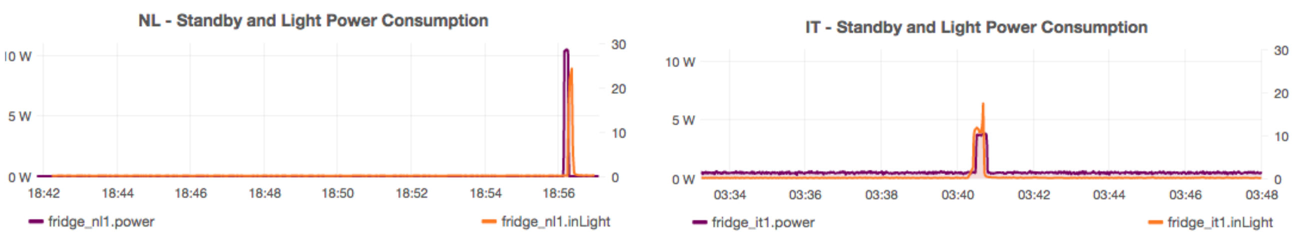


Fig. 63 - Standby and opening (light) power consumption (W) and light (Lx)

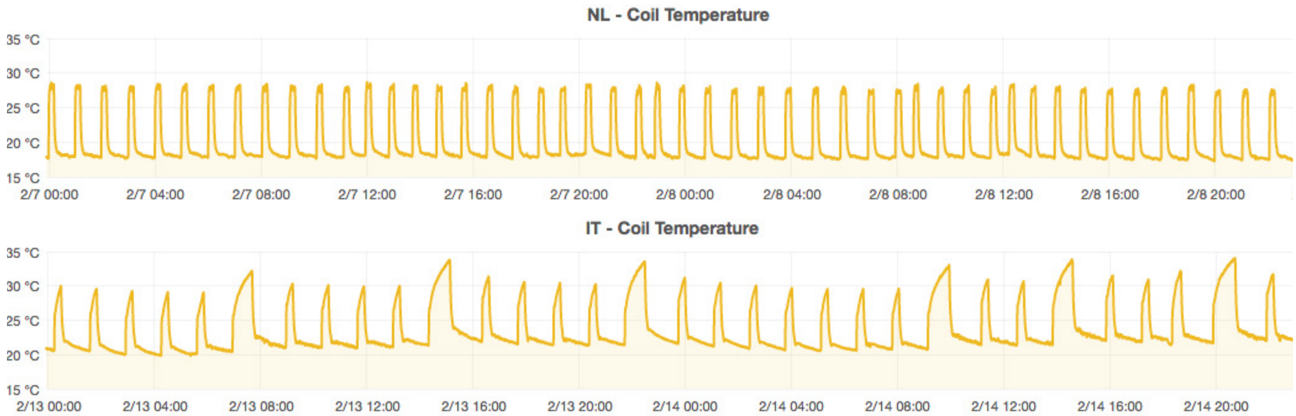


Fig. 64 -NL and IT Coil temperature

do not perceive both effects. From the experiments conducted in both IT and NL refrigerators, we measure this source of unnecessary heat dispersion in the environment. The temperature recorded in the proximity of the coil, however, changes according to the outside temperature and thus to the season, the place, the type of building and the HVAC system (Figure 64). Cycle duration and frequency vary as well, according to the refrigerator and its power consumption. The temperature of the coil, in fact, ranges cyclically in both experiments reaching 30°C, up to 39 °C. In one day for the NL experiment, we recorded 6.5h of heat dissipation, while for the IT one approximately to 5.75h. This side effect is well known since latest refrigerators integrate an insulating panel to hide this inefficiency to the user's eyes. Nevertheless, this side effect has been addressed in a designerly way exclusively in Oltu case study (p. 116 of this thesis). We point out the lack of a design approach, which can solve the problem or exploit this side effect in a positive way, where it cannot be avoided. In this context, the data help us to assess the heat dissipation in typical conditions, thus providing a reliable and quantified view of the issue to address. Systemic Design (SD) Approach (Bistagnino, 2011) claims that the output of one process should become the input to another process, exploiting its valuable, remaining properties.

Design driven by Product-Specific Indicators
From this insight, a winning strategy would be integrating knowledge through multidisciplinary teams, including for example mechanical, physical, environmental, chemical, computer engineers and designers, thus providing an overview of all aspects involved in the cooling process. In this way, a company could assess the feasibility of changing the operation of the compressor in favour of getting a constant temperature, move the coil so that the heat is more efficiently exploitable, conveying the heat for other uses or combining different technologies to reach different temperatures according to foodstuffs. Moreover, this approach aims to extend the product lifespan, and it would fit better innovative and sustainable business models (Bocken et al., 2016), which are no longer based on benefits from planned obsolescence and the purchase of more goods.

Diagnostic, predictive maintenance and user alert
During the first experiment, we detected that energy patterns are highly recognisable, being characterised by activity and inactivity alternate phases. Thus, all indicators follow this cyclic behaviour dictated by the energy footprint. When the user does not open the refrigerator door for a long time, this cycle stabilises into a standard cycle. From the analysis of data, broader conclusions can be drawn, highlighting how the knowledge gained from them can be exploited in the design stage, specifically on the potential benefits of using indicators to detect different situations. A future step of this study will be analysing and detecting patterns capable of directly affect the product design and lead to predictive maintenance. With the aid of IoT learning system, a future refrigerator should alert the user when they experience energy anomalies, preventing cooling failure, annoying noise and water leaking, up to prevent the refrigerator breaks by monitoring several parameters of the fridge itself (Fiore and Bourgeois, 2017).
When the steady-sample cycle of the refrigerator differs from the one shown at purchase time, it may

indicate some object inefficiencies (e.g. the gasket is no longer supple, the drain is clogged, we need to defrost/clean the refrigerator, an issue occurred in the cooling system, compressor, fan motor) or the user is doing something wrong (e.g. user left the door open or introduced warm food). Moreover, single components can be monitored defining which parameters are suitable to prevent breakups that will compromise the whole product functioning, eventually leading to replace it. This stage would require analytics to measure and combine data inputs over time (Henne, 2015). Monitoring some parameters of the refrigerator as a form of predictive maintenance could also affect new business models (PTC Inc., 2015) and added value services throughout the lifecycle, being particularly relevant for the circular economy. Moreover, the product and its components can be monitored with ad hoc experiments, to make their recovery suitable for a second valuable use.

Implications for product durability and circular business models

Designers can consider and investigate (i) the fridge as a unit, (ii) group of components or (iii) single components. The design team establishes which indicators are relevant for understanding one aspect of the product or analyse multiple/aggregate indicators to understand and detect more complex dynamics, correlations and patterns.

This could be the case with the following three examples, considering:

- **functional groups**, i.e. system of parts grouped by a specific function;
- **essential components**, whose breakup will compromise the whole product functioning, eventually leading to replace it;
- **wearing parts**, which can be easily replaced.

Some relevant indicators should be defined and verified by measuring them through ad hoc experiments on these components, providing a more precise knowledge of the system. Data about the real use of a product can be collected for a short time, with an object instrumented for the experiment. Then the R&D or design team could make projections over time of the expected use to determine when the object should be replaced or updated to obtain the maximum value from it. In another scenario, few sensors could be kept on the final object, to allow continuous data transmission of the most important indicators. However, these two scenarios have different purposes. The first deal with experiments, with instrumented objects used for testing, the second aims to reconfigure the product to obtain real-time data and intervene promptly, shaping the object behaviour on the user habits. Both scenarios would require analytics to measure and combine data inputs over time (Henne, 2015). The proposed strategy is suitable for both current product-centred economy and a future service-centred one. It provides some guidelines and directions for future studies that want to address the extension of the product life cycle, based on predictive maintenance while promoting efficient use of products. IoT data open a variety of possibilities in monitoring, accessing more precise knowledge of goods and households, useful for design purposes. Many smart interventions can be done on appliances before talking about connected products, pointing out the difference between 'smart' and 'connected'. Among them detect failures in advance, notify, inform, communicate are only a few possibilities and it raises the need for learning systems able to recognise patterns, together with a platform on which to share and communicate directly with the user. Since creating algorithms is out of our skills, we can focus on the platform as a tool for processing and exchanging information between team members and those stakeholders involved in the process.

7.4.3 User-Specific Indicators

We prove the assumption that a recording of the light stimulus implies that the door is open. When the door is closed, no recording occurs inside. This assumption can be extended to other experiments on user behaviour.

Besides this observation, other implications deriving from data are harder to read, since door opening affect the noise, inside temperature and humidity in a non-regular way (Figure 65). We know that refrigerator cycle is related to the temperature, so if the door opening affects the temperature, in turn, it affects also the cooling cycles and thus the energy consumption. We still need to match the reason of the door opening (by asking the user), the duration and the frequency of the opening (by measuring them) in current home environments, to draw broader conclusions able to affect the design phase.

Design driven by User-Specific Indicators

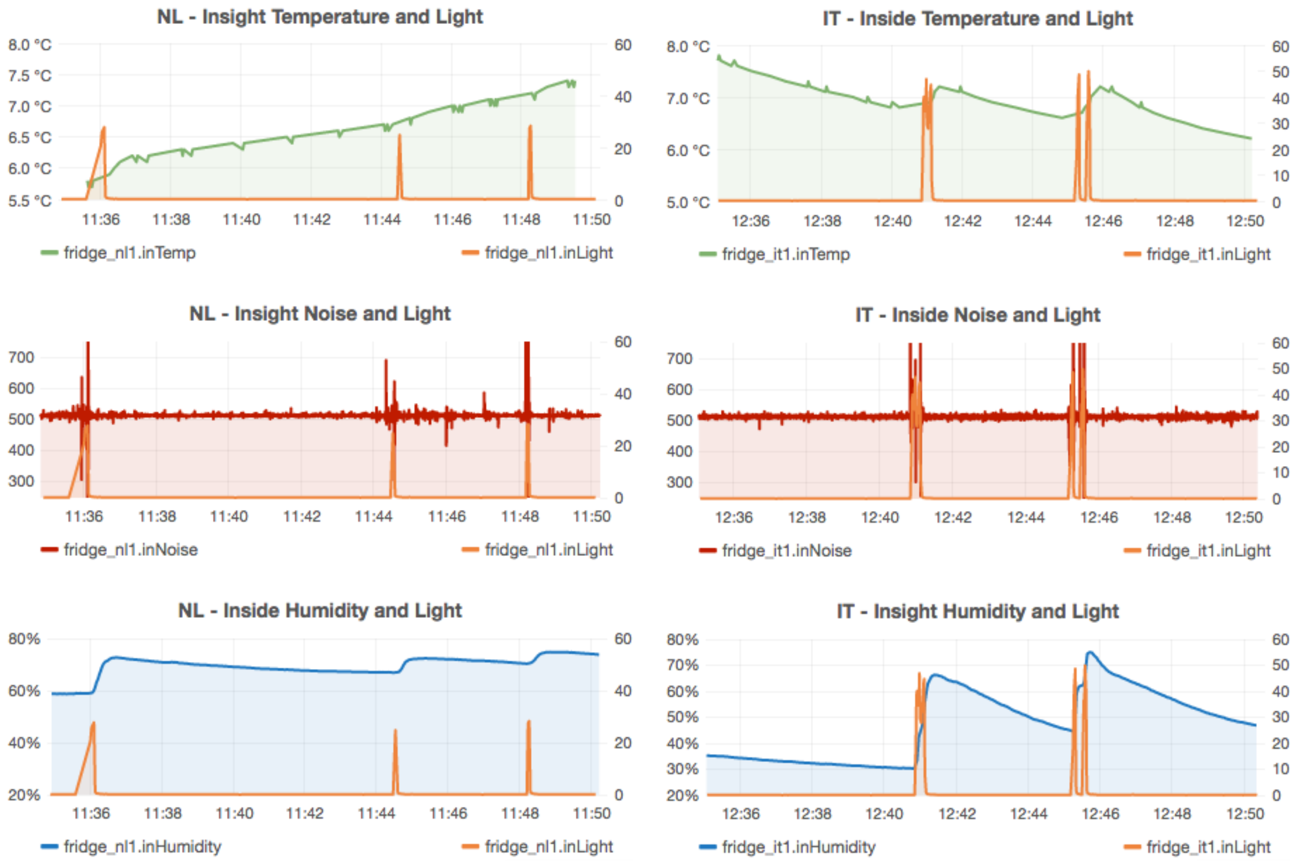


Fig. 65 - Light matched with inside indicators in both NL and IT experiments

During this experiment, we were looking for patterns that could derive directly from the user's behaviour. However, the patterns we found were activated solely by internal temperature changes, since objects did not have intelligence nor algorithms able to identify anomalies in regular cycles. According to Norman and Stappers (2016), people fail when systems require them to perform tasks for which they are unsuitable, or tasks documented to poorly fit human capabilities, such as:

- Monitoring events for long periods with little happening, yet to be able to take over rapidly when some abnormality occurs.
- Providing the accuracy and precision required by the technology

Moreover, we were looking for cyclical changes directly activated by single openings, but we fail, because other studies indicate that a single door openings do not affect appreciably the operation of a refrigerator which is normally kept closed. These studies (e.g. Bhabaranjan, 2015; Haines et al., 2010) clearly demonstrates that the consumption of energy increases when the frequency of opening increases.

The increase is maximum when the door is opened for only 1 minute after every 3 minutes for total 6 hours, so that total opening time in 6 hours remains 90 minutes. This is due to the fact that the door gets opened before the thermostat reaches its minimum temperature at which the compressor gets 'OFF' [..] It is evident from the graph that the compressor remained in running position i.e. kept on running without any break (OFF) after about 90 minutes from starting. Before that the effect of 1 minute opening was not evident. So, it is clear that opening the door for only 1 or 2 minutes will not have much effect on energy consumption if it is not repeated at frequent interval. (Bhabaranjan, 2015)

These were the main reasons for our failures since we pretended to read the data on our own, without the use of algorithms and we left the door open for 2 and 3 minutes, considering it to be a reasonable amount of time. This useful insight provided by Bhabaranjan supports the hypothesis that some patterns and more interesting dynamics can be found in real application domains, i.e. with users. We could indeed exploit machine learning and demonstrate the correlation among door-opening time, an increase in temperature and an increase in energy consumption, by linking these three parameters with the reason behind that behaviour. We would investigate 'how' and 'why' user behaviour affects refrigerator operation.

