Università Iuav
di Venezia

Doctoral dissertation
of Alessio Franconi

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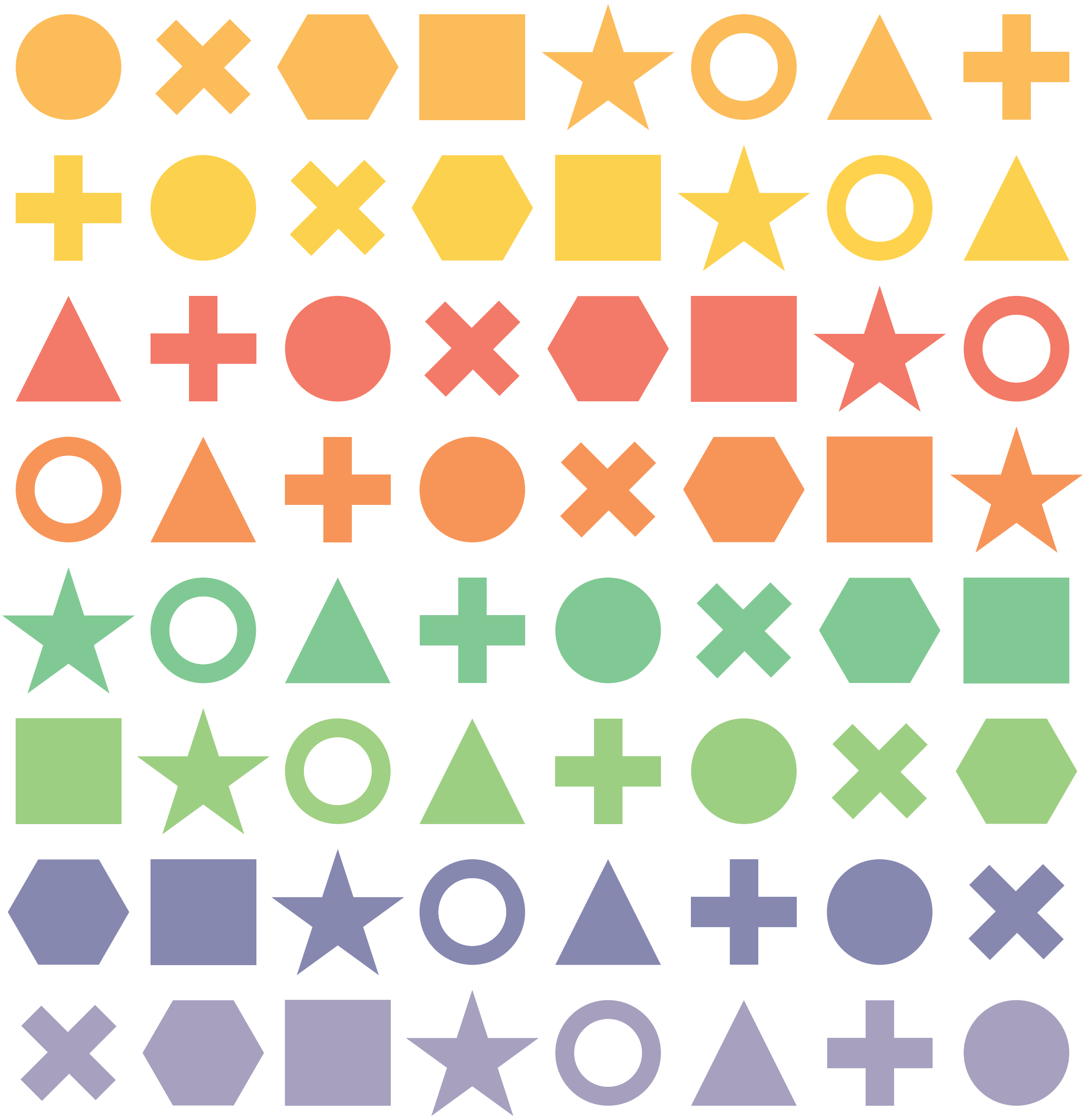
Multiple Design Perspectives for the Transition to the Circular Economy

Managing Design Strategies Between Systems, Designers and Time



Multiple Design Perspectives for the Transition to the Circular Economy
Managing Design Strategies Between Systems, Designers and Time

Alessio Franconi

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London, March 2020

Summary

The complex system of superstructures promotes well-being and innovation, but at the very high price of valuable natural resources. The race to evolution and advancement has made humankind forget that precious goods must be maintained and managed appropriately. It is necessary to recognize the problem and understand how better resource management can guarantee prosperity for the next generations to come (Brundtland et al., 1987).

