2018

New strategies for the refrigerator in the transition towards a circular economy

Fiore, Eleonora

New strategies for the refrigerator in the transition towards a circular economy

Eleonora Fiore*

[a] Politecnico di Torino, Department of Architecture and Design

* Corresponding author e-mail: eleonora.fiore@polito.it

Abstract In the last decade, the values of the traditional economy have been strongly challenged, considering the concept of development of the last century as the leading cause of many environmental issues we are facing today. Recently, new strategies have been introduced to provide a renewed concept of development, to achieve a transition towards a circular economy such as the development new revenue models, the importance of intangible value, the merging of products and services as opposed to the strategies of the linear economy. This study carried out a case study on the refrigerator in order to assess which strategies can bring this traditional home appliance towards a circular economy. It has been evaluated every step of its life cycle hypothesising some strategies, following the R-list edited by PBL (Potting et al., 2017) and eventually discussing the need for more strategies on the usage phase and a greater focus on the user as an active part of this necessary change.

Keywords: circular strategies, design strategies, circular economy, predictive maintenance, refrigerator

1. Introduction

In the last decade, the values of the traditional economy have been strongly challenged, considering the concept of development of the last century as the primary cause of many environmental issues that we are facing today. Recently, new strategies have been introduced to provide a renewed concept of development, including some strategies to achieve a transition towards a circular economy that consist for example in the development new revenue models (Potting et al., 2017), a greater importance given to intangible value, the merging of products and services (de Arruda Torresa, 2017) opposed to those of the linear economy.

Another step forward is the introduction of shared responsibility between the consumer, the producer and the recycler, especially for Waste Electrical and Electronic Equipment (WEEE). The European legislation on WEEE, indeed, requires producers and importers to collect and recycle the discarded items from households (Potting et al., 2017), taking care of the end-of-life (EoL) of such products, and the user should dispose of those products in the right way. Consumers can leave electrical and electronic items in the shop where they buy new equipment or take them to municipal recycling centres or second-hand shops (Potting et al., 2017). However, in less regulated fields, many companies continue to pay scant attention to their products after the sale, once the warranty has been expired.

About household appliances, such as large devices and refrigerators and freezers, table 1 provides an overview of the volumes of their collection and recycling in the Netherlands. Discarded equipment could be (i) exported, conferred to Wecycle & ICT Milieu (i.e. two Dutch organisations in charge for the WEEE recycling process) that collect about 30% of large devices discarded and 51% of refrigerators & freezers discarded, (ii) disposed of in other documented ways, (iii) disposed of in not documented ways or (iv) incinerated. The latter option is not practised, although we are aware that in Italy, some parts of the refrigerators (polyurethane foam and other expanded materials) are separated, compacted, extruded in briquettes and then used as solid fuels in the construction sector. However,

the recycling rate in the two Dutch facilities is estimated about 85% (table 2), compared to the recovery rate of 57% (Center for Sustainable Systems, 2016) of home appliances in the U.S.

Table 1. Collection and recycling of discarded electric and electronic equipment, Source Potting et al., 2017

Collection in kiloton in 2012			
	Large devices	Refrigerators & freezers	Total
Dutch market	131	64	175
Discarded equipment	106	49	155

- Export	4	10	14
- Wecycle & ICT Milieu	31	25	56
- Documented otherwise	46	6	52
- Not documented	24	7	31
- Incineration	0	0	0

Table 2. Recycling in percentages of collected equipment in 2014. Source Potting et al., 2017

Collection in kiloton in 2012		
Via Wecycle & ICT Milieu	Large devices	Refrigerators & freezers
- Regulatory aim	75	75
- Realised	85	85

Table 3 shows the refrigerator's material recovery.

Table 3. Composition of output flow of WEE recovery of refrigerators, according to industry take-back scheme, based on real performance recyclers. Assumption of Mt collected by industry across EU (Magalini et al., 2018

EU collection - refrigerator materials		
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

Strategies focused on the end of life could increase the efficiency of material recovery. However, to progress from 85% to 100% is still a long way to go.

If we want to achieve the 100%, manufacturers should rethink all the materials that currently do not have a profitable recovery, in particular, the ones that lose value and cannot be exploited for a second use (i.e. material to energy recovery, polyurethane foam and some types of plastics). Moreover, considering that recycling, especially the low-grade one is relegated to a linear economy, a more ambitious CE transition towards substantially, lower resource and material consumption and less generation of waste will preferably be based on high-circularity strategies (Potting at al., 2017) that we will see in the methodology section. For this reason, in this study, we focus only on some strategies indicated in Fig. 1 as "extend lifespan of product and its parts", avoiding considering “useful application of materials”.