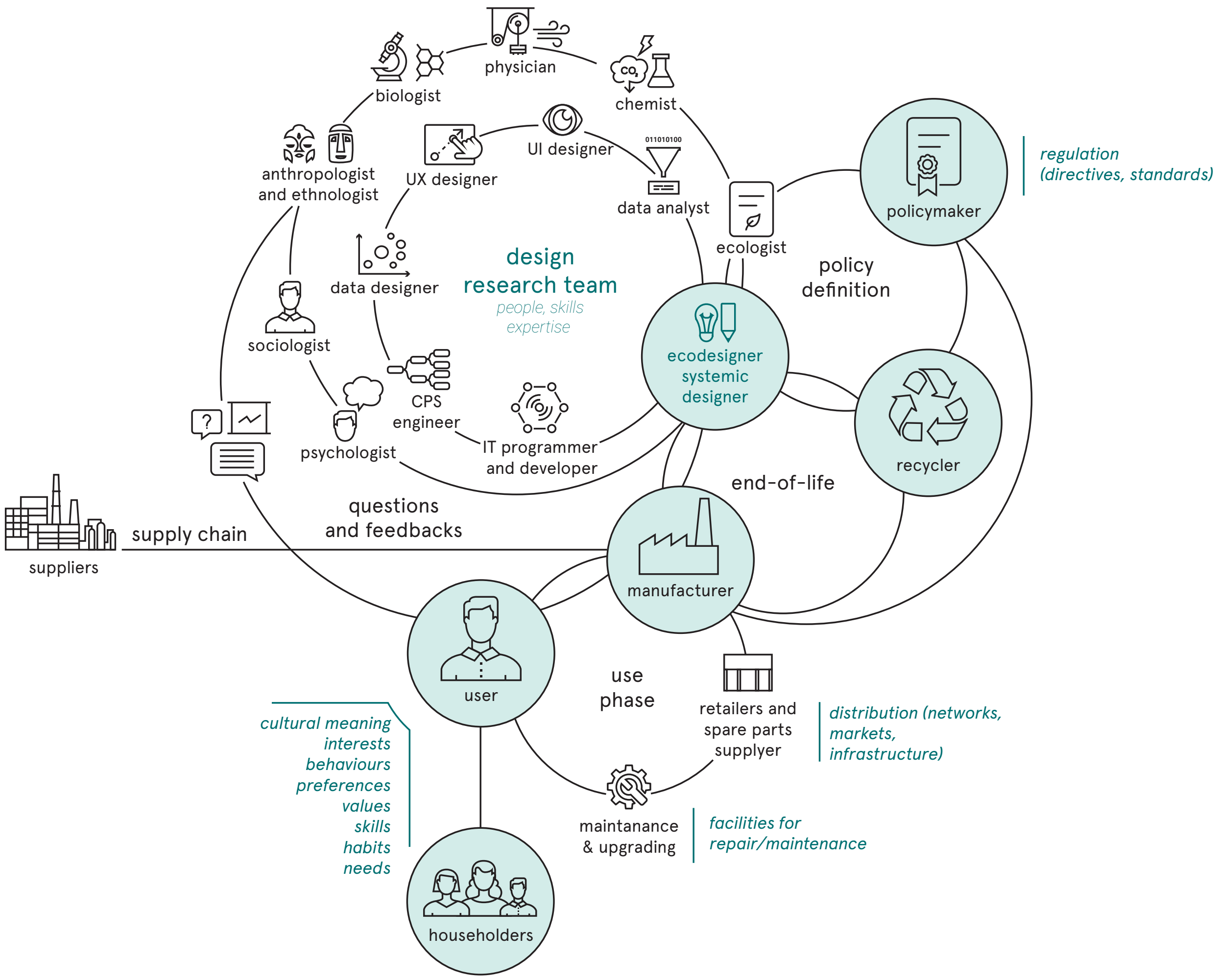
Learning Systems
This scenario foresees the use of learning systems able to detect and predict what the user is going to do. By using 'uses recognition algorithms' future research in design could benefit by activity detection, applying application-specific aggregation functions (Kortuem, 2010). Once found patterns, refrigerator operation can change accordingly, varying cooling cycles or refrigerator operation in different time slots, according to user routines, e.g. detecting differences when the user (i) stores the food shopping, (ii) takes things out of the refrigerator for preparing, cooking or eating, (iii) stores food that comes from a different temperature (room temperature or warm food). Indeed, redesign process may exploit user activity to enable corrective actions performed by the product. This study paves the way for further investigations of user-specific indicators, to assess the direct link between the cause of the action and the action pattern. Previous experiments (Tang and Bhamra, 2009) have investigated these aspects by monitoring with camera recording one week of household activity. Soon we would like to study user behaviour by using sensors for longer periods to highlight user-specific patterns to be leveraged for design purposes. Moreover, we claim the need for machine learning-based model to support the designer and enable several automatic corrections, thus saving energy. Once again, designers should rely on technology for those tasks that are unsuitable for people.

7.4.4 Remarks

As we understood during this experiment, many reflections may result from simple parameters such as energy consumption, showing several unexplored potentials. Introducing the flow of information in the design process, indeed, could allow us to reach a better overview of products. Moreover, every designer could question the product in different ways, according to the heterogeneity of the working team. On the one hand, this data collection can lead to improve current products and their maintenance (proactive monitoring, remote control, predictive maintenance), introducing services (meaningful information to the user, interaction with other connected things such as the supermarket card, predictive food shopping). On the other it could lead developing new products more focused on sustainability, simplifying people's lives in daily actions. This study aims to provide a methodology for designing meaningful products with the use of different sources of data. Retrieving data from the refrigerator itself gives an objective approach to decision-making. From the user perspective, this approach could lead preventing refrigerator breakdowns, find a powerful way to reduce the power consumption of a device 'always on'. On the other hand, the methodology provided leads the designers to make decisions in a more structured way, avoiding stochastic and incremental decision-making. Instrumenting current objects requires planning of which data the designer need according to the design task and what the sensors should collect to understand the real behaviour of a product. Then, once the designer knows which parameters can provide the information needed, designers could reduce the amount of technology on the final product, focusing on a few targeted sensors. Designers should foresee systems able to learn and adapt evolving over time, along with changes in both context and user behaviour. During the operation, the product should use the constant flow of data through a machine learning algorithm, while the designer should study the data gathered to reach product development. This approach has the dual aim of implementing the product and develop new solutions when the project is no longer able to satisfy the user's requirements. This model brings together user-, context- and product- generated data. Combining two scientific domains such as product design and computer science was challenging and highlights the need for interdisciplinary teams able to convey different expertise and address the issue from many perspectives. The dream team to exhaustively tackle these topics should include knowledge from many other different domains (as anticipated in chapter 2 and shown in Figure 66).
This methodology considers multidisciplinary approaches as successful ways to improve the design stage, pointing out the benefit of collaboration. Against the myth of the compartmentalisation of knowledge, this work encourages sharing knowledge within interdisciplinary teams, since multiple

perspectives lead to a more comprehensive view of the issues as well as more creative and successful ways to redesign a product. According to Calabretta et al., 2016, designer needs a multidisciplinary team to co-design solutions, specialists in the domains that would impact (Calabretta et al., 2016). In this chapter, remarks on how to address the problems of the current refrigerator are provided. Chapter 8, instead, explores future opportunities and provides a strategic direction to the activities of designers, while Chaper 9 provides an accurate explanation of the methodology outlined.

Fig. 66 - Complete network of stakeholders



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Chapter 8

A data management platform

During this thesis, we highlighted how design is gaining fluidly, with evolving requirements and open-ended questions. We also highlighted the need for collecting different perspectives (people, objects, environments) through several methods and tools, and we dealt with digital innovation, which begins to fit into our everyday activities.
What we have not yet addressed is a strategy to manage the collection of this information in the specific case of the refrigerator. In chapter 2 we suggested using a digital platform of interaction between the designer and the user to carry out a process of co-design, then extending the platform to other stakeholders. This should help the designer addressing different perspectives and requirements that derive from different phases of the product lifetime (concept/production/use/end-of-life). Moreover, the platform should enable to keep the requirements at hand in every step of design, validating, testing allowing running changes, thus providing the fluidity needed in dealing with sociotechnical systems, as well as providing a platform on which to share concepts and models. Herein, we point out that such a platform should be able to integrate IoT data within the co-design process. In this way, we could keep both requirements and IoT data at hand, and share the elaborated data with the user, so that the information we want to share is intelligible. It should represent a tool to perform data management, from planning to sharing.

	Acquisition method	Outcome
Action, task	sensors, direct observations, measurements	quantitative data and qualitative data
Needs, motivation	questions, questionnaires, interviews, direct observations and reporting	qualitative data
Pattern	algorithms	IoT data can be translated into models, predictions, evaluations

Table 10 - Elements to be analysed, acquisition methods and outcomes

8.1 Investigating the user behaviour

Planning the data collection is part of the designer's task, which begins by identifying which parameters can provide the data that he/she needs, in a way he/she can translate them into design features. With longer experiments and more households involved, we can investigate how households use the refrigerator, how long the user leaves the door open in his/her routine tasks, (e.g. meal preparing, arranging the food shopping in the fridge and so on). We realise that we need to instrument more products used by real people in their daily activities, to detect patterns, if we want to obtain timely data for developing new products. Furthermore, we highlighted the need to combine these data with direct feedback from the user. Considering refrigerator as a case study, the elements to be investigated are reported in Tab. 10.
Without the correlation of these three aspects, we are not able to draw appropriate design conclusions.
For example, if we want to redesign the fruit drawer and define its size, we need to know what the user usually eats, the average quantities of food purchased, how many time the user does the food shopping and where, if he/she buys packaged or loose products. These data cannot be collected without the user involvement through direct questions and observations. The interaction of consumers with the fridge exposes cultural and social values (Tang and Bhamra, 2008). This combination of objects/sensors/human input, tasks and processes analysed together, opens new ways for human and non-humans of collaboratively framing and solving problems, thus merging the data that things give access to, and the theoretically informed analysis that humans bring to it (Giaccardi et al., 2016). Designers should be able to combine the external co-creation (Vitali et al., 2017) and the data obtained by smart objects with environmental sustainability goals. In his paper 'Human-Centred Design Considered Harmful', Norman identifies some challenge in HCD to move this practice closer toward 'products and services that truly fit human needs'. (Norman 2005; Lindley et al., 2017; Cruickshank and Trivedi, 2017), i.e.:

- know your user (householders)
- adapt technology to people (IoT and sensors)
- focus of the static product over the dynamic system (the refrigerator over the home environment)

Addressing the user alone is not sufficient. We should provide a context for these interactions (territory, climate, type of food etc.). Many factors form the application domain and show the designer both the area to explore and the aspect to be leveraged in the final design. We need to manage this complexity through a simplification of the information provided by the user (Lindley et al., 2017), together with the data retrieved from the environment and from the object itself. We should consider that this analysis could involve people from different EU regions, climate conditions and culture, aspects that varying according to user-specific information (age, household economy, value, needs, habits, interests, skills,..) and his/her culture (tradition and cultural aspects, eating habits at different meals), territory (temperature, local availability of food, prevalence of fresh or preserved products) purchase dynamics (household composition, time availability, purchasing habits and frequency).
The generation of higher level information on top of raw IoT data (models, predictions, evaluations) is essential to support an effective conversation between experts, designers and end-users toward sustainable design. Thus, in collaboration with TU Delft, which shared expertise on IoT applied to design, we explored this approach with a focus on domestic refrigerators
Figure 67 shows the data and the interaction

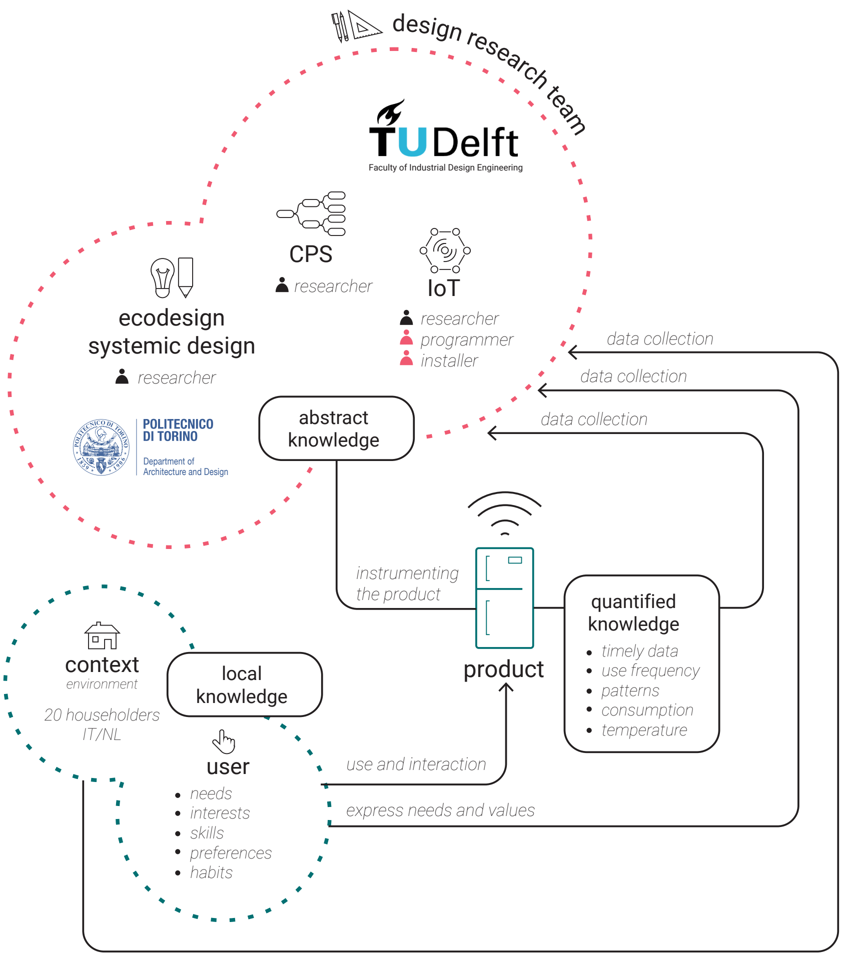


Fig. 67 - Design team for the second experiment

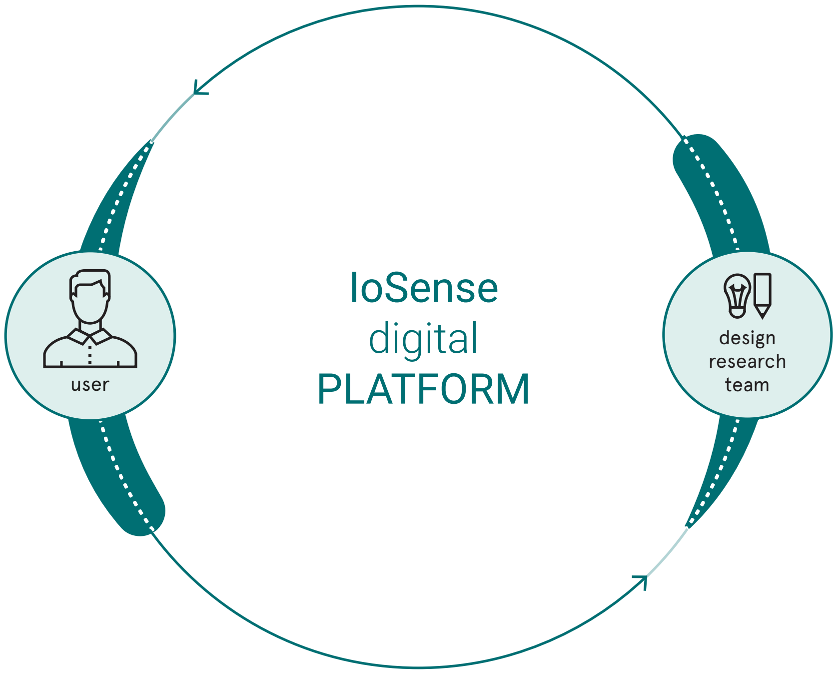
infrastructure we want to use for this project, while figure 68 shows the ioSense cloud platform, an initiative of the TU Delft IoT group to support research and teaching of designing with data. IoSense ingests, stores and distributes quantitative and qualitative data. Its design facilitates the interaction with data for designers, from data visualisation and analysis to the development and deployment of data-driven applications. ioSense will provide an interactive interface between the designer and the householder, through a web or smartphone application. Through this study, we can answer questions deriving from the researchers involved since now, i.e. an ecodesigner, a computer scientist and a CPS researcher:

- How can IoT data support designers assessing and reflecting on products and services, and evaluating improvement options (what-if studies)?
- How can a cyber-physical fridge be realised that, ultimately, collects its own data and adapts itself in an ad-hoc way to changes in its environment (user patterns, home climate)?
- How can we bring the user in the study and involve him/her, considering needs, values, behaviour?
- How can we improve the sustainability of the home system, starting from its appliances?
- How can we use data to support decision-making in design?
- How can we design meaningful and relevant product in evolving contexts, by planning and designing the data collection in the early design stage?