Chapter 1. Introduction: the usual design perspective and its limitations.

The circular economy (CE) has been considered from many countries, governments, cities, and institutions as a possible solution to overcome resource, social, and environmental problems related to overconsumption. The CE is opposite to the linear economy, where resources are taken from the ground to make products that will be used and then disposed in landfills. The linear economy is an ill-system where growth is directly connected to the "sell more" approach. Therefore, there have been tendencies to increasing limit the service life of products through different obsolescence strategies. It is, therefore, necessary, as suggested by various researchers, to accelerate the transition from a linear to a circular economy. However, this transition requires to change the way products, services, and systems are designed to meet adequately circular and sustainable challenges.

This thesis addresses the topic of design for the CE in a modular way, examining how it is possible to achieve a circular economy through a multi-design perspective approach. If properly conceived, the CE could represent not only an environmental advantage but also an economic opportunity. Several pieces of research in the field of design for the CE led to analyze how specific design disciplines can tackle the challenge of the CE independently. While studies are vital for the comprehension of how to cope with circular design, it is incredibly complicated to be effective from only one designer's perspective. In other words, design for the CE requires understanding and action from multiple scale systems, multiple design approaches, and multiple time dimensions. Therefore, the challenge is not only to define specific design strategies but also how these design strategies can be used and how they can influence one another to increase the optimization and strength or to avoid conflicts. The better management of design strategies can improve the quality of the design approach and consequently accelerate the CE. To bridge this gap, this thesis focuses on the questions:

Chapter 2. Research scope and questions.

Main research question (MRQ):

1. What would be a comprehensive design framework that supports multiple design perspectives throughout the design process for effective circular products, thus accelerating the circular economy?

Sub-research questions (SRQs):

2. How could a multitude of heterogeneous decision-makers (designers) and their strategies be organized for a collaborative design approach in the context of CE?
3. How can design strategies be systematized and organized more

efficiently to help designers to cope with cross-system, cross-loop, and multi-phase perspectives over multiple product life cycles?
4. How might multiple design perspectives be integrated into an agile and fast process to developed circular products?

To address all the research questions, a qualitative approach has been designed and organized to create a reliable and replicable study. The challenge is to understand and organize multiple design perspectives to facilitate collaboration and dominate complexity, to implement a circular design approach and the maintenance of resources in use through the system.

To answer the research questions above, a four-stage design-based research approach has been used:

- A preliminary research stage, aimed at grasp and organize how many design decisions and design strategies, both for a sustainable and curricular approach, are organized, used, and applied. This stage was based on a literature review and aimed to provide an answer to SRQ1;
- A multi-level structure model stage, aimed at developing a design approach to enable collaboration between multiple and different design perspectives among cross-system, cross-loop, and multi-phase approaches. This stage was based on literature review and semi-structured interviews and aimed to provide an answer to SRQ2;
- An experimental stage, aimed at formulating possible agile approaches and solutions to the design of circular products. This stage was based on an interactive and iterative research approach, where different solutions have been tested and refined through three workshops. This stage focused on answering SRQ3;

A final iterative stage, where results have been discussed and, based on the three SRQ answers, it has been attempted to answer to the MRQ.