The tendency to think that the environmental responsibility should fall on government, policymakers and manufacturers, is a reductive vision of the shared responsibility. If we think about the mediatic echo of the recent Plastic-free movement, it has been encouraged by the European Parliament and the Council of the European Union that have reached a provisional political agreement on the ambitious new measures proposed by the Commission to tackle marine litter at its source, targeting plastic products (single-use plastics). From there onwards, the big players are all looking for a strategy to tackle the challenge. However, little attention is paid to possible strategies that companies can perpetrate to give the user an active role, as a prosumer, in environmental challenges, or to inform and change some wrong consumer behaviours, that maybe are given for granted with the use of new technologies/digital systems able to facilitate the communication.

In this study, we take into consideration the use of fuzzy products to reduce the environmental impact of the products in which they are embedded. In the case of home appliances, they can achieve a reduction a decrease of energy use and resource consumption, in the case of the fridge it may also addressing the food waste, in addition to energy consumption. While, over the years, refrigerators have reached technological improvements able to halve their energy consumption (manufacturer's side), all the tests that characterise both energy labels[1] and LCA analyses refer to a refrigerator empty, closed, without any interaction with the user.

Therefore, the indicated energy consumption (expressed in KWh/y) is not only underestimated, but it fails to consider the number of variables that change the real energy consumption once the refrigerator is placed in the real context of use and is affected by the householders' dynamics.

Products, people, environment are three variables that affect each other and determine the real impact of a product during its life cycle. For this reason, the LCA, unbalanced on production and EoL cannot work as an indicator for assessing the real impact of products. Moreover, we cannot refer to a product that is more sustainable than another, if we do not consider usage dynamics and the context in which it is placed. Approximations on these aspects risk overshadowing the benefits of a circular economy if we refer exclusively to measurable indicators. We do know that the usage phase impacts more in products such as the refrigerator, which is characterised by a long lifespan (according to

[1] 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 pieces of information to the customer to compare and choose among different products.

Bakker at al., 2014 the ‘optimal lifespan’ of new purchases is now estimated around 20 years) and a continuous use (400-1100 KWh/y according to the related energy class).

In this paper, we take into consideration how products could continuously evolve after their implementation (Hansen et al., 2008) and how manufacturers could benefit from them throughout their life cycle, delivering new services while changing their revenue models. This approach leaves room for addressing every step of the traditional life-cycle in a more circular way, shifting the focus on a more complex vision about the product. This scenario could radically change by introducing new business strategies such as reducing product ownership through sharing, remanufacturing activities and so forth, while extending the product lifespan, without the need to rely on linear strategies such as planned obsolescence, company downsizing, delocalisation or the push on the purchase of more goods.

2. Methodology

Various approaches, known as R-strategies, have been developed to achieve less resource and material consumption in product chains and make the economy more circular. Several R-lists exist (Potting et al., 2017, CE and MVO, 2015; EMF, 2013; RLI, 2015; Vermeulen et al., 2014) in order to give an identity to these strategies and to share them with policymakers and manufacturers. In this study, we refer to the R-list represented in Figure 1.