8.1.1 A glimpse on user involvement

When users can express themselves, they spend their time to provide their opinion. We can observe this phenomenon every day, on our social media. Undoubtedly, not all opinions are useful. We observed the opinions expressed on the controversial article

Fig. 68 - IoSense Platform



'Internet fridges: the zombie idea that will never, ever happen' by Charles Arthur. Arthur (2014) suggested that no smart fridge will ever succeed because there is no technology capable of efficiently scanning the products, knowing the expiration date and seeing inside the fridge in the off light. Charles refers to the practice of pushing technology into existing objects. When addressing the IoT applied to a refrigerator, there are many other things to consider, especially when your goal is different from incorporating technology into a fridge. As already happened with the additive manufacturing, there is a big difference in printing a 3D objects similar to the current one and designing for additive manufacturing. For the same reason, the object itself should be redesigned to include features aiming at simplifying certain daily tasks (organisation of food shopping, product visibility, detect the quantities through weight sensors and so on). Although his considerations have been overcome by technological advances, it is interesting understanding how users reacted to the post, by reading their comments, concerns and insights (as they were potential users) and the replies they give each other. Going through the 154 comments, we can get a general idea of what people think. A substantial difference from participatory design is that these comments are spontaneous, as people decide to dedicate their time for free.

It emerges that users have different needs, values and visions. We retrieve it from comments like

User A) A case of a product solving a problem that for 99% of the population does not exist.

User B) Welcome to the 21st century welcome to the truly tedious 'data-me' bores who want everything to give them precise quantified information even when it largely doesn't matter at all.

opposed to

User C) running out of milk and not noticing the item that about to go off are real for most of us I think, it's just that as the article says the Internet Fridge doesn't really offer a workable solution.

Regarding 'keeping the list at hand' and 'predictive shopping' one says *"human memory has served fridge owners well for long enough, so why should we change it?"* However, users have different needs according to the dimension and composition of the household. To this regard, the exchange of comments that follows gives us an idea:

User A) Even if a bottle of milk had an RFID chip, it wouldn't tell you whether it's nearly full or three quarters empty

User B) But your fridge could track how often you buy milk and eventually

be able to predict when you will need more milk. Similar to how the Nest Thermostat can 'learn' when and how you use your heating.
User C) I can do that myself.
User B) But what about larger families, where there are 5 or 6 people using the milk in the morning? Do you check how much milk you have every day before leaving the house?

In another exchange, a user proposes a solution, ‘send a picture of the fridge when you are at the supermarket’. In the answers people notice that one can do without technology, by looking inside the fridge or using a common shopping list, someone says that the solution makes sense, but it would be too expensive, while someone points out as the solution, however, is not satisfactory in other respects.
User A) How about one that could send you a picture of its shelves when you pinged it? Easy to do and cheap to make I would have thought.
User B) How about opening the door having a look and deciding whether you need to pop to the shops or not. What a load of tosh and a waste of resources and money.
User C) It's more the other way round - trying to remember if I'm low on butter while I'm already at the shops. Still not worth spending thousands of pounds to achieve, though.
User D) Still won't tell you whether your two litre carton of milk is almost full or almost empty!

Some users pointed out that there are scenarios other than the ‘supermarket’ and packaged foods
User A) And not to mention people who buy food from local shops and markets rather than supermarkets and 'Shock Horror' cook their own food then store it in the fridge…
User B) But what about the people that buy all their food from the supermarkets and shock horror cook and store their own food in the fridge.
User C) How would my fridge recognise the chicken that was left over after cooking and was kept in the fridge afterwards, or any home made meal? Could it look inside a home made pie?

Some users show concerns about technological obsolescence:
User A) Given how awful Samsung are at pushing out software updates for phones that are only a few months old, would anybody care to guess how good they'd be at doing updates for something that has a working life well in excess of a decade?

Some others show concerns about food waste:
User A) It's a poorly executed solution, and the article is correct for the most part. However to state that there isn't a problem is to neglect the vast quantities of food waste produced by households in the UK (and the economic and environmental costs of such waste)...
User B) there is an obscene level of food waste generated by western habits. Indeed supermarkets are even beginning to consider improving consumer habits as one of the easier areas to improve environmental performance (having exhausted the easy supply-side improvements). A smart fridge as part of a larger home management system may well be part of the solution.

Finally, we can identify some ‘lead users’ that could potentially be our co-designers.
User A) I always had a thought about these fridges using pressure pads in certain places for certain items, a special place for butter, milk ect. I shall get in the shed and make the one that WILL work for consumers.
User B) This only works when you put the butter/milk/etc back in the same place each time. Given that after 14 years I've only reliably trained my husband to put the butter back in the dairy shelf 50% of the time [..].

User C) what would be handy would be a scanner integrated to an online shopping *account of my choice so that as I was running low on something I could add it to a virtual shopping list by scanning it in. Then, at the time of my choosing, I review the list and place my order with Tesco/ Ocado/Whoever. I don't need it to weigh my butter or know when my milk is out of date. It would just be handy to be able to interact with an online shopping service in a way that is integrated with the device rather than having to go through a lap top, onto the internet etc.*

User D) It wouldn't need manual scanning or RFID - As people have pointed out, much better data could come from shopping data and camera imagery. I'd add one more input to that: pressure sensors. The ob vious quick-win is managing inventory of short-life staples - it's low complexity and high impact (in terms of waste and convenience). The more advanced stuff (meal-planning, anticipating needs) could be bundled in but is less likely to be taken up. Supermarket partnering/ subsidy is likely to be a component as the information is valuable to them. [..] The original purpose of a fridge was to increase convenience and postpone spoiling. The smart fridge is a sensible extension of this and it's time will come.

User E) I think the problem here is that someone is trying to come up with a completely automated solution, taking the human out of the loop. This creates all the problems (and more) described in the article. However - simpler approaches could be quite useful. For example - when you take your bottle of milk out of the fridge and notice it is almost empty, then it would be handy to simply scan the label and have it added to a shopping list - which can then sync over the web with your smartphone for easy access next time you're at the shops. And, while you have your nose in the fridge you may notice some other things have run out/missing, and that would be an opportune time to pop those on the shopping list - which could be made all the more easy by having a computing device right there by the fridge, with easily accessible 'favourites', supermarket catalogues and even recipes with hyper-linked ingredient lists, so you can answer the question ('ok, I have some pork I need using, what else do I need to get to make that XYZ recipe?'). [..] So - don't try to over-ride or remove human intelligence, but provide some tools to make our role more efficient. And, put it right there conveniently on the fridge door (or similar location within the kitchen). That's the type of 'internet/intelligent' fridge I'd be interested in buying. Some clever apps on a tablet velcroed to the fridge door would almost do the job (recharging would be the biggest hassle). Better integration into the fridge door should be trivial.

Over 154 we can identify at least 11 users that can be involved in the co-design process because they show the necessary 'positiveness and openness' for this approach.

8.2 Platform

Creating a collaborative platform is fundamental to gather the data, then we can investigate user's requirements, especially when they are unknown at the beginning of the process. Two authors provide explanations for the degree of uncertainty of the requirements:

> *Requirements cannot be fixed at the beginning of the process and may (need to) change rapidly. In general, requirements will not lose their importance if they are able to adapt and respond as an open, evolving system. If requirements are fixed at the outset and cannot change, they will become obsolete and irrelevant to how the project or discourse evolves and matters to the people engaging in it* (Reymen and Romme, 2009 p.100)

> *Solutions to unknown user-led evolution involved increased reliance on interface standards and standardised "platforms" embedded into products. Rather than specifying specific functional requirements, as these can*

not be known, standard interfaces that may accommodate multiple add-ons have become the main object of requirement (Hansen et al., 2008)

My role in planning the data collection is to give the temporal scan for questioning the user, thus planning the data collection in advance and setting the questions. We identify which parameters allow collecting data that can be translated into design features, thus managing feedback and using them to develop design solutions. Then we will test both assumed needs and design solutions directly with the user, through the same platform.

On the one hand, the designers will be able to ask contextual and general questions to the end-user. On the other hand, the end-user will provide feedback, reactions and suggestions to the input received by the designer (data visualisation, concepts, questions) about data, product features and concepts. Moreover, the user could access his/her own data to understand his/her habits better. Norman and Tognazzini (2015) argue design products and services that help their users imply discovering people's true, underlying needs, understanding human behavioural patterns, beliefs, values, habits, desires, motives, emotions and needs and translate this into possible future. If we assume that the insights gained from consulting users can guide designers to go beyond their own assumptions (Mink, 2016), we should acknowledge that involving user does not ensure that all the relevant insights are identified (Steen 2008). On the other hand, as anticipated, to be a truly collaborative experiment, the user should be able to access his/her own data, selecting the information he/she wants to see and understanding for what extent data are used. Requirements should thus be defined for open, adaptive and adaptable systems (Reymen and Romme, 2009).

We need to acknowledge that managing data is a matter of trust. Although some users will not be willing to share their data, a new branch of consumer behaviour has emerged recently. There are some users, indeed, who are glad to share their data for technological and scientific advances, as well as if the company they trust uses them to improve products they love, i.e. in exchange for a product or service they value and a brand they trust (Olenski, 2016). Far from being exhaustive on this topic, we hope that users' consent for processing data for good purposes will not be difficult to achieve. We are planning activities in which we ask people to do some tasks, recording their operations, habits, postures and way of doing things. A second part of the observation could be carried out by asking questions while they are doing those tasks. In this way, the designer can stimulate users to think of the way they are doing things, to highlight which critical aspects they find when they are doing a certain task, what could help them, how could the task be simpler. A third part could involve supporting participants, stimulating creativity, providing views and tools for encouraging ideation, expression and visualisation (de Arruda Torresa, 2017). The insights gained from users will be combined with the experience gain in the refrigerator domain to develop scenarios of potential futures, demonstrating what could happen if these cases were to spread and consolidate, becoming mainstream ways of doing (de Arruda Torresa, 2017). Moreover, with test and prototypes, video and 3d modelling, we can give shapes to these objects, contextualising them to collect feedback also from the general public. This process promises to be long and expensive. For this reason, it will not be included in this PhD dissertation and will be developed through *ad hoc* funded projects starting from this work.

8.2.1 Beyond the user: other stakeholders

This kind of platform could be extended to other stakeholders, such as OEMs, policymakers and waste operators to promote 'design for recovery'. This collaborative platform could allow other stakeholders to join the design process (Movilla et al., 2016). The refrigerator could become a policy-aware object, and in the next future, it could be updated with information from other objects, services, infrastructure. Moreover, through this platform we could validate the requirements reported in this thesis and grouped in figure 69.

Table 11 - Platform questions divided into functions

8.2.2 Platform questions

Designers cannot indeed design future systems until they make sense of the relationship between the part of the system (Calabretta et al. 2016). Below, some questions that could be asked during the early design process of a fridge are listed (Tab 11). They serve for investigating beliefs, values, habits, desires, motives, emotions and needs. Far from being exhaustive, however, we seek to provide a starting point for designing products with meaning and values.

MAIN FUNCTION	METHOD
Prevent food spoilage	
- What? Different food items	ask and monitor validate with agronomists, biologists
- How? *"cold temperature" is one of the answers to protect valuable foodstuffs from bacteria. Preservative methods such as salting and drying were also effective. They were not well suited to all kinds of food. Besides the temperature, which other requirements should be met for optimal preservation? Humidity decreasing? Light protection? Ethylene removal? Atmosphere composition?*	ask agronomists, biologists, chemists literature evidence
Cool down	
- Which temperature should be reached? *According to the optimal temperature and properties of different food* *Different technologies, low-tech techniques, material properties can meet the goal of lowering the temperatures according to the peculiarity of different foodstuffs.* *We should investigate product features vs people know-how*	ask experts agronomist, biologists,.. literature evidence
1) Which is the current role of the user in the "cool down" operation? Temperature adjustment through refrigerator thermostat. a. What gesture/step does the task involve? How does he/she do it? b. When does the user change it? 2) Which could be the future role of the user in the "cooling down" operation? 3) How important is frozen food in your life? Do we actually need frozen foods? Can someone do without it?	1a. ask and monitor 1b. measure and when occurs, ask the reason to the user, to link the action with the motivation 2. ask users 3. ask users
- Which temperature should be maintained?	ask experts
- Temperature fluctuation. Which temperature variation is considered acceptable? Which variation compromises the conservation up to interrupt the cold chain? *It varies according to the optimal temperature of different foodstuffs. Therefore, it should be investigated with experts.*	ask experts

- What currently increase the refrigerator overall temperature? - *opening the door introduce air at room temperature* - *introducing warm food (more than room temperature)* - *introduce large amounts of food at room temperature* - *insufficient seal,* - *gasket, door failures*	literature evidence
- How can we avoid a temperature increasing? - *testing the dissipation of different openings (front, top, modules) with temperature sensors* - *testing different insulating materials with temperature sensors* - *reducing the opening time required to perform a specific action (connected to 3rd and 4th functions)*	literature evidence
Managing food and organise foodstuffs	
a. Which is the fridge load condition? b. What does the user usually eats? Which type of foodstuffs, quantities? It should vary according to the territory and the context (e.g. dairy products in the Northern countries compared to the Southern) c. How many time does the user do the food shopping d. Where? e. How many time does the user eat outside? f. Is he/she buying packaged or loose products? g. How does the user place different food items, where does he/she put them? How many jars? How much are they left in the fridge? h. Is the organisation of food items related to different time slots of the day? Does the meal bring to a different organisation of food items inside the fridge? *Understanding how the refrigerator fit the daily routines of both the household and single users, shared and private dynamics. It reflects the social complexity of the household with pattern complexity (dynamic dependencies, individual values, needs, routines). For example, abstracting from what was done in LEEDR project about washing machines, we could consider in detail the dynamics related to the refrigerator.* i. Who is part of refrigerator-related tasks such as cooking and do the food shopping? j. What role does each user play as reflective and habitual agents in fridge-related tasks? k. What are other materials and technologies involved (objects)?	a. b. question, monitor and measure c. d. ask users e. f. ask users, direct observation f. g. h. record the arrangement and position at different times of the day. Sensors, cameras, photos i. j. k. ask users and record ‘who is doing what’ at different times of the day. Sensors, cameras, photos k. camera recording
- What people actually do with the product? *According to Tang and Bhamra (2009), the main tasks are:* - *unpacking* - *put food* - *making room for new items inside the fridge* - *transferring items between the shelves* - *looking for the desired item* - *take desired items out*	Investigate with the user through questions, questionnaires, interviews, direct observations and reporting literature evidence

Access foodstuffs	
1) How does the user open it? When does he/she open it? 2) Why does he/she open the door	1. question, monitor and measure 2. ask users
Maintenance	
- How to ensure the hygiene of the fridge? a. how often does the user wash it? b. how to automate cleaning? c. how to avoid bacterial proliferation?	a. ask users b. c. ask experts
Ownership	
1) How many fridges does the user own, which are still working? 2) What does he/she use them for? 3) What features do they have?	1. 2. 3. ask users literature evidence

Fig. 69 - Requirements

8.3 Investigating the food waste

Our refrigerators ended up welcoming all sorts of food items, even those that do not require low temperatures (e.g. eggs, tomatoes). It conserves, indeed, 750 kg of food per person every year (Magalini et al., 2018). We do not know if it is due to consumer laziness or a lack of knowledge, surely it is easier storing everything in the fridge, fueling the demand for bigger appliances. Moreover, Tang and Bhamra (2008) highlighted that there is a gap between user's environmental intention and real action as well as issues arising from the routine practice performed automatically with little deliberation ingrained in use patterns related to refrigerators. James et al. (2008) reviewed operating temperatures of domestic refrigerators, summarising key findings of this research, that dealt with both (i) the refrigerator thermostat operation and (ii) the energy use. They cite 21 studies related to refrigerator operating temperatures where a total of at least 3.424 domestic refrigerators were tested. The results showed the most common storage temperature was between 6 - 6.9°C with temperatures ranging from 3 to 8.9 °C. This variation in storage temperature can have a considerable effect on energy use (Haines et al. 2010).