The first stage of the research has been set to determine "what the designer look at?" and "how the designer look at it?" in designing circular products. A review of the literature has shown that the anthropic system can be divided into four different design levels: socio-technical system level, spatio-social level, product-service system level, and product level. In all these levels, it is possible to defined and determined specific expertise, tools, methods, approaches, and decision-makers (from now on designers). Through the example of bike-sharing, it has been demonstrated that a circular product should be jointly managed among all these four systems to be effective. Nevertheless, it is not simple to approach all the circular products from all the four systems; for this reason, the research has been focused more specifically on the product-service system level and product level.

Chapter 3. Multiple design perspectives.

In those two system levels, designers should look at the circular product design in a multidisciplinary, cross-sectional, and systematic way to be able to answer to both market/business and environmental requirements over multiple product life cycles. In order to understand

and cope with the overlapping design dimensions eight phases have been identified, which represent the product life cycle and are as follows: (1) business design & network, (2) resources used & production, (3) forward logistics, (4) sale, (5) use & operation, (6) service & maintenance, (7) reverse logistics, and (8) recovery. For each of these phases, three dimensions have been defined and described, design dimension, systemic dimension, professional dimension. Several design questions were added to guide designers at the beginning of their CE project for each phase. Because in the circular economy, products are reintegrated to be used for multiple lifetimes, each of the eight steps listed above might be repeated and understood by all the designers that design the specific phase of the product. By doing so, multiple design perspectives can be organized into collaborative strategies to design circular products.

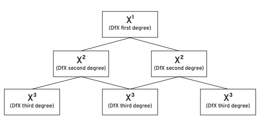
Chapter 4. Design strategies for the circular economy.

Design for collaboration might only happen if a common terminology is shared among different designers alongside the product life cycles. Implementing and understand this aspect of design is crucial and necessary to achieve an effective circular economy. Based on a literature review, it is first defined what “design strategy” means, strategies can then be generalized in Design for X (DfX), where X refers to every possible strategy. After defining the appropriate terminology, two main DfX hierarchies have been analyzed together with many case studies to understand and describe how DfX strategies can be used by designers. In both hierarchies, DfX are classified based on the material flows.

These hierarchizations are then criticized, as they focus only on material flows and the value related to the Inertia Principles. Based on logical assumptions, it is stressed that value is created between multiple stakeholders in the CE and that for designers is therefore fundamental to understand which values can be exchanged with all the stakeholders involved in the product life cycle. It is highlighted how stakeholders such as customers and partners who can be considered the “sequester” of value from the hands of the customer, play a crucial role in the circular economy. More research in this chapter would be needed to understand both the values related to material flows and the role of key stakeholders in the success of the circular economy.

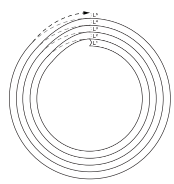
Chapter 5. Design strategies for the circular economy.

This central chapter is the most important and crucial for the development of the empirical research explained in sections 7, 8, and 9. Based on a literature review, and built on the Design for X (DfX) approach, it is assumed that design strategies may be categorized into three different DfX hierarchies; (1) degrees of priority of DfX strategies, (2) Phases of the product life cycle system and (3) Loops. An example for each hierarchy can be:



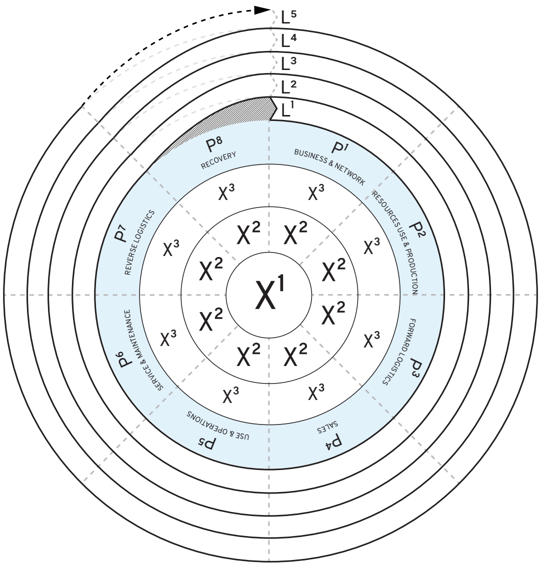
Design for Remanufacturing (X^1);
Design for Disassembly (X^2);
Design for Reassemble (X^3).