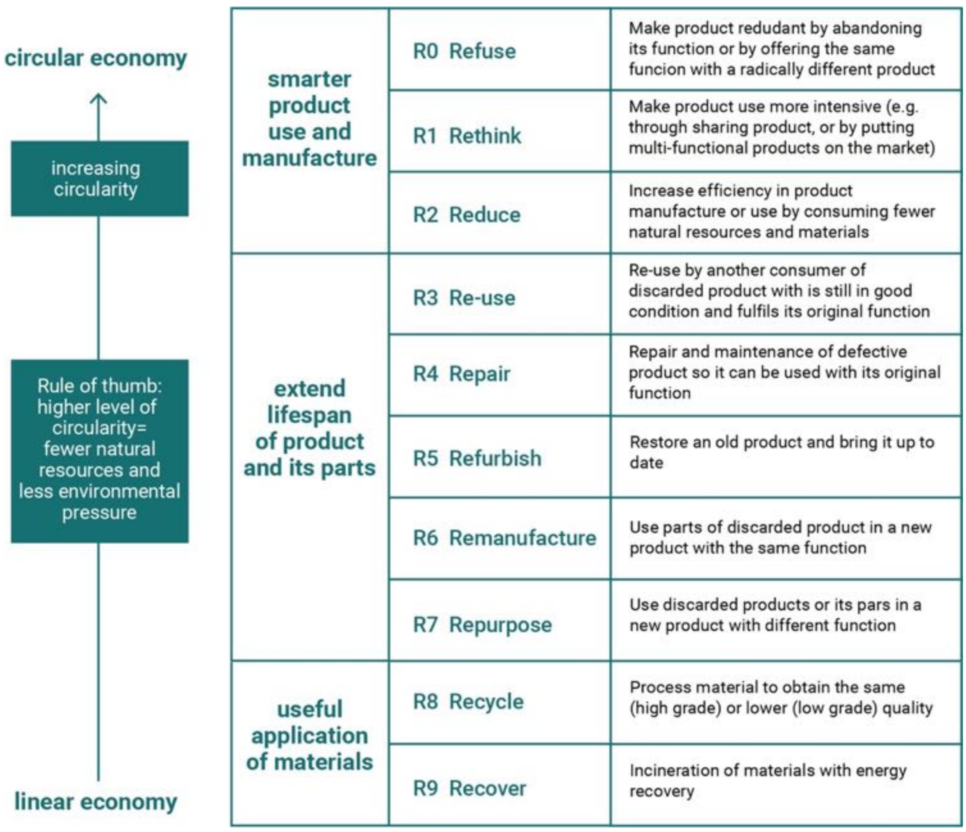

Figure 1. Circularity strategies and the role of actors within the production chain (Source: Potting et al., 2017)

These types of list all elaborate on the *Ladder van Lansink* which establishes a priority order for waste treatment methods on a Dutch level, similar to the influence of the waste hierarchy on an international level (Potting et al., 2017; EC, 2010).

They differ mainly in the number of circularity strategies they indicate and they typically present a range of strategies ordered from high circularity (low R-number) to low circularity (high R-number). Nevertheless, when Circular Economy best practices are analysed, they often fall back on efficient ways of recycling, thus remaining low in the R-list (R8- high R-number). A few examples are able to satisfy high circularity strategies, among which the most well-known are referred to the sharing economy (R1 - Rethink), which apparently has some benefits on the decrease of the ownership of material goods, the full exploitation of products, real-time maintenance, but can also lead to undesired effect (rebound effect), well-explained by Potting et al. (2017). However, these strategies lack the user's active involvement and little or no attention has been paid on the usage phase that for some products is the phase that impacts the most. It is the case of large appliances such as the refrigerator that are characterised by high durability and a high cost to operate.

Moreover, observing both Figure 1 and 2, we can notice how these strategies mainly involve EoL scenarios, without addressing both the usage and partially the design phase.