8.3.1 Domain experience

Designers generally starts to approach a problem without being a domain expert (Jones, 2015). However, in order to succeed, designers should be able to ask questions to experts to clarify any doubts or acquiring the knowledge needed on his/her own, which requires time and efforts. In the case of food conservation, a designer should not address it without investigating the food requirements. As they do not vary over time, the web is considered a sufficient source of information for this investigation.

Current

The refrigerator generally encloses foodstuffs which have no shared feature nor requirements. The minimum temperature is defined by the most perishable elements such as milk and meat and the rest of the foodstuffs are stored at that specific temperature, which is not optimal for their conservation. At this stage, we assume the properties and requirements of a single foodstuff as steady, although we know that even a single foodstuff changes properties over time (from unripe to mature, from fresh to expired or rotten). Far from transforming the designer into an experienced agronomist, however, a start-level knowledge of food is needed for designing its proper conservation.

Detecting ripening and ethylene production

Popular wisdom could help the designer, especially referring to popular knowledge domains. For example, 'put unripe kiwi fruits or avocados with apples' is a well-known strategy to stimulates their ripening. As someone already knows fruit traders pick unripe fruits to prevent it from spoiling during the transport. Then the fruit is artificially ripened before selling it, using different agents such as calcium carbide (CaC2), which is reported to be carcinogenic (Singal et al., 2012). Calcium carbide is applied over fruits, reacting with moisture to form acetylene, while other methods use ethylene or acetylene, by introducing these gases in ripening rooms at food wholesalers. Why do we need to know it? Because gases are intangible and they are often not considered as a design issue. However, they have implications and should be considered like water and other resources. Ethylene, for example, is naturally produced by certain fruit and, being an ageing agent, accelerates the degradation of some fruit and vegetables which are sensitive to that gas.

This raises our interest in investigating how to detect spoilage in advance to avoid throwing away more food than necessary. Although the binomial 'Ethylene & refrigerators' has been investigated by WRAP (2011), the goal of that investigation does not answer the questions addressed in this dissertation.

Collecting different sources, we provide a classification of food based on ethylene features; we divided into production and sensitiveness, acknowledging that fruits that do not produce ethylene could be either sensitive or not to that gas and the same applies to ethylene producers.

- **Ethylene producing fruit** (climacteric fruit): increased ethylene production and a rise in cellular respiration

E.g. apples, apricots, avocados, ..

- **Non-climacteric fruit/vegs** ripens without ethylene and respiration bursts

E.g. asparagus, strawberries, grapes, broccoli, cabbage, carrots, ..

- **Ethylene sensitive fruit/vegs** show an altered response to ethylene (ripening, changing colour,..)

E.g. apple, broccoli, Brussel sprouts, cabbage, cucumbers, avocados, mangoes

- **Ethylene insensitive fruit/vegs** do not show any altered response to ethylene

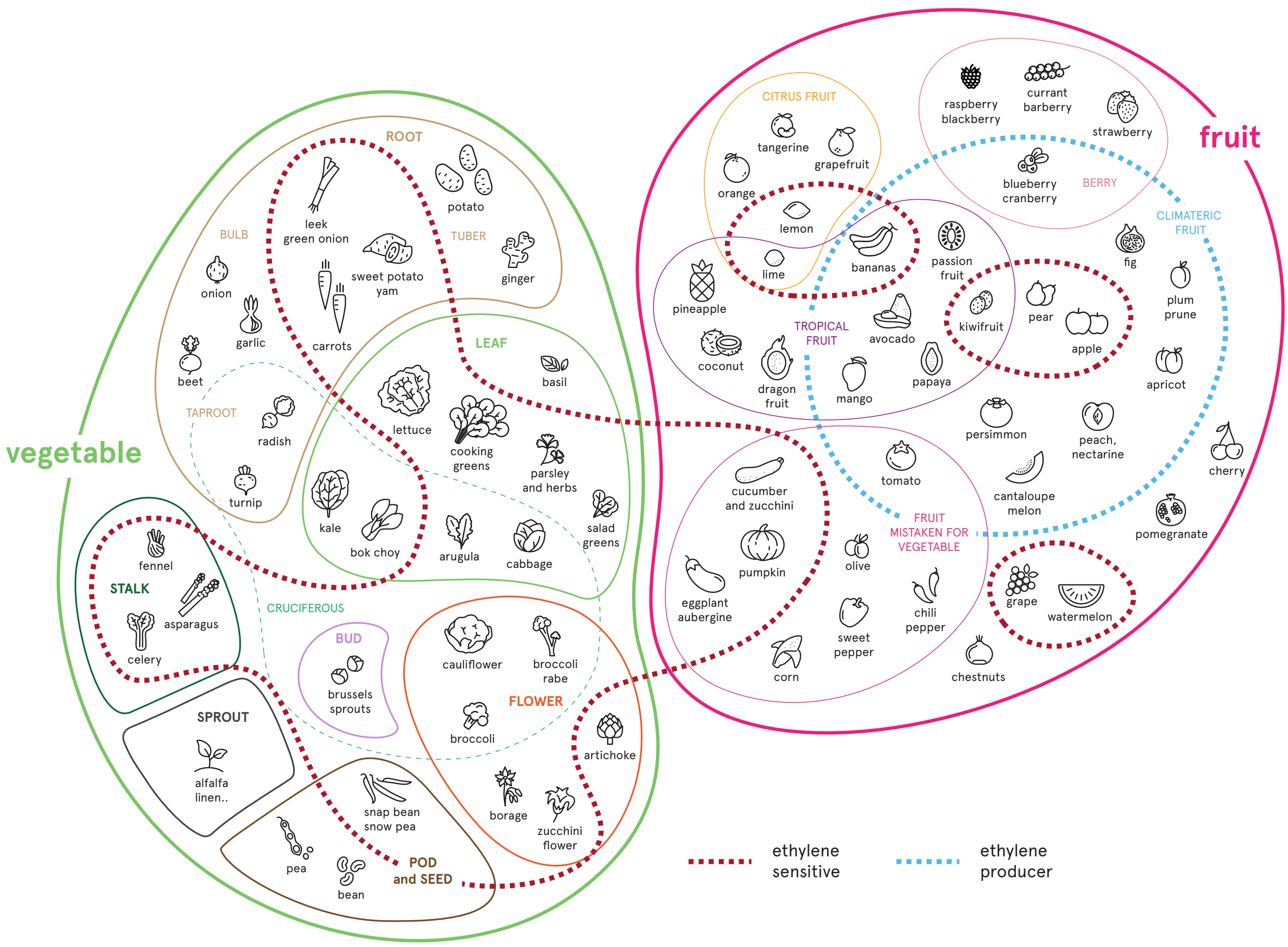
E.g. red fruits, cherries, pumpkins, grapes, garlic

Below (Figure 70) there is an attempt to overcome the complexity of grocery, cataloguing fruit and vegetable stored in the fridge and dividing them into types of food, reporting with dashed lines if the item produces or is sensitive to ethylene.
Now at a glance, we know that almost all the leaves and flower are ethylene sensitive, while some fruits proved to be producers. Why is it important? Because from now on we know that those vegetables enclosed in the red dashed set must be kept far from those inserted in the blue dashed circle. Moreover, we know that the vegetables included in the subsets by type, show some common features and we can ask agronomists what these features are and how they can be enhanced in the project.

8.3.2 Detecting gas and spoilage

Many experiments can be performed sharing the same methodology. For example, if we want to detect the spoiling patterns of food waste and prevent it somehow, we should define a research team able to cover the expertise required and investigates the object with the use of gas sensors (Figure 71), i.e. devices that respond quantitatively and reversibly to presence of gaseous by changing the physical

Fig. 70 - Classification of fruit and vegetables according to their nature and features.



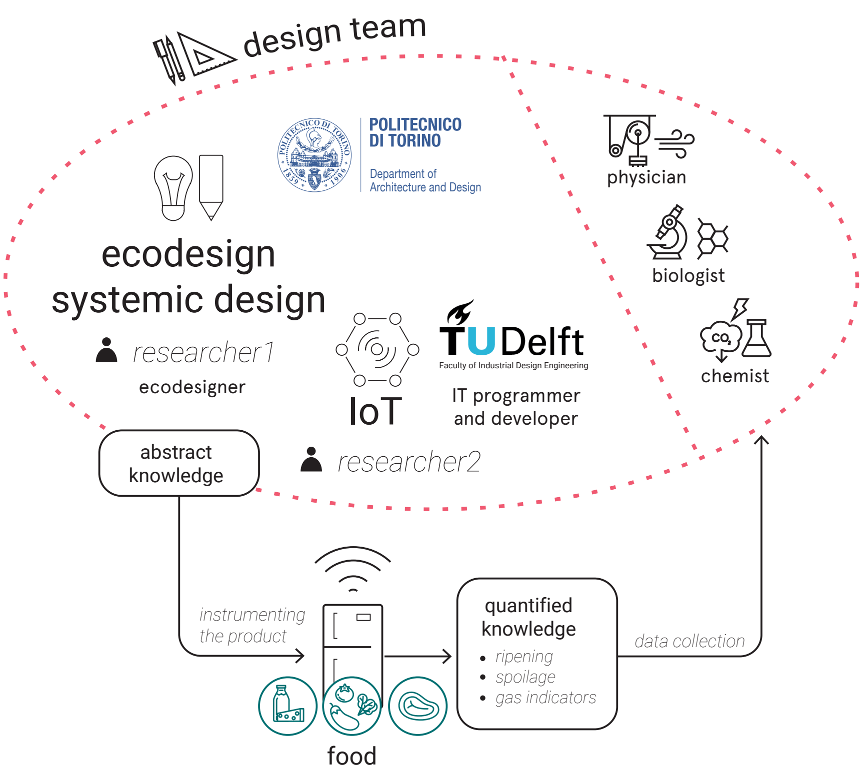


Fig. 71 - Design team for the spoiling experiment

parameters of the sensor, monitored by external devices. These sensors could help understanding which gas (or combination) is released during spoilage and ripening processes. Not limiting the study to the ethylene (C2H4), but investigating different gases (such as alcohol, Benzene, NO and NO2, sulphide gas H2S, O2 and CO2) some of which are already documented in the literature as involved in these processes, other should be tested to exclude any inference.

Goal

The methodology described applied to food waste aims to:

- provide the user with reliable and correct information on the condition of the food, the environmental and packaging integrity
- enhance food safety and biosecurity (salmonella, campylobacter, e. coli, listeria)
- reduce food waste
- reduce the suggestion that food has expired without actual evidence, which leads to over-throwing edible food

Solutions in this field can be multiple, addressing the different aspect of the problem, including but not limited to:

- systems able to detects some of the most dangerous food spoilage;
- using materials in contact with food that can react with toxins by changing colour or using phase-changing materials able to detect spoilage;
- absorption systems for gas such as ethylene which, while not indicating indicating serious deterioration, fostered the spoilage of other products.
- reuse gas such as ethylene for other uses (as it is an ageing hormone, it regulates germination, flowering, ripening Corbineau et al., 2000; Blankenship, 2000)

However, the designer should consider other aspects, such as the cost and the environmental impact (e.g. consequences on the recyclability), about the benefits for the user or the environment. Tang and Bhamra (2009) suggested designing an effective way of communicating to make sure consumers know how to use the product efficiently. Providing information, choices, feedback or behaviour spur, can bring some changes.

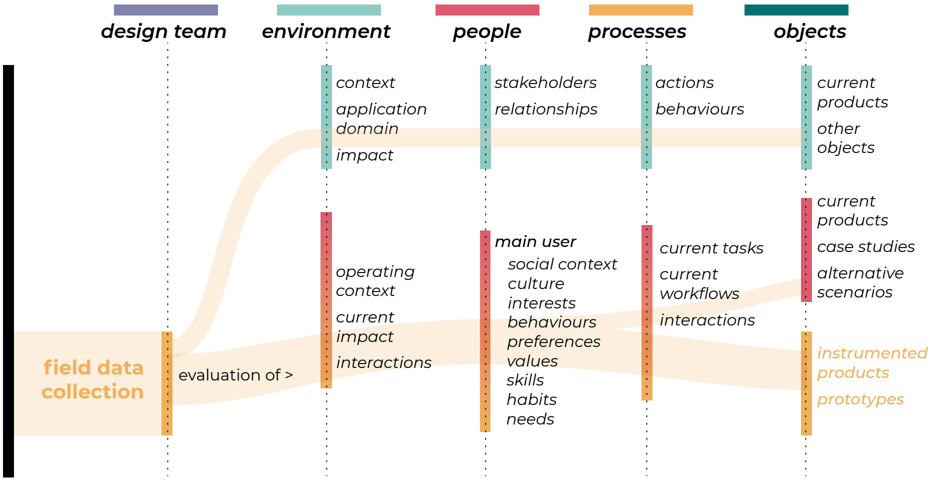


Fig. 72 - Field data collection

8.3.3 Remarks

In this section we provided some examples of how the methodology could be used in practice, showing how we could question the user, how we understand how the user relates to the fridge, in which environment the fridge works, but also what we can draw from other objects in the refrigerator (e.g. fruit and vegetables). This section relates in particular to the field data collection that can be made through a platform able to manage:

- Direct questions (e.g. allowing interviews, surveys)
- Data gathered by object instrumented ad hoc, such as prototypes

In the next chapter, we abstract the methodology to apply it to data-driven product design for sociotechnical systems in general, providing a practical guide to its use.

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Chapter 9

A data-driven design methodology for STS

This design methodology aims to guide the designer in considering complex context and environment characterised by significant impacts in terms of resource consumption. This methodology helps to gain a broad knowledge of processes, context, stakeholders and products and combine it with smart enabling technologies able to provide data and quantified knowledge. It prepares the designer to work in trans-disciplinary research projects in STS, with the final goal of design meaningful and relevant products for the user, with the environmental sustainability in mind. The presented methodology is focused on the pre-design process, that can be followed by the other steps of a traditional design methodology (ideate-prototype-test or design-develop-deploy).

Research questions
Throughout the whole thesis and therefore within the developed methodology, I tried to answer the following two research questions:

1. Which analytic guidance Systemic Design approach combined with data-driven design can provide designers?
2. Which is the role of the designer in planning data collection in the early design stage in order to design meaningful products?

Relevance
This methodology is based on the principle of Systemic Design and is intended for massively under-constrained problems that were difficult for traditional engineering approaches to address. Many situations are currently in dire need to be considered and handled as systems, rather than attempting to convey the elements into a unique perspective (and solution).

What do you need to know before you proceed?
This methodology requires that the design team guides the process, as designers must gather the necessary insights to design new products suitable for STS. It is not intended to be universal or definitive. It only applies to certain situations, and it is useful here clarifying which characteristics the problem to deal with should have, as well as the characteristics of the work team, before star to apply the methodology. This section is intended to explain subtleties and difficulties to designers who want to use it in practice.

When should it be used?
It is suitable for trans-disciplinary research projects in which the manufacturer/research group want to explore messy, problematic situations characterised by conflicting perspectives of the stakeholders, which cannot be accurately modelled and cannot be addressed using other design approaches.

When should it be avoided?
This methodology is not suitable for well-formed problems, characterised by explicit assumptions, well-defined dynamics and actors. In this case, it may result in complicating the standard design process.

9.1 Terminology

I want to clarify the terminology used.

1. *What is a sociotechnical system?*
   The complex systems defined as 'sociotechnical systems' are made of software, hardware and people, somehow linked to the policy and many stakeholders. They show complex dependencies and functional-based constraints. Healthcare, workplace, home environment are among STS.

2. *Which kind of system do we have in mind?*
   We would like to shape future systems through their products. I refer to systems characterised as follows::
   - **Self-healing systems**, able to recover dynamically from unexpected errors or attack;
   - **Self-optimising systems**, able to optimise their performance dynamically with respect to changing operational profiles, or adapt at run;
   - **Biomimetic systems** able to draw inspiration from biological systems, by simulating the behaviour of a natural organism.

3. *Which is the difference between an interdisciplinary team, a transdisciplinary team, a multidisciplinary team?*
   According to various sources (Neil Kokemuller, n.d. and Columbia University, n.d.), we report the definitions of these terms.

A **transdisciplinary team** is one in which:
/ members come together from the beginning to jointly communicate, exchange ideas and work together to come up with solutions to problems.
/ each team member becomes sufficiently familiar with the concepts and approaches of his and her colleagues as to blur the disciplinary bounds and enable the team to focus on the problem as part of a broader phenomenon.

An **interdisciplinary team** has many facets:
/ more than one discipline is involved in a situation, although the interaction between members of different disciplines may be limited.
/ various disciplines are involved in reaching a common goal.
/ each discipline brings to the situation or problem its expertise.
The last scenario actually most appropriately describes an interdisciplinary model, while the other situations are more examples of various levels of multidisciplinary interactions.

A **multidisciplinary team** is characterised by:
/ members from more than one discipline;
/ problems that are subdivided and treated in parallel, with each provider responsible only for his or her own area;
/ a collaborative way of working, but every expert has his/her own task;
/ members that use their individual expertise to first develop their own answers to a given problem, and then come together (interaction) bringing their individually

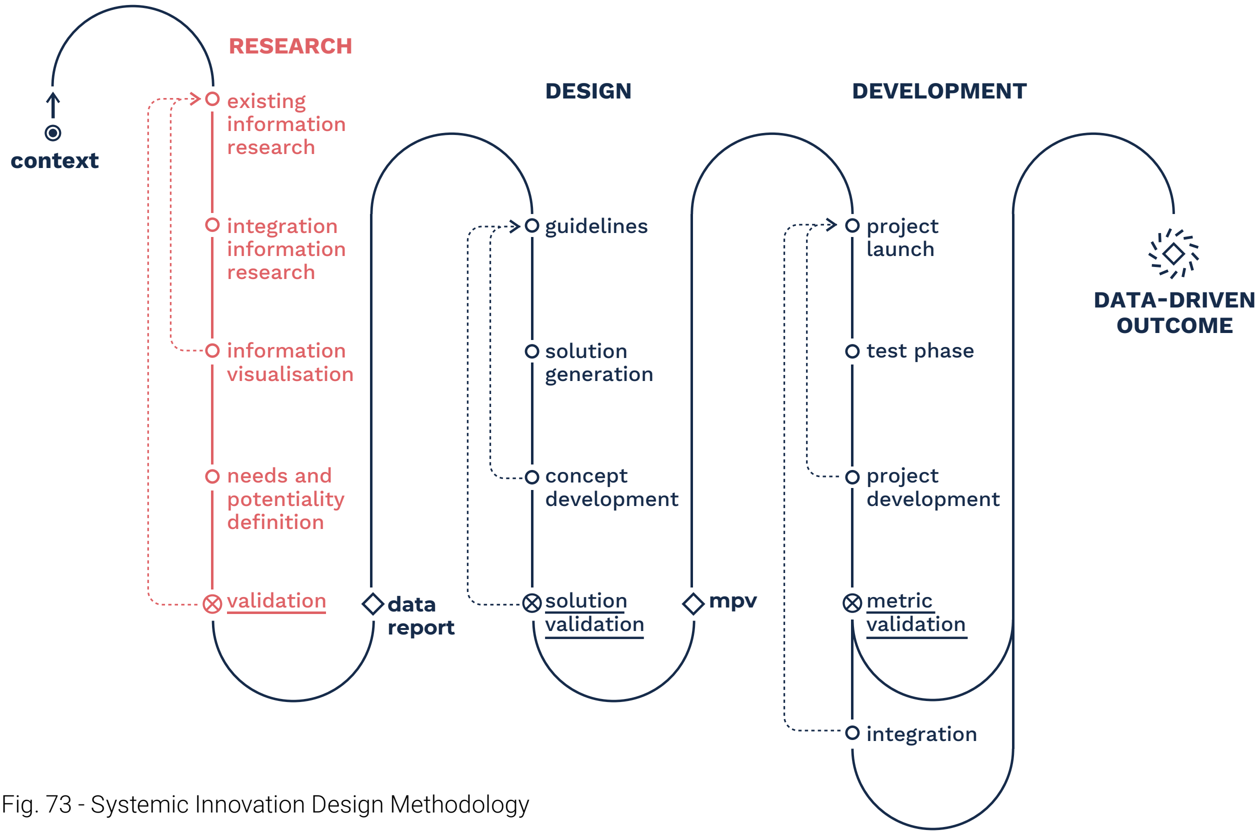

Fig. 73 - Systemic Innovation Design Methodology

developed ideas to formulate a solution;

/ a project manager or team leader that may mould these parallel efforts at the end of the process.

4. Which are the differences between a method and a methodology?

According to the definition provided by Conley (2004):

- A **method** is "a means or manner of procedure, especially a regular and systematic way of accomplishing something".
- A **methodology** is "a body of practices, procedures and rules used by those who work in a discipline or engage in an inquiry; a set of working methods" (Conley, 2004).

For this reason, the methodology in this work is a collection of methods.

5. What do we mean with "need", "classes of needs" and "requirements"?

Although the terms 'need', 'classes of needs' and 'requirement' may seem to be used with the same meaning

- **needs** give a general idea of necessity;
- **classes of needs** collect and unify needs with a similar meaning, assigning a unique name;
- **requirements** are the structured way to define those needs to be translated into design features (**performances**).

9.2 How does it work?

The methodology developed throughout the thesis focuses only on the pre-design phase, also known as research or fuzzy front-end (according to Sanders and Stappers, 2008) or holistic diagnosis (according to SD). We chose to contextualise this phase within the Systemic Design Innovation Methodology applied by the Innovation Design Lab (IDL) of the Politecnico di Torino (Gaiardo and Tamborrini, 2017). Fig 73, indeed, shows the methodology applied by the IDL which aims to enhance territorial needs and potential through design. Although more focused on data,

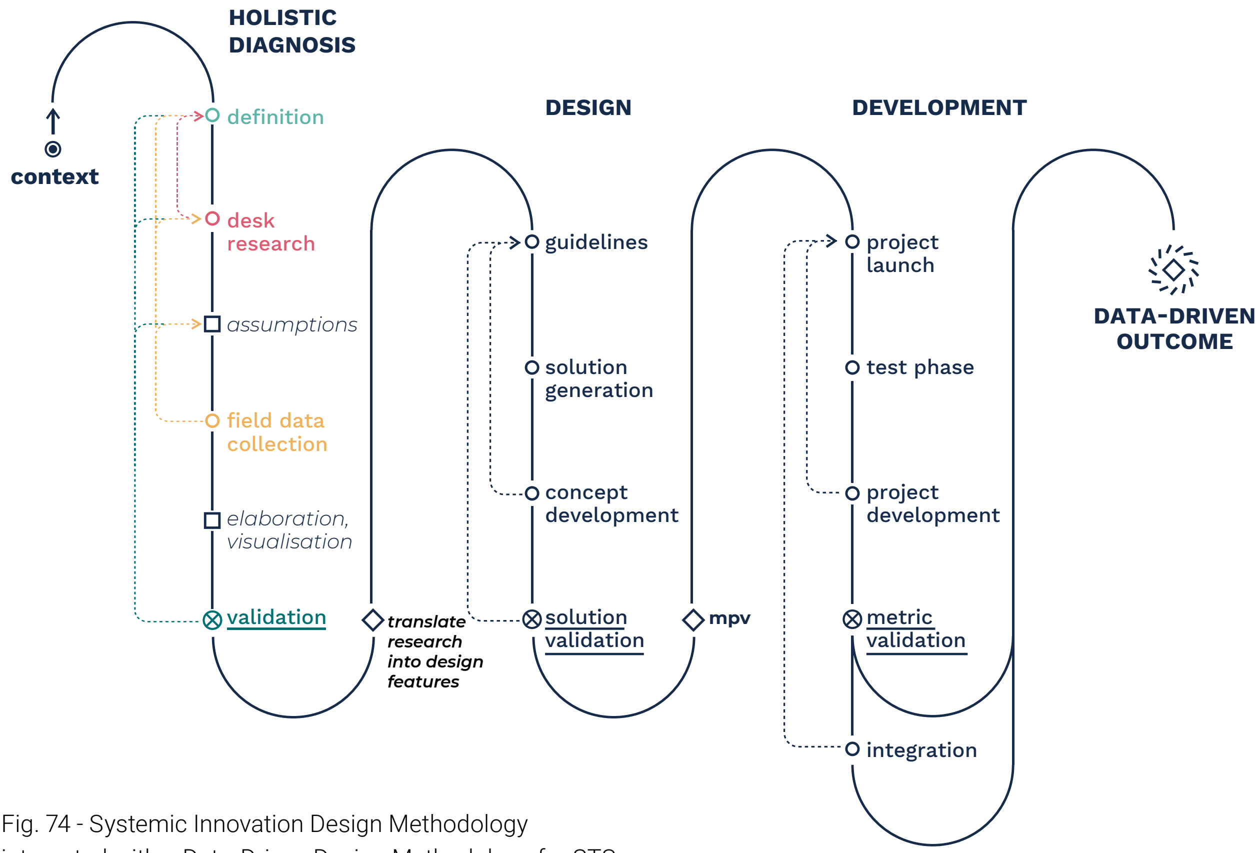

Fig. 74 - Systemic Innovation Design Methodology integrated with a Data-Driven Design Methodology for STS

the Systemic Design Innovation Methodology falls along the general structure of 'conceiving an idea, designing an artifact and then testing the design'.
I focused on the first part, that is the pre-design stage or research phase and I modify it to make it suitable to deal with sociotechnical systems.
Four phases characterise this methodology:

1. **definition**;
2. **desk research**;
3. **field data collection**;
4. **validation**.

9.2.1 Definition

The context gives us the starting point of the analysis. It can be an environment, a territory, a situation and it can include a problem as a starting point. We do not intend design as a form of problem-solving, but the process of framing problems in terms of intentional actions that lead to a desirable and appropriate state of reality. I believe that asking questions is the effort of intelligence that designers are required to provide, as well as framing the research, understanding where we want to go and how to reach a specific goal. In the analysis of a system, we could identify critical issues. During the process, we need to understand how to address them. In this process, problem definition and problem solution evolve together, in a never-ending 'problem reframing'.

9.2.2 Desk research

The desk research can be performed as ethnographic research with the methods preferred by the designer. It can integrate qualitative or quantitative data, retrieving them from different sources that include web data, open data, books, reports, blogs, journals and so on. Each research should be performed with the most suitable methods for addressing it.

9.2.3 Field research

As for the desk research, the field research can be performed with the most varied tools (data recording, surveys, interviews, prototyping, co-design participatory session etc.). In this thesis, we explored new technologies and communication tools and new forms of 'knowledge' (i.e. IoT data and Artificial intelligence), and we promote their use as

tools for the field research.
The use of IoT data for design purposes provide us with the tool necessary for grounding the decision-making on reliable information. Throughout the thesis, we listed the potential benefit of using IoT indicators to collect missing information about, the product, its use, the dynamics that concern it and the environment that surrounds it, up to understand how to fill the gap perceived by the user between needs and solutions. Planning the data collection is part of the designer's task, which begins by identifying which parameters the designer can investigate, the data that he/she needs, in a way he/she can translate them into design features. Then, setting the questions is a relevant activity for this methodology.
Instrumenting products in the field research aims to investigate:

- the current scenario
- the environmental impact of the product
- the use of materials related to the product
- the product operation
- the usage dynamics
- the relation with the user
- the relationship between the product and other objects in the application domain

However, I believe that the best insights are obtained by combining those IoT data with direct feedback from the user.

9.2.4 Elaboration and validation

The insights gained from users will be combined with the experience gained through the field research (about context, application domain etc.) to develop scenarios of potential futures. Then we need to validate what we found. The designer that follows this methodology should return to earlier phases to re-evaluate previous decisions.

The need for a data management platform

Throughout the thesis, I expressed the need for new tools able to keep all the pieces of the holistic diagnosis at hand, enabling to keep the requirements at hand in every step of design, managing the information, validating, testing allowing running changes, thus providing the fluidity needed in dealing with sociotechnical systems and providing a platform on which to share concepts and models. Herein, we renew the need for a tool that keeps track of all the decisions, the considerations, the data that have been filtered by the research team. In this way, the designer should be able to act when an assumption is not validated at the exact point at which that decision was made, reanalysing the data or repeating the research with new variables, reformulate questions and so on. This design strategy promotes the communication with the user, involving his/her active understanding of the design process and the data used.

Validate the results of desk research

We can ask our users how they behave towards the critical issues that we have highlighted through the desk research. In this step, the design team should investigate the user behaviour related to different aspects of the product through surveys, games or other methods.
In particular, we suggest you collect insights on:

- needs and requirements
- attachment dynamics and how users would like to extend product lifetime
- purchases dynamics
- how they deal with repairing objects
- what they do in case of product failures
- how they dispose of products.

Validate the results of field research

After the field research, you will have collected a huge amount of data and you will have to structure it to obtain relevant information.
If the process has been conducted in a structured way, the field data collection should have already been done based on desk research, and, therefore, data processing should be sufficient to validate or discard the initial hypotheses.
However, while collecting data, we may come across new assumptions that derive from the patterns discovered in processing. It may therefore be necessary to interview the user again to understand if the patterns are coincidences or if the user really behaves like that and is aware of it.

9.3 Research factors

This methodology aims to access more precise forms of knowledge, starting from the abstracted knowledge of the design team, addressing local, tacit, practical and situated knowledge of different factors which will be analysed using the same

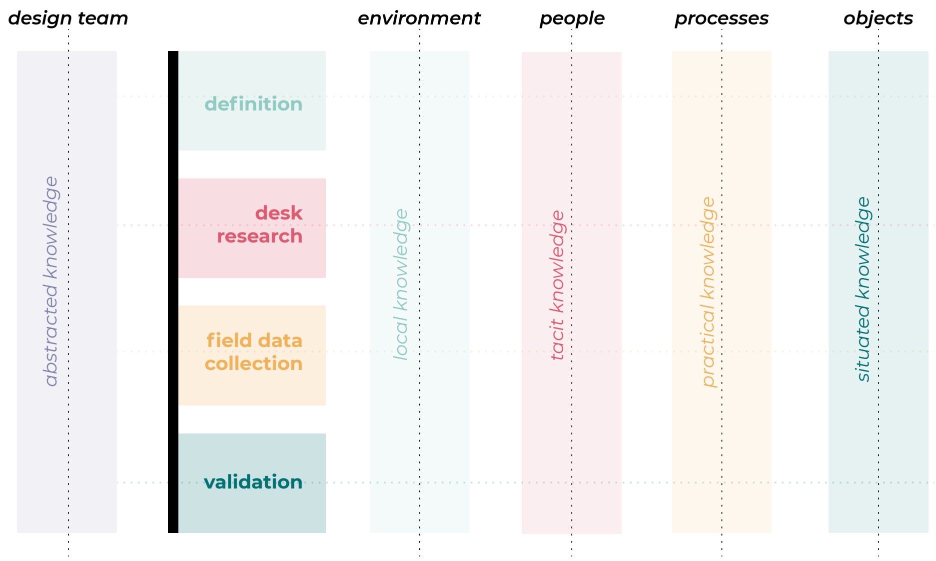

Fig. 75 - The factors being analysed and the knowledge they provide

methodology.
The factors that constitute the vertical axes of the scheme and are:

1. **Environment**: natural environment, context, operating environment, social environment, but also territory, town, region country.
2. **People**: direct and indirect stakeholder of the system.
3. **Processes**: tasks and workflows in the operating environment concerning the object of the analysis.
4. **Objects**: the object on which the analysis is performed but also those closely related to it.