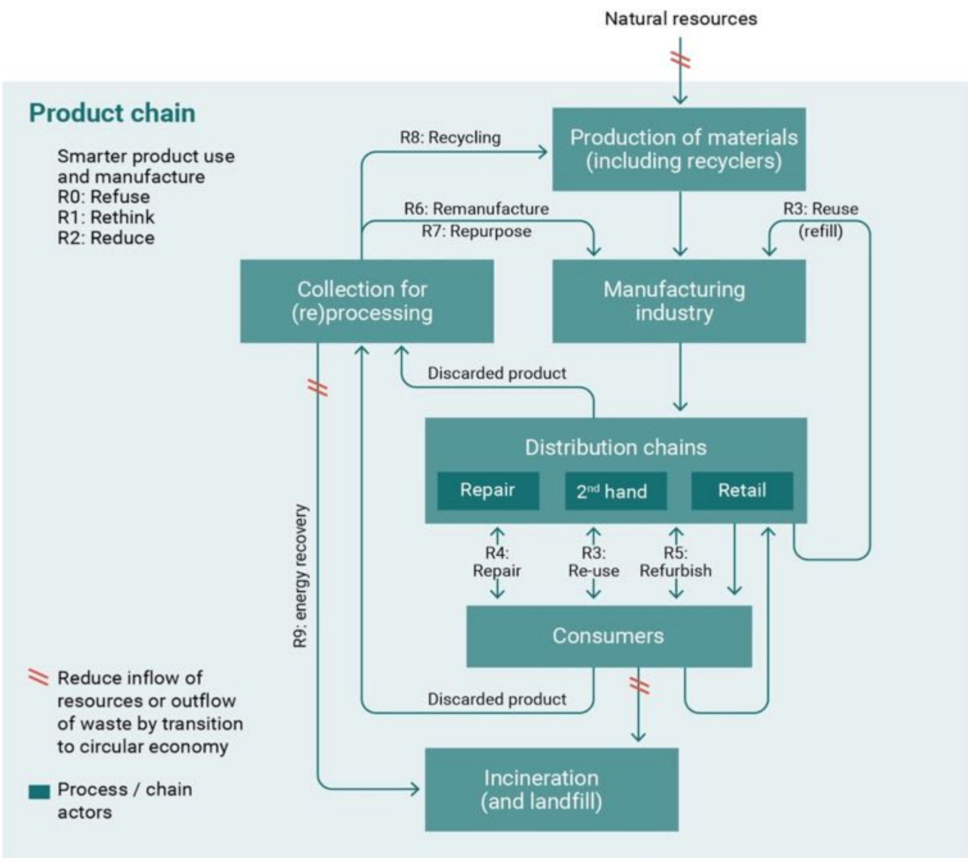

Figure 2. Circular strategies and the role of actors within the production chain (Source: Potting et al., 2017)

In figure 2, indeed, consumer represents the use phase and the box related does not have any outcome. About the manufacturing block, instead, some strategies (R0, R1 e R2) are shown on the left side. We can consider the design phase included in the manufacturing phase, although we prefer to keep them separate later in this paper. The same work seems to indicate that the sole responsibility attributable to the user is related to the correct disposal of the product, relegating the user to a rather marginal and not very active role.

In this paper, however, both the design phase and the use phase play a fundamental role in reducing environmental impacts and should be addressed and innovated with new strategies. For the household appliances' value chain, the design phase impacts the EoL direction the product will follow after discarded, while the usage phase weighs heavily on the energy of the housing sector.

In their type 2 CE transition, Potting et al. (2017 p.17) stated that:

> *"It is possible to design [..] a washing machine that lasts longer, is easier to repair and can be readily disassembled at the end of its lifespan. This is technologically far less invasive than developing a radically new technology, leading to a fundamentally different product grounded in a fundamentally new knowledge base and within a new innovation system. CE transitions around incremental technological innovation lead to adaptations to an existing product within an existing innovation system. Consequently, this* ***makes the adapted products less easy to distinguish from their previous versions. After all, there is little technological difference between the old and the new product, and no new innovation system has had to be built.*** *Here, to keep track of progress, the subtle changes in existing innovation systems need to be monitored, rather than the development of distinct new innovation systems."*

However, innovation can be related to product design instead of technology. This kind of innovation does not imply that the product cannot be distinguished from previous products. Indeed, it could be more distinguishable for functional and, by consequence, formal changes.

3. Results

We adapted some of the strategies of the circular economy listed by Kirchherr et al. (2017) within the standard life cycle of the product (Figure 3), by facing the gap of a certain lack of circular strategies related to the use phase. Hence seven strategies have emerged, two of which are based on the early design stage, three strategies are suitable for exploring new scenarios based on the concept of flexibility, and two strategies are based on the idea of predictive maintenance.

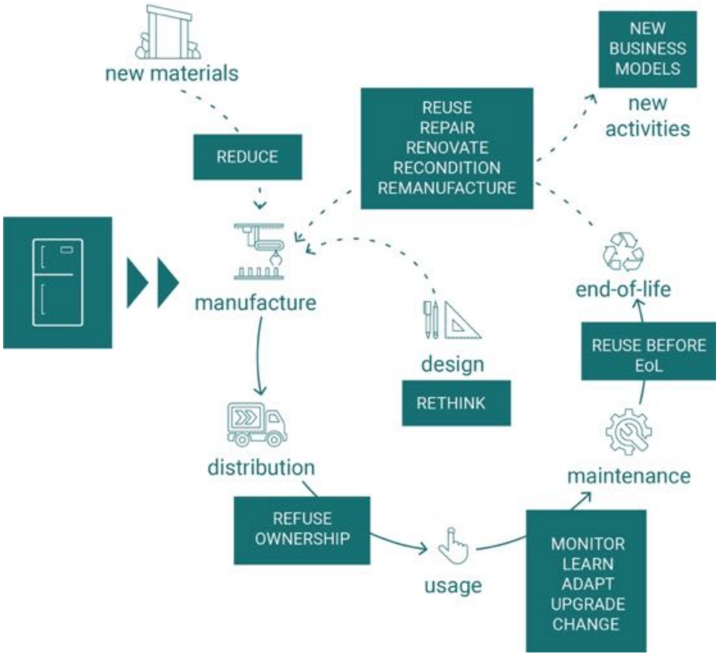

Figure 3. Introduction of circular economy strategies within the standard life cycle of the product

3.1. Design Strategies

This first section provides two examples of investigating design strategies for pursuing product innovation or its optimisation (Figure 4).