9.3.1 The design team

No matter if we are a design practitioner or an academic, before starting to deal with sociotechnical systems we should make sure we have all the expertise on board and that our team can cover most of the issues that we may face. We should not be afraid to integrate team members along the way, as the different steps of the analysis become more defined.
This kind of systems, in fact, should be addressed in interdisciplinary or transdisciplinary teams.
We give our basic team hypothesis, which seems appropriate to address projects especially intended for STS (Figure 76).
Experts from natural sciences could help us to address the issues related to the environment
Social scientists help understanding people, their needs, behaviours, etc.
Information technology experts help the design team to collect, manage and process data.

9.3.2 The environment

Definition

Analysing the application domain consists in defining for which context the project is designed, where it is intended to work, for which environment and with which characteristics. It includes which stakeholders are involved and how they interact with that environment, what they take, what they leave, what they change and for what purpose, which stakeholders indirectly influence that application domain and how. The application domain or operating context, indeed, can be described and observed by humans, but also sensed by objects.

Desk research

Studying the operating environment means analysing which resources, materials and flows are involved in it. The desk research can be performed with different methods, integrating qualitative or quantitative data, retrieving them from different sources that include web data, open data, maps, books, reports, blogs, journals and so on. We do not place restrictions on it.

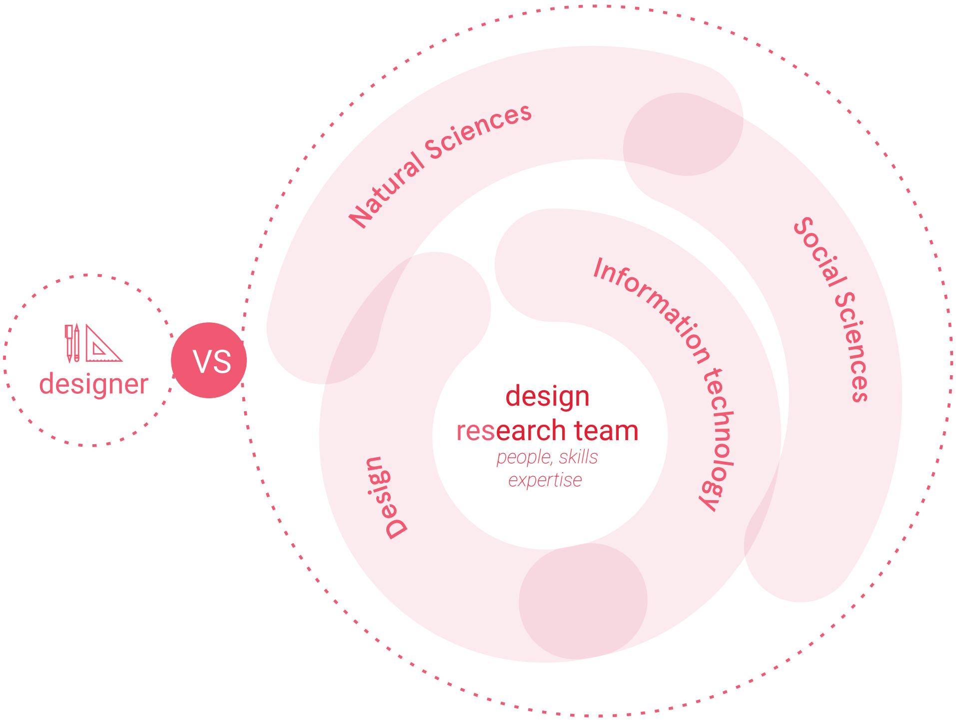

Fig. 76 - A research team for STS (hypothesis)

Field research
The field research should be directed towards the measure of environmental impacts (resource consumption and waste generated), the materials used and the relationships that are established in the context. These data could be measured and collected and could reveal insights about the environment and the relationship with the users.

Validation
During the validation phase, we can validate if the field research also supports the data collected through the desk research and if the process leads to discovered new interactions that we had not considered before.
Figure 77 provides an overview of how the environment has been addressed.

9.3.3 Users and stakeholders

When we talk about sociotechnical systems we also deal with human factors and we implicitly consider that they derive from 'different stakeholders'. For this reason, every project has its own stakeholder network. Complexity goes hand in hand with the segmentation of knowledge to tackle a specific node of the system. Setting the dialogue combining expertise creatively and effectively is a difficult task (Norman and Stappers, 2016).

Definition
The first step consists of identifying the relevant stakeholders, direct and indirect actors of the STS. The stakeholders are peculiar to the system we are considering, cannot be generalised and their correct identification allows us to proceed with the analysis. For some products, the task of identifying stakeholders may be easy to perform. In sociotechnical systems, however, the same task can turn to be complicated. It depends on the boundaries that we set in the system itself and the dynamics that we want to consider. Once defined, we may realise that we lack the skills to address the needs of all the stakeholders, and therefore we may have to implement the design team.

Definition: Needs and requirements
Designers should empathise with the user "considering their needs and desires from an external observer's perspective and working to embody the people they made things for (Zimmerman et al.,

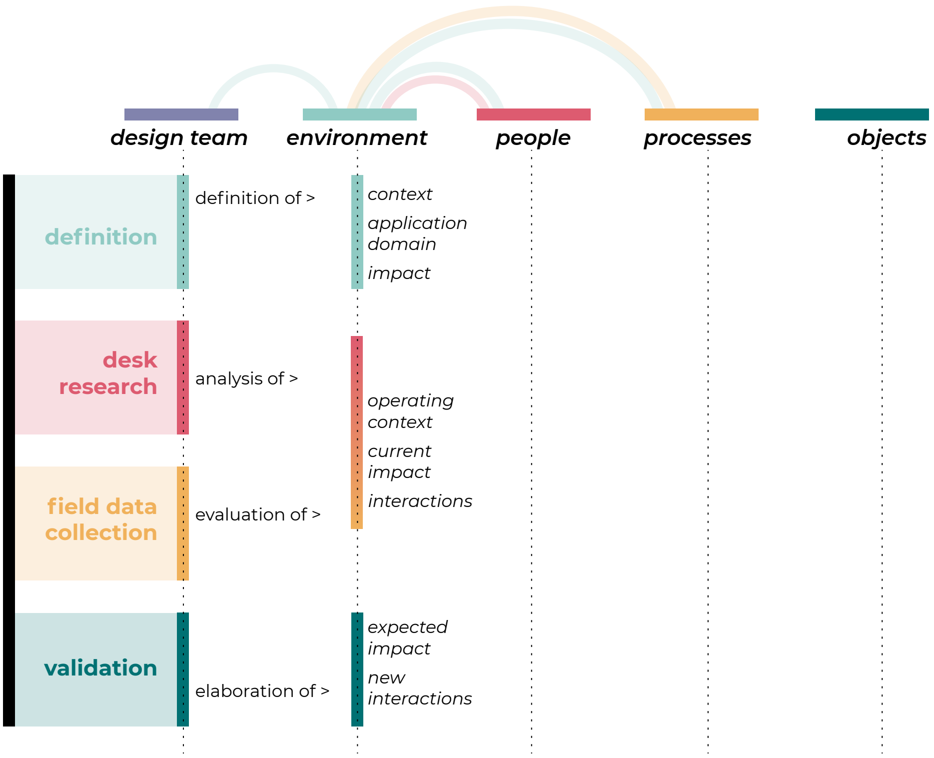

Fig. 77 - An overview of the category "environment"

2007). Needs and requirements are assumed through a well-defined process described in chapter 2 which consists of:

1. **Requirements elicitation and discovery**
2. **Requirements specification**
3. **Requirement validation and verification**
4. **Requirement management**

We consider identifying, prioritising and managing requirements as an expression of the system's values.

Desk research: requirements elicitation and discovery
Performing the desk research consist of investigating social contexts, culture, interests, behaviours, value, skills, habits and needs of the users involved.

Understanding the needs of different stakeholders
- Mapping stakeholders
- Metaphor and personas definition, ethnographic research, scenarios, brainstorming are among the methods used for the requirement elicitation, enhancing the identification and the assimilation of information.

Understanding the current operating context of the product
Collect data about the social, cultural, economic and political context. Investigating social contexts, culture, interests, behaviours, value, skills, habits of the users. This task could partly overlap with the analysis of the environment.

Selecting from collections of proposed requirements
The designer can choose the ones he/she prefers, we try to propose our classes of requirements (Figure 78) After this process, the designer should be able to define a set of context-specific requirements about stakeholders involved in the process.

Field research: requirements specification
The field research consists of two stages
- Modelling requirements
- Prioritisation through co-design activities

Modelling
Modelling refers to the creation of abstracted representations (models) of the worlds (application

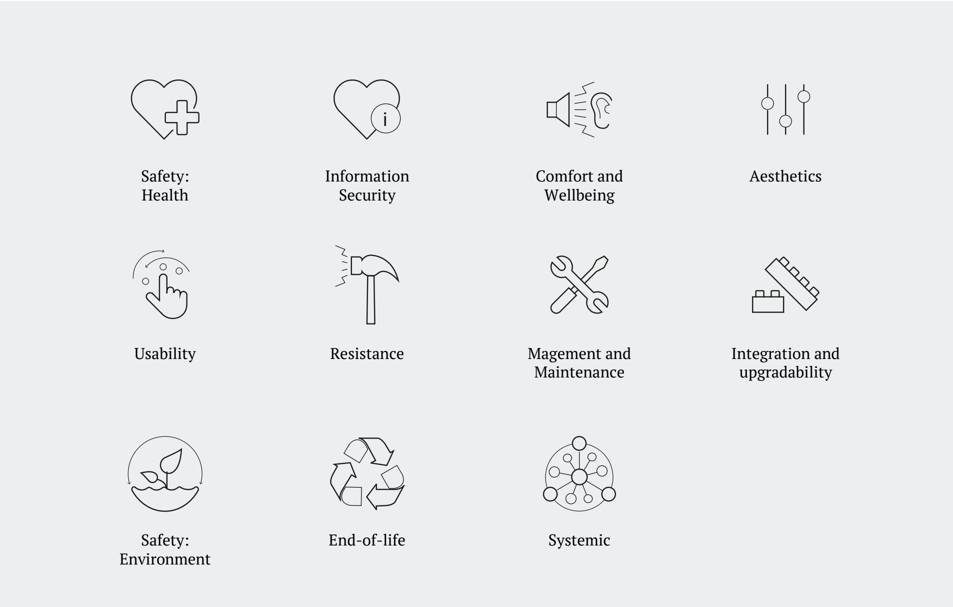

Fig. 78 - Proposed classes of requirements

domain) that leads to requirements specification. In contrast to elicitation models, late-phase requirements models tend to be more precise and unambiguous (Cheng and Atlee, 2009). Modelling activity leads to requirements description, defining lexicon, structures and rules to understand the problem (on the one hand, system boundaries and constraints, on the other hand, assumptions, dynamics, relationships and behaviours). Models seek to identify unstated requirements, predict behaviour, determine inconsistencies between requirements and check for accuracy (Hansen et al., 2008). Eventually, models lead to skim the information, up to record and monitor a single piece of information to answer a specific requirement. Among the tools used for modelling the requirements for the stakeholder comprehension and subsequent validation, we list scenario-based models, animation, prototyping to name a few.

Functional vs non-functional requirements
Functional requirements are measurable requirements that can be validated objectively.
Non-functional requirements (NFR) incorporate the quality expectation for a system, often referred as "ilities" (usability, maintainability, reliability, adaptability) (Mylopoulos et al., 1999), but also security and privacy. By definition, NFR do not have quantitative satisfaction criteria (Ernst et al., 2008). Functional requirements are represented as hard goals, while non-functional requirements are represented as soft goals (Ernst et al., 2008)

Prioritisation through co-design activities
Designers should mediate between stakeholders' conflicting requirements values, roles and goals while keeping the system's overview. For the prioritisation of those requirements, all the relevant stakeholders should be brought together to discuss and find a common view of the issue. We consider co-design methods such as games, that can also be performed on strategic cases, to extract different points of view and mediate opinions. These participatory sessions should result in a possible mediation on specific needs and produce an increase of knowledge. At the end of the process, the design team should be enriched by the direct observation and should be able to collect all the perspectives to convey in the project.

Validation: requirement validation and verification
For the validation of the abstracted requirements that come from the above-mentioned processes, the design team should first understand if the needs individuated reflect the real needs of the relevant stakeholders. This can be done in different ways, e.g. by interviewing them individually. Social contexts, culture, interests, behaviours, value, skills, habits can be verified in the same way or they can be verified through experiments.
Figure 79 provides an overview of how the category "people" has been addressed.

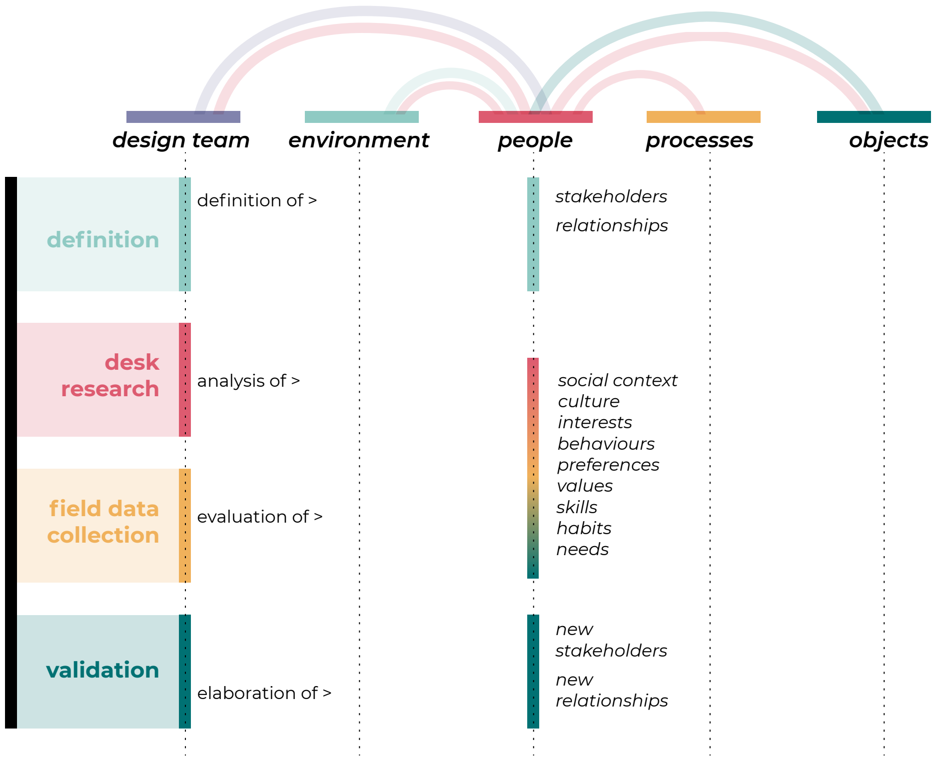

Fig. 79 - An overview of the category "people"

9.3.4 Processes

Definition

If we want to address real problems, we should understand the actions and behaviour relater to a certain product or operation. Focusing on actions and tasks, simplifying them and trying to recognise them in complex patterns could be a way to reduce consumptions.