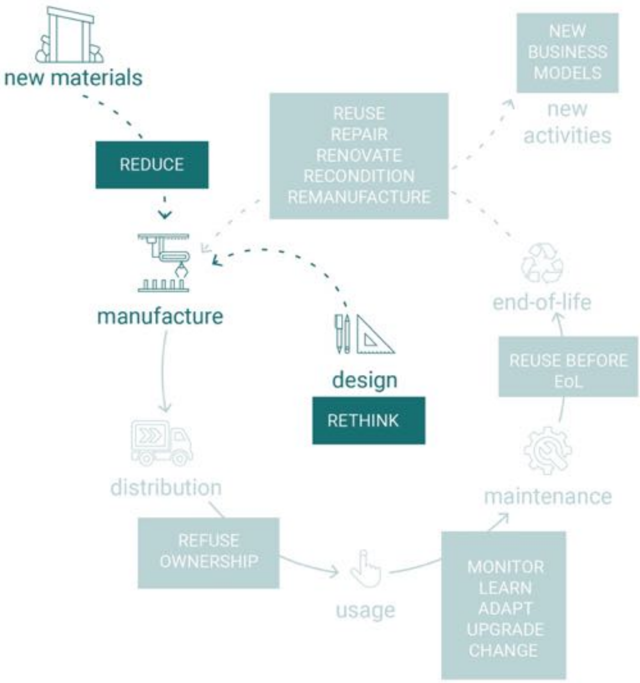

Figure 4. Design phase - rethinking and material reduction

Rethink (R1)

Improving the environmental sustainability of a home appliance does not mean just replacing parts, changing materials and designing for disassembling, but it could also mean rethinking functionalities and aesthetics to adapt to the user's renewed need and better respond to the functions that are expected to be delivered. Moreover, by changing the functions, we can obtain a reduction in environmental impacts introducing new processes that are not even comparable with the original ones (e.g. using the last rinse of the dishwasher and the washing machine for the next cycle reduces the use of water, even if the whole process does not use less water). If we consider the design strategy “design by components” (Bistagnino, 2008), the shape of each part should reflect the function it performs. If we consider the washing machine, the current form is dictated by the standardised space dedicated to this appliance within the bathroom furniture (60x60cm). Therefore, the washing machine has the shape of a box, almost empty inside. According to the Design by Components, the washing machine should have the shape of its functional components, showing the pipes and the parts to be maintained. This is what we mean to completely rethink a product (R1) and its functions and the reason why we need to give value to the design phase to obtain product innovation.

Optimise and reduce materials (R2)

Regarding the optimisation of the product, both designers and manufacturers could rely on one of the Design for X (DfX) strategies (Fiore 2018). Otherwise, they could carefully consider the materials to be used to reduce the impact of its components, i.e. using materials from renewable sources, take full advantage of the mechanical, chemical and performance characteristics of each material chosen, use materials according to the expected duration. For long-lasting product, one option could be choosing materials that age gracefully, easy to clean and which do not change characteristics over time. In general, reducing materials and lighten the weight of components can lower the impact on production and transport. Choosing additive manufacturing strategies, where possible, could lead to completely change the aspect of components if we choose “design for additive manufacturing” (DfAM) as a design strategy.

3.2. Product Flexibility

This second section provides three non-inclusive examples of exploring new scenarios based on flexibility, empower the user to personalise the object and develop new behaviours of purchase, use and consumption.

Refuse ownership (R0):

The first scenario in this section could be the integration of sharing or pay-per-use strategies, that leads the user to reduce the ownership of goods (Figure 5), by paying for the actual product use, saving money when the product is used in a virtuous way. In this paper, an in-depth analysis of scenarios is carried out, based on the literature which considers ownership and planned obsolescence as two obsolete strategies.