Desk research

To investigate the user habits, the designer should define the classes of habits he wants to investigate by analysing:

- Current tasks
- Current workflow
- Current interactions

Field research

Investigating tasks

The field research could be performed through prototypes instrumented with IoT technology that may help the design team to:

- address critical aspects in the design stage
- investigate requirements related to tasks
- extending products' lifetime

Field research: participatory sessions

The selection of participants must take place through questionnaires and games that could highlight if the user shows the attitude necessary to be a co-designer.

1. **First part: observation**
   We are planning activities in which we ask people to do some tasks, recording their operations, habits, postures and way of doing things. This observation could be made with traditional methods (camera recording, audio recording) or through objects/prototypes instrumented ad hoc to collect qualitative or quantitative data. We must differentiate the direct observation from the one carried out remotely with the use of monitoring instruments. Moreover, this first step could be performed in an environment set up for experimenting or by bringing instrumentation into the contexts in which that operation normally takes place (hospitals, domestic environment, workplace). Observation may last from a few minutes up to require monitoring

long periods of time. In the second case, the means of observation should be placed in the real operating context.

2. **Second part: reflection**
   A second part of the observation aims to make the users aware of what they are doing and could be performed by asking questions while they are doing things. In this way, the designer can stimulate users to reflect on the way they are performing those tasks with the goal of highlighting which critical aspects they find while operating, what could help them, how could the work be more straightforward. Even in this case, the performance could be done remotely, by asking questions with the help of tools (apps, web portals or other platforms).
   A face-to-face discussion between the user and the design team is necessary. After the user is asked to notice how he/she is performing tasks he/she become aware of the purposes of the study and the design team must be available to answer all the questions. At the end of this session, the team should introduce the next co-design practice.
3. **Third part: co-creation**
   A third part should involve participants, by stimulating their creativity, providing views and tools for encouraging ideation, expression and visualisation (de Arruda Torresa, 2017).
   As the design team acquires insights on the real use of products, on dynamics experienced by the users while performing some tasks, the design team must start making hypotheses, which should be validated with the user. These hypotheses must be presented to the user as concepts, prototypes, visualisation of data or scenarios, storytelling, etc.

Possible issues

The design team may find it difficult to explain to users the purposes of the study, without revealing too soon some aspects that should be introduced gradually. At the beginning of the process, users should be involved without revealing exactly what they should do. Users should behave normally, without being influenced by the purpose of the study. Their unawareness is necessary for the first step. However, while this is true for short experiments (a few hours or days), it becomes irrelevant for long periods of time, because the length will lead the user to behave normally, forgetting about the study. In general, users must trust the team, which should explain and guarantee that they will collect data that will be used exclusively for improving products and facilitating the user's daily operations. Moreover, the design teams must be clear on the commitment required to users, specifying how long the user will be involved and how much effort has asked him/her to provide (how often he/she will have to provide feedback or participate in co-design sessions). Clear scheduling could help.

How to engage users is not trivial, especially when a sort of invasiveness is hypothesised. Moreover, find users which are suitable for our experiment, able to carry out all the steps, is not easy too. The high risk is that, especially for long experiments, the user gets tired, changes his/her availability of time, or becomes uncomfortable with the experiment, deciding to abandon the process. The risk for the design team is significant (in terms of efforts, time and money wasted), so the premises must be clear, the attitude of the people involved must be carefully studied before proceeding.

Validation and verification

The validation task can be performed with the user through interviews or surveys.

Figure 80 provides an overview of how the category “processes” has been addressed.

9.3.5 Objects

According to Zimmerman et al. (2007), we could be able to analyse artefacts to discover patterns. Researches can be performed with prototypes or current products instrumented with sensors for a specific purpose. The material objects’ perspective adds a perspective to the investigation of patterns, interaction, places, contexts. The potential of using ‘thing ethnography’ as a tool for designers is gaining appeal among researchers in the design field:

Things’ perspective gives a different point of view about things’ use and movements, understanding relationships among people, objects and use practices that would be difficult to elicit through traditional observations and interviews alone (Giaccardi and Cila, 2016).

Definition of current products

In this first step, we should understand which products are used to perform a certain task, which

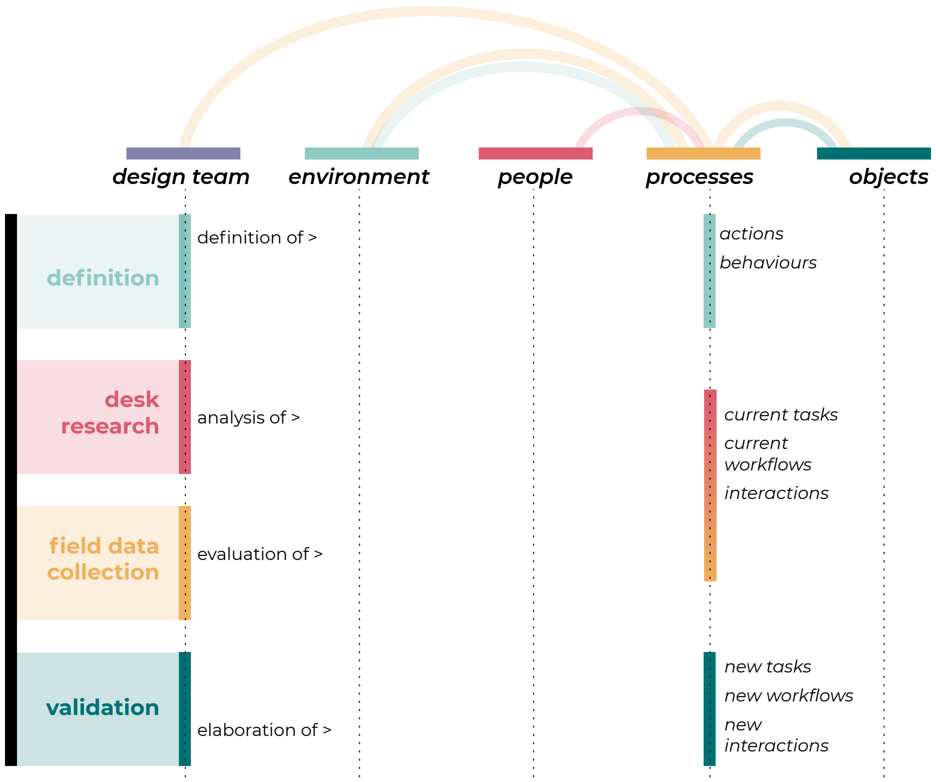

Fig. 80 - An overview of the category “processes”

classes of products we want to address up to detailing only one category of products. Then, there may be other complementary products that deserve to be identified and analysed to understand the dynamics around the “product-focus”

<u>*Desk research: the analysis of current products*</u>
Products are current solution to specific tasks, issue and contexts.
Current products, indeed, contain "knowledge", because they have been considered (in a certain time) functional to respond to a certain need. This knowledge can be obtained backwards, through the decomposition of the object. In this way, designers can study the individual pieces, how they are connected, how they work together to perform a certain function, what materials are used and why. At the end of this analysis, the designer should be able to divide the product into functional groups and understand which functions the product analysed was asked to perform.
Background information, history of product development, context, functions, alternatives, market and purchase dynamics, impacts along the lifecycle are among the data that designers should collect, together with trends analyses, the features of the most recent and premium products.
The final goal of this analysis could be:

1. Extending the product lifetime
2. Work on attachment dynamics

Investigate attachment dynamics and other lifetime extensions
The designer should investigate the current attachment dynamics with the product, in order to investigate how to establish new relations with the object and, in general, how to extend product lifetime. The designer should gather materials for interviews and make simulations to stress this topic.

<u>*Desk research: deconstruct current products*</u>
This task should guide the designer to extract valuable information from a physical object to redesign it. It can be performed on every object having the possibility to disassemble, measure and observe it. These considerations should help designers to question, understand, reconsider every part (or group of parts) of current objects and their functions, individually or by grouping them. This process leads to define the performances of the

product. It also allows members of a design team to focus their efforts on manageable tasks.

Note: Although shapes and features of different products may be different, we could consider that most of the products of a certain category are quite similar, presenting a similar structure and characteristics and, hence, similar disassembly processes. However, we advise the designer not to analyse premium class products and to consider that some conclusions will not be generalizable nor applicable to all the products in that category. The intent is to acquire deeper knowledge about the product composition and get insights on the design choices that led to that product.

- **Disassembly.** Disassembly methods such as reverse engineering and design by components could provide designers useful guide on how to perform product disassembly and reduce the product into functional groups. The designer should physically deconstruct the product and write down for each component:
    - o how it was connected,
    - o which group it was part of
    - o its weight
    - o its materials
    - o ..

  The designer should get an exploded view of the object parts on which to mark these annotations. Then he/she should make a summary in a table with components, weights, functions and materials (Bill of Materials), establishing how many connections are reversible or not, how many different materials are involved and how many components
  are made of materials that are irreversibly combined. These data can be provided by a manufacturer and the connections between components can be appreciated on a 3d model. However, the physical disassembly of an object gives the designer pieces of knowledge that we define as a mix between situated and practical knowledge.
- **Accessibility**. On an exploded view of the components, the designer should consider the ease of accessing each part for maintenance and replacement purposes, highlighting if the task is easy, medium or difficult to perform.
- **Functional analysis.** It comprises activities that enable the understanding of goals. Functional decomposition of a product represents a way of identifying product's major functional aspects (Alexander, 1964). This analysis helps to identify specific functions, understanding which parts are needed to perform that function. Designers should try to obtain the maximum simplification and abstraction able to foster new design ideas. Products should be reduced to functional units.
- **Understanding the behaviour of the product in a controlled environment**
  We can measure dissipations, energy consumption, use of resources and so on (i.e. some parameters that are directly related to the object itself) only if we place the object in the laboratory within controlled dynamics. In this way, we can deepen the reverse engineering process, by understanding the object's operation through tests, using the product for a specified period in a controlled way, perhaps having multiple objects at the same time acting as a control.

<u>*Desk research: case studies*</u>

The case studies section aims to investigate either conservative or disruptive scenarios (from the redesign of the current solution, up to promote new scenarios and paradigm shifts). We perform this task through the analysis of the case studies. Some of them could be deliberately chosen to deny the idea of the product itself, by investigating alternative scenarios (e.g. without the use of energy or with a completely different form, breaking down the different functions into individual components, etc.). The choice of case studies is fundamental and should be lead to formulate some 'preliminary guidelines'. Therefore, the case studies convey the idea of the designer on future products, because some specific keywords will be used to search for them and then select them. For this reason, case studies research should be repeated throughout the design process, to refine the research as insights are acquired from other analyses.

If we want to direct the research towards sustainable product-systems, case studies should include those products characterised by proper management of energy and resources, reuse of output and the recovery of dissipation (in a systemic perspective). Biomimetic alternatives to perform functions are encouraged. Case studies can include experiments, research projects, prototypes. Products should not be necessarily on the market.

Field research: product instrumented with sensors in its operating context
Instrumenting current objects or creating prototypes that contain sensors requires careful planning of which data the designer needs, according to the final goal and what he/she want to prove. This part does not focus on the technology itself, but results it achieves, the performances, the functionalities, the tasks it allows. Dynamic data are those data which vary over time, deriving from the context of use and interaction with users, which can be acquired by investigating the
object in its everyday environment, combining:

- **quantitative data acquisition** (sensors) by monitoring, accessing more precise knowledge of products and stakeholders useful for design purposes
- **qualitative tools** (feedback, questionnaires, interviews).

We see the 'potential' in new technologies and the data they make available to be used in the design process, overcoming our computational brain limits and thus playing a role in problem-solving. This phase has the main goal of discovering patterns in the use of those objects. Data insights should be used for the development of meaningful products. Technologies can be exploited to improve the precision, accuracy and variety of information collected.

Objects in relation to users and contexts of use
If we place the instrumented object in a real-use context, those parameters become closely related to how the product has been used by its users. Beyond question "How does the product work?" addressed in the previous section, it is now important defining what happens when the product is being used, by monitoring some physical parameters over a continuative period of real-use.

Implications on product lifetime:
Moreover, the design team could monitor a prototype and then make projections over time about the expected use, to determine when the object should be replaced or updated to obtain the maximum value from it. This could be the case with the following three examples, by monitoring:

- **Functional groups**, i.e. system of parts grouped by a specific function;
- **Main components**, i.e. parts whose breakup will compromise the whole product, eventually leading to replace it;
- **Wearing parts**, i.e. parts which can be easily replaced.

Some relevant indicators should be defined and verified by measuring them through ad hoc experiments on these components, providing a more precise knowledge of the system.

Objects as part of STS
This phase has the second goal of understanding the behaviour of the object as part of STS dynamics, highlighting a potential innovation at three levels:

- redesigning the product;
- foresee systems able to learn and adapt evolving over time;
- discover implications for product durability and circular business models (e.g. product evolution, adaptability and reduced ownership);
- redesigning the dynamics around the product;
- redesigning part of the system;
- readdressing users' motivations in its purchase, use and disposal.

Expected benefits:

- More accurate repairs
- Connections to other services
- Save time, save money
- Conserve energy

Ethical implications
Ethics: designer's responsibilities and ethical implications of dealing with new ubiquitous technologies are undeniable. For this reason, the designer should always ask him/herself

- "Is there someone who can suffer from some actions or could be subjected to improper actions?"

If the answer is "yes", "probably" or "maybe" the second question is "could this consequence be avoided or foreseen in any way?". If the answer is "no", then that action or task should not be developed nor be carried forward. If the answer is "yes" then the process can be reiterated to include a solution that solves the problem, so that the first question can be

answered "no".
Moreover, safety and security, environmental sustainability must be considered as non-negotiable values.
When we want to push technologies over products, then we should ask ourselves:

- "Which task does the individual want to perform?"
- "Could the task be facilitated by some technologies/automation?"
- "Could the use of technology/automation affect human wellbeing or environmental security?"
- "After the implementation of the technology, will the human still be the decision-maker?"

To prevent or at least mitigate side effects, the designer should ask him/herself:

- "Can the technology be manipulated for other purposes, even by the same user? How?"
- ""Can the technology if misused become counterproductive for the same goal for which it was intended? How?"
- "Can I foresee them in the early stages of design? How?"

To prevent most of the adverse side-effects of technology, I suggest taking into consideration the following guidelines, which derive from the question asked above (we refer to chapter 3 for detail on those aspects).

1) **Consider privacy, security and data accessibility**
2) **Protect the human agency**
3) **Promoting physical interfaces**

In general, the guideline to follow is to improve the well-being of our users.

Validation and verification
The validation can be performed with the user through interviews or surveys. However, the designer now should study the data gathered to reach the product development. The main validation will come later, by applying those results to shape products and then testing the concepts and prototypes obtained with users and measuring the related performances.
Figure 81 provides an overview of how the category "objects" has been addressed.
Figure 82, instead, gives us an overview of all the pillars and how they influence each other.
We can see which steps refer to traditional ethnography and which refers to the 'things ethnography', supported in this thesis.

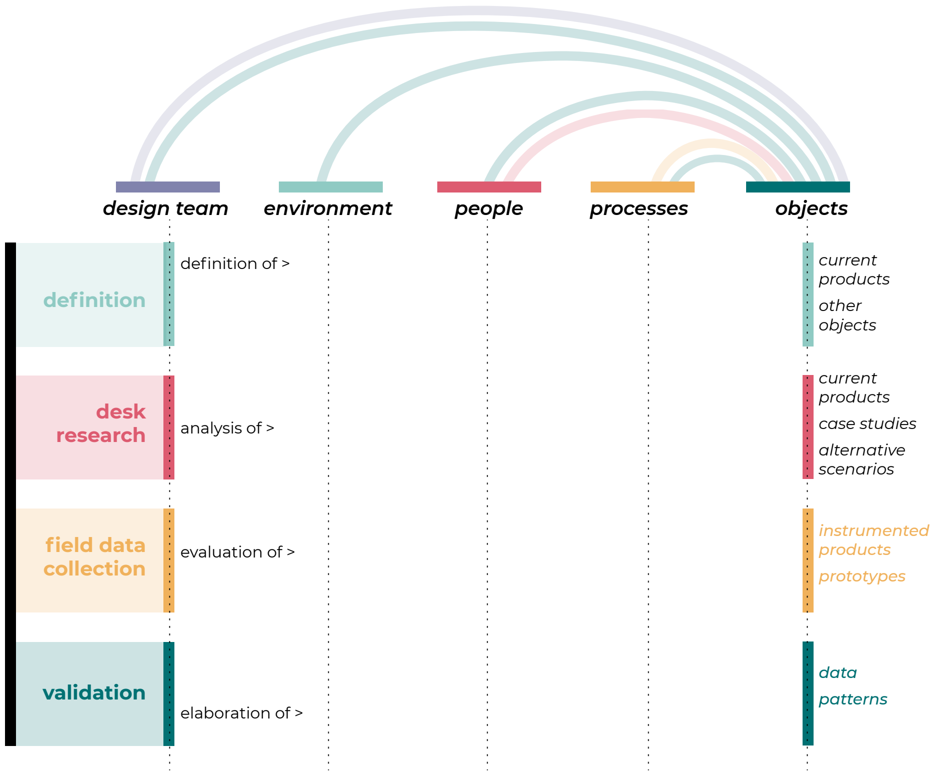

Fig. 81 - An overview of the category "objects"

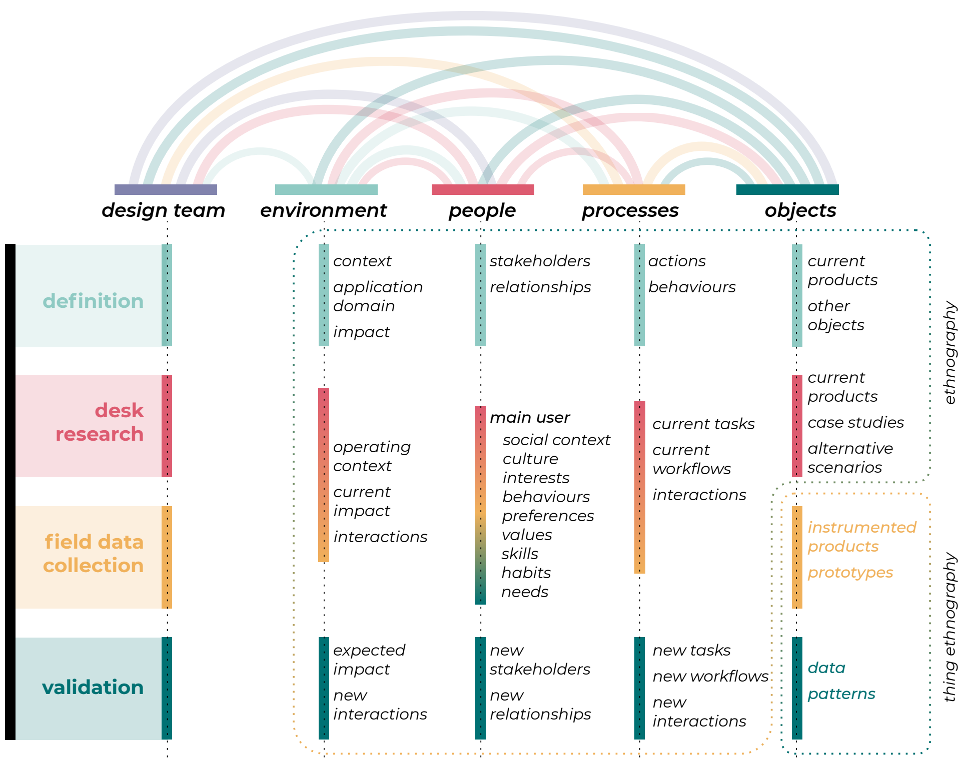

Fig. 82 - An overview of all the pillars and how they influence each other

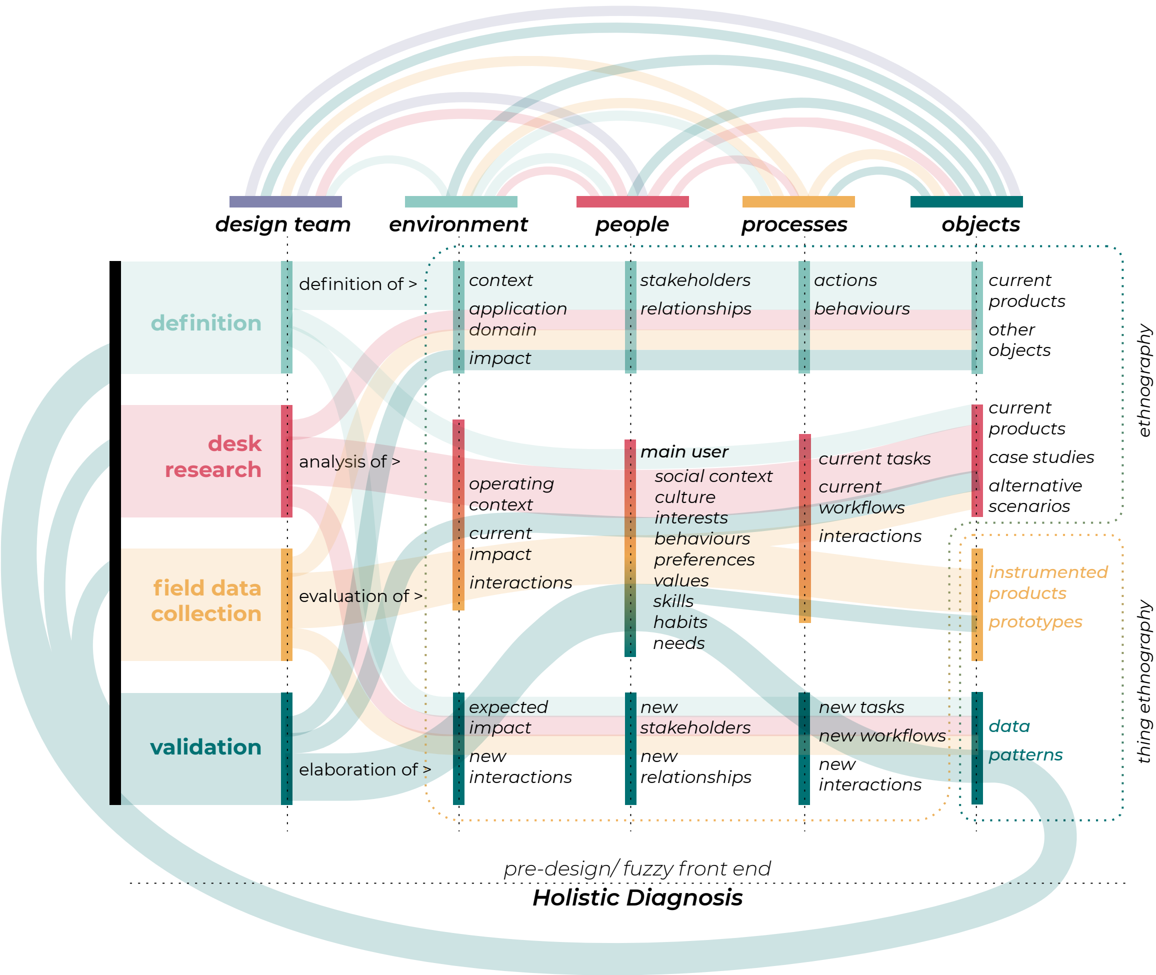

Fig. 83 - Complete methodology

9.3.6 The whole methodology

Figure 83 provides us with an overview of the methodology, which has been seen in pieces throughout the thesis, especially in this last chapter, which can now be unveiled. We can see how all the parts intertwine and how the validation part is reflected in all the other steps.
This methodology should support the designer to perform the holistic diagnosis for designing products that fit into STS.
I decided to extract guidelines from every step making a simplified handbook for the designer (figure 84) which is a summary of the concepts that have been addressed in this chapter.

9.4 Final remarks

9.4.1. The new role of the designer

In 1980 User Centred Design (UCD) codified a way for designers to conceive of their relationships with people that will use their designs, structuring the role of the user (or 'human') that matters in design processes, whose understanding of needs, abilities and perspectives should improve the effectiveness of a design. (Cruickshank and Trivedi, 2017). Now we need an inclusive design approach to deal with the new smart objects able to sense and experience the world and collect information from environments and contexts (Cruickshank and Trivedi, 2017). How can we design for this complex system of people and

things? Understanding how designers adapt their design practice to deal with the IoT is not enough.
Throughout this work, we addressed the question
Which is the role of the designer in planning data collection in the early design stage in order to design meaningful products?
We have seen which efforts are required to designers, which ethical implications they must take into consideration, their role in the processes of mediation between stakeholders and within the team and how they should relate to the objects they analyse.
Design research probably needs new platforms for performing future design practice (Lindley et al., 2017), able to provide the necessary fluidity to address both uncertainty, evolving requirements and things perspective. It can be noticed that many design researchers consider design tools and methods as insufficient to deal with the complexity of STS, evolving requirements and the new challenges of smart technologies.

9.4.2 Critical aspects in applying the methodology

This methodology undeniably implies long times, involves the organisation of participatory sessions, the need for spaces and equipment to perform the disassembly of objects, the construction of prototypes and the instrumentation of products. Moreover, it requires designers to set the dialogue with different experts who should be involved in the project from the very beginning. For these reasons, we do not expect it to be used when time and cost constraints are too tight. The methodology is indicated for long-term research projects when the client does not expect results that can be immediately translated into marketable products. It is, therefore, suitable for large research groups, R&D centres of big companies, or start-ups that can afford to enlist all the required experts. Reasonable time of application is to be estimated around a year, a year and a half to get complete results, starting from established teams and suitable laboratories.

9.4.3. Iteration and validation process

A simplified methodology will be refined through workshops and courses at the Politecnico di Torino, giving our students some briefs already designed and shaped to be suitable for its application. Nevertheless, we would like to test the complete methodology by asking practitioners and researchers to test it. However, intercept designers who are working on sociotechnical system projects at an embryonic stage, so that this methodology can be tested from the very beginning, is not trivial. Moreover, not only intercepting the suitable condition but also convincing the designers could be complicated.
Hopefully, the publication of the thesis and the disclosure of a more practical annex which contains this last chapter will help to intrigue researchers in design and practitioners, encouraging them to test this methodology voluntarily. It would be essential for us to receive feedback on the process to improve it. For our part, we will test it in the next research projects on STS that we will carry out in our research group.

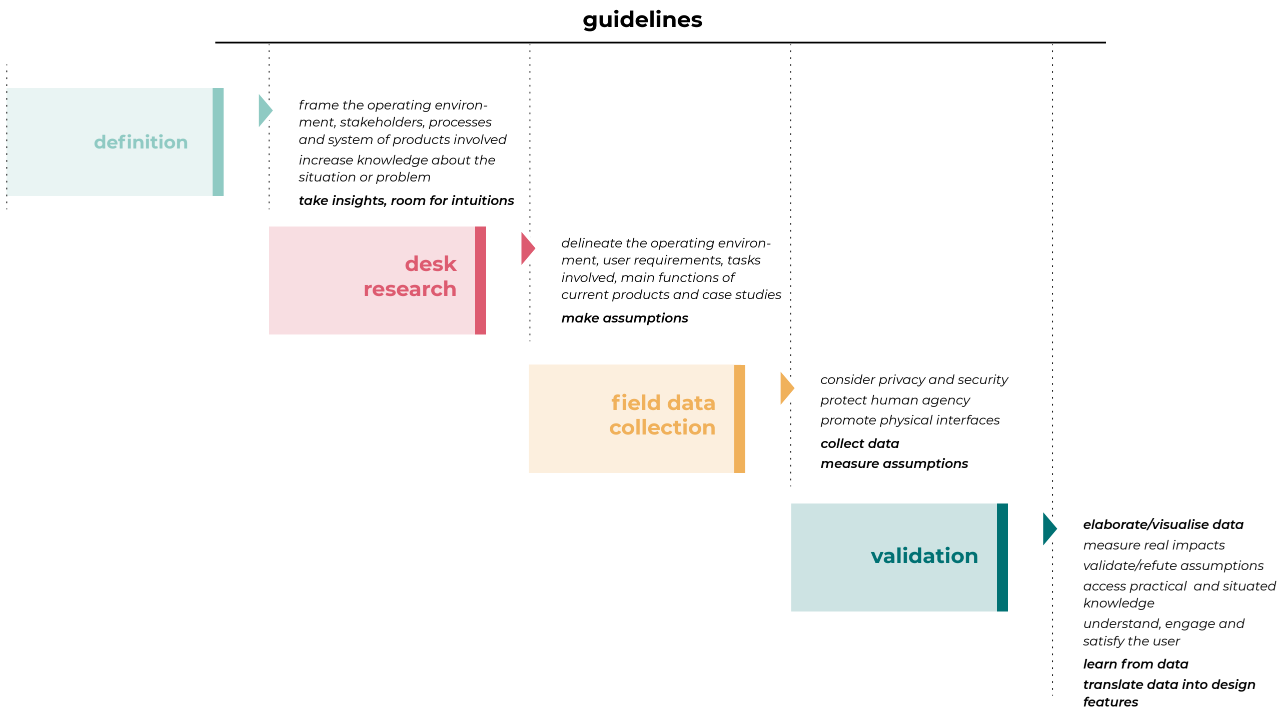

Fig. 84 - Guidelines

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Conclusions

This thesis aims to demonstrate how Systemic Design theoretical framework could be successfully applied to product design in socio-technical systems, as well as to the new challenges derived from new technologies. The ubiquitous nature of emerging technologies, indeed, opens multiple opportunities for supporting designers throughout the design process. While it becomes easy to collect a vast amount of data from the physical world, examples of effective use of this data in the design process remain limited. We introduced the importance of combining the flow of information with the analysis of the most traditional flows of energy and resources. Moreover, we highlighted the need to consider a larger number of stakeholders in requirements definition, decision-making and product development. For this reason, a methodology with a wider vision of the user, the product and the environment has been proposed, with a focus on a data-driven approach. It has been considered the potential benefits of using IoT indicators to collect missing information about both the product and its use, monitoring, accessing more precise knowledge of goods, households, environment and processes, useful for design purposes. In this thesis, I highlighted how the knowledge gained from IoT data could become valuable intelligence and can be leveraged in the design stage, addressing and preventing possible misuse of these data. A more traditional product design approach towards sustainability is intertwined with this focus on object-oriented information and a focus on circular product design is carried out. The systemic design contribution to this work resides in the ability to manage the complexity through the analysis of different levels at different

times (changes of scale), pointing out the inefficiencies of current products and exploiting these output in other meaningful ways in product performances. Moreover, with the definition of an online platform, we can investigate the users' values, preferences, habits directly question them, asking for real-time feedback on design solutions.
The path followed should lead to developing innovative products, more focused on sustainability, able to simplify people's lives in their daily tasks and actions.

List of figures

Tables

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