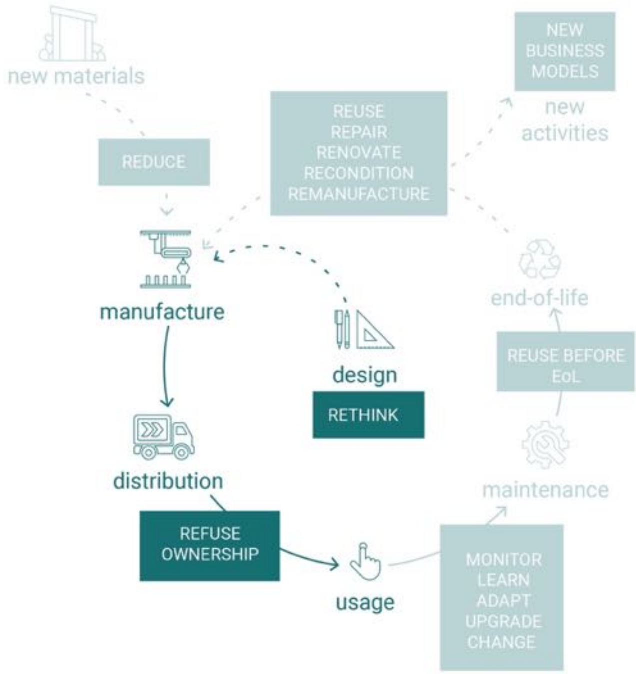

Figure 5. Refuse ownership

However, Italian households are accustomed to having their own appliances, and thus, they are not inclined to sharing household appliances. In other northern and western European countries, however, residents of flat complexes typically use centralised laundry facilities for example (R1a). In those cases, the costs for maintenance, repair and renewal are factored into the rent or contributions to the owners' association (Potting et al., 2017). This kind of services could be implemented with digital systems to facilitate booking a machine and paying for its use. In this regard, sharing refrigerators and freezers with other households seems less obvious. However, in some countries, refrigerators and freezers are already often included in the rental of flats and houses. Regarding the refrigerator, how suggested by PBL (Potting et al., 2017) homeowners or landlord (on behalf of all tenants) could refrain from buying a product and instead go for a service&use contract with the manufacturer (R1b). This encourages manufacturers to continuously improve their equipment, for example, by designing them to be easy to repair and refurbish by replacing components (R4 and R5).

Product evolution (Rethink R0)

Focusing on the usage phase, the software update is just an example of a product that evolves over time, changing and adapting to external changes (e.g. technological). What if the same concept would be extended to every part of the product and every step of the life cycle? In this scenario, the user purchases/rent a product and then he/she could transform it and shape it according to his/her needs with components and functions that can be integrated or updated. However, the user alone is not enough to put this strategy into practice, but he/she need to be supported by a careful design of how this product service system (PSS) works. Therefore, updates must be planned and provided by the manufacturers, as well as possible integration in functionalities and components should be foreseen in the early design stage.

Product adaptability (Rethink R0)

About the user's relationship with the product and vice versa, what if the product could 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 starts using and providing feedback to the product and after a while his/her expectations will be delivered, because the product evolves to meet user's requirements and expectations. Equipping products with intelligence makes them adapt and respond to change and remain fit-for-purpose over more extended periods (McAloone and Pigosso, 2017; Ellen MacArthur Foundation 2015). In this perspective, IoT data can be used to improve current products, but also for developing virtual services and sharing economy platforms to support the technical lifetime. The introduction of learning systems can transform the product into a fuzzy logic product (Lanzavecchia et al., 2012) which pursues environmental goals such as the reduction of impacts, the correction of wrong user behaviour and so forth, according to the actual use of the product by the user.

The latter two strategies are shown in Figure 6.

Figure 5. Refuse ownership

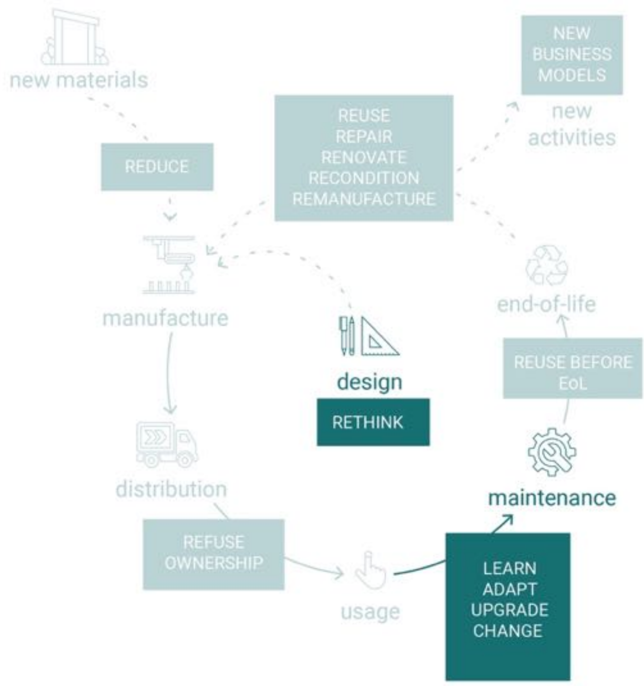

Figure 6. Product evolution and adaptability

3.3. Predictive Maintenance

This third section of the result, instead, investigates how to combine IoT data with the design of new products, suitable for addressing the usage phase and the following phases of the life-cycle. McAloone and Pigosso (2016) suggested that combining IoT data with participatory tools IoT could be one driver for the success of the circular economy, together with sustainable design/eco-design and Business model innovation. The circular economy can benefit from this intelligence for up-cycling processes, monitoring the condition of individual components or whole product systems. Data about the real use of a product can be collected for a short time, with an object instrumented ad hoc for the experiment or alternatively on the marketable products.

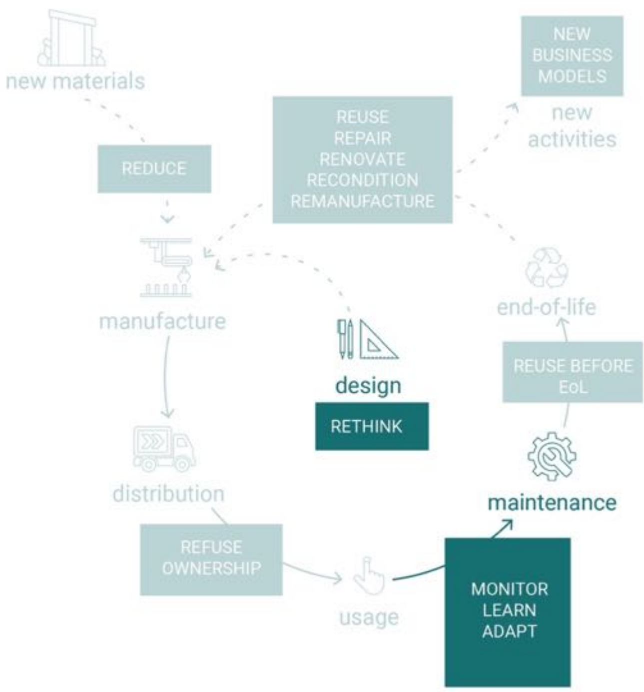

Figure 7. Monitoring strategies

Monitoring experimental products

In the first case, the product or its components can be monitored with experiments, to make their recovery suitable for a second valuable use. The R&D or design team, indeed, could study a prototype and then 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. This could be the case of the following three examples, considering:

- Functional groups of components, i.e. a 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.

Monitoring the final product

Monitoring some parameters of the refrigerator as a form of predictive maintenance could also be performed on real products, to provide added value services throughout the lifecycle. It could be done by introducing a few sensors on the final product that will be delivered to the user, to allow continuous data transmission of the most important indicators. Among the possible outcome, 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.

In this paper, we decided not to go through the end of life strategies, since many works already addressed them.

4. Discussion and conclusions

In this study, we focus on a specific product chain, the one that refers to the refrigerator. CE transitions based on higher circularity strategies call for more radical change throughout the whole product chain than transitions based on lower circularity strategies. For this reason, this paper refers to circular strategies that range from R0 to R6. Potting et al. (2017) proposed innovation in enabling technology, product design and revenue models as important strategies to facilitate changes.

In the first section related to the **design strategy**, we focused on the role of designing for reaching a deeper change in new products, for pursuing product innovation or its optimisation. We considered rethink strategies such as “design by components” in order to obtain a reduction in environmental impacts introducing new processes that are not even comparable with the original ones. We also considered general strategies for optimising and reducing the materials (R2) drawing from “Design for X” strategies, including strategies to extend the product lifetime (choosing materials that age gracefully, easy to clean and which do not change characteristics over time) and “design for additive manufacturing”.

In the **product flexibility** section, we addressed the introduction of sharing services which poorly addressed the refrigerator, but they adapt better to other appliances. This approach would require a change in the mind-set of residents since, at present, the market is dominated by privately owned appliances. We have seen the introduction of different revenue models in which home appliances remains the property of the manufacturers and is returned to them at the end of the equipment’s service life, giving both manufacturers and consumers a more active role in product management (Potting et al., 2017). In this section, we also highlighted the need for smarter manufacturing and use of products (Potting et al., 2017) using fuzzy logic products. Focusing on the usage phase, we highlighted the need to design functions that can be integrated or updated after the product has been delivered and the need for carefully designing new product service systems (PSSs). We also investigated the need for a feedback system to allow an exchange of information between the user and the product. Collecting and elaborating feedback could be a strategy to deliver new functions of the product and make them evolve over time.

The two scenarios provided in the section **predictive maintenance** have different purposes. The first deal with instrumented objects used for testing and monitoring objects to intercept the product when is suitable for a second use (R1, R3), before it reaches its end of life, avoiding the product disassembly by preserving its integrity.

The second aims to reconfigure the product through repairing, refurbishing and so forth (R4-R5-R6) to obtain real-time data and intervene promptly, shaping the object behaviour on the user habits and behaviour. This could be possible by interacting with the user, facilitating the predictive maintenance (R1, R4), upgrading or replacing parts (R4), improving the product or eventually allowing the product to adapt to changed conditions (R1) and learn from users' usage (R1). Both scenarios would require analytics to measure and combine data inputs over time (Henne, 2015). The proposed strategies are suitable for both current product-centred economy and a future service-centred one, providing directions for further studies that want to address the extension of the product life cycle while promoting efficient use of the product itself. IoT data open a variety of possibilities in monitoring, accessing more precise knowledge of both home appliances and households, useful for design purposes.

In conclusion, to achieve such a transition toward a circular economy, we should challenge existing ways of consuming, producing and doing business.

References

Bistagnino L. (2008) Il guscio esterno visto dall'interno. CEA, Milano.

Bakker, C. A., Wang, F., Huisman J., and den Hollander M. C. (2014). Products that go round: Exploring product life extension through design. Journal of Cleaner Production 69: 10–16.

CE and MVO Nederland (2015). The potential for high value reuse in a circular economy. Online publications (Consulted May 2016.

Center for Sustainable Systems (2016) Municipal Solid Waste Factsheet. Retrieved April 2017, from http://css.umich.edu/

de Arruda Torresa P.M. (2017) Design for Socio-technical Innovation: A Proposed Model to Design the Change, The Design Journal, 20:sup1, S3035-S3046

Ellen MacArthur Foundation (2016) Intelligent Assets: Unlocking the circular economy potential, Report of the Ellen MacArthur Foundation, February 2016.

EMF (2013). Towards the circular economy. Economic and business rationale for an accelerated transition. Online publication. Ellen MacArthur Foundation (EMF).

Fiore E. (2018) Integrare i dati nella progettazione di prodotti complessi. Un approccio sistemico e multidisciplinare applicato al caso studio di un frigorifero, In: FRID 2017 Sul metodo/Sui metodi. Esplorazioni per le identità del design. pp. 371-384

Hansen, S., Berente, N., Lyytinen, K. (2009) Requirements in the 21st century: current practice and emerging trends. In: Lyytinen, K., Loucopoulos, P., Mylopoulos, J., Robinson, B. (eds.) Design Requirements Engineering. LNBIP, vol. 14, pp. 44–87. Springer, Heidelberg

Henne, B. (2015) How IoT Data Becomes Valuable Intelligence. Retrieved June 20, 2017 from http://blogs.ptc.com/

Kirchherr, J., Reike, D., Hekkert, M. (2017). Conceptualizing the circular economy: an analysis of 114 definitions. Resources, Conservation and Recycling 127, 221-232

Lanzavecchia, Barbero S. and Tamborrini P. (2012) Il Fare Ecologico. Il prodotto industriale e i suoi requisiti ambientali. Edizione Ambiente, Milan

Magalini, F., Kuehr, R., Huisman, J., Deubzer O. And Sinha Khetriwal D. (2018) Material Flows of the Home Appliance Industry - CECED Retrieved January 2018, from www.unu.edu

McAloone, T.C. and Pigosso, D.C.A. (2017) From ecodesign to sustainable product/service-systems: a journey through research contributions over recent decades. In Sustainable Manufacturing: Challenges, Solutions and Implementation Perspectives (ed. R. Stark, G. Seliger and J. Bonvoisin), pp. 99–111. Springer International Publishing.

Potting, J., Hekkert, M., Worrell, E., Hanemaaijer, A. (2017) Circular economy: measuring innovation in the product chain. Policy report. The Hague: PBL Netherlands Environmental Assessment Agency.

Rli (2015). Circular economy. From intention to implementation. Council for the Environment and Infrastructure (Rli), The Hague.

Vermeulen WJV, Witjes S and Reike D. (2014). Advice about a framework for measuring the impact of circular procurement. Faculty of Earth Sciences, Utrecht University, Utrecht.