Design for Sharing (P^1);
Design for Maintenance (P^6);
Design for Ease of Cleaning (P^8).



Design for Reuse (L^1);
Design for Second-hand Product Acceptance (L^2);
Design for Timeless Aesthetics (L^3).

A semi-structured interview with experts on the field, and a workshop was carried out to validate the assumptions. Consequently, a framework was created to guide designers during the design phases in choosing strategies that do not conflict with each other in the various loops.



At the heart of the framework, there is always one of the five main circular design objectives from which a team of designers can decide of (X^1), namely, design for maintenance, design for reuse, design for refurbishment, design for remanufacturing, and design for recycling. Once the main circular objective has been defined, it will be possible to set in sequence one or more than one DfX (X^2) for each phase of the product life cycle that is inherent X1. The third level of strategies (X^3) represents precise strategies that refer to the X2 strategy, and it can come later in the design process. This process may be repeated for each phase (P) and each loop (L) of the product. In this framework, designers can manage design strategies (DfX) as well as value and stakeholders related to each phase of the product life cycle and each loop. Understanding the strategic dynamics of different design disciplines can help the designer to predict how certain design strategies can be useful in specific loops. The framework represents a valid alternative to compare new and well-known strategies from the early stages of the design process in a collaborative way.

Based on the Multi-hierarchical DfX framework, three bike-sharing systems are compared and analyzed to understand specific DfX strategies for the Use & Operation phase of the framework (P^6). In this phase, three design dimensions are introduced and evaluated through a literature review and a semi-structured interview, which are as follows: functional, aesthetic, and symbolic dimensions. This study has the purpose of improving the knowledge and understanding of managing specific DfX strategies for the usage phase, primarily focusing on Design for Sharing. The results show that in the design of bike-sharing systems for the functional dimension designer can use DfX strategies such

Chapter 6. Analysis of the Multi-hierarchical DfX framework in the light of practical application.

as Design for Reliability [Df Voluntary Behavior (Design for Customer Cooperation, and Design for Reward) and Df Maintenance (Design for Preventive Maintenance, Design for Security)], Design for Flexibility and Efficiency of Use [Design for Ergonomics (Design for Adjustability, Design for Comfort, and Design for Lightness) and Design for Usability (Design for QuickStart, Design for Simplicity, and Design for Upgradability)]. Whereas, in the aesthetic dimension, a designer can use DfX strategy such as Design for Attachment and Trust [Design for Simplicity (Meaningful Design, Design for Robustness, Design for Lightweight) and Design for Timeless Aesthetics (Design for Upgradability, and Design for Ageing Gracefully)]. Finally, in the symbolic dimension, designers can use DfX strategies such as Design For Attachment And Trust [Design for Emotionally Durability (Design for Repair Relationship, Design for Motivations, and Design for Smart Features)] and Design For Interactive Experiences [Design for Satisfaction (Design for Eco-feedbacks, Design for Reward, Design for involvement, and Design for rewards)].

The general conclusion of this analysis demonstrated that whenever the business model change (in this case, the product is sold as a service shared between many people and not as a product), all the other design strategies in the subsequent phases may change accordingly. The identified strategies refer only to the Use & Operation Phase of the Multi-hierarchical DfX framework and where, in X2, Business Designer decided to apply the Design for Sharing strategy.

Chapter 7. Circular Design Cards.

In order to accelerate the circular economy from a design perspective, there is a need for tools and instruments to help designers in doing so. Therefore, different instruments have been created and tested. In this chapter, it is presented a deck of cards that designers can use during brainstorming or workshops named Circular Design Cards. The cards presented different DfX strategies clustered around four main categories, system, material, business, and design. Each card was designed for individual DfX, explaining HOW and WHY the specific DfX was used, and one or two prompts for questions designers can ask themselves during the design process. On the flip side, case studies that embody the specific design strategy are described with text and images.

The deck was tested in a one-day circular workshop with an MBA class at the European Institute of Design in Venice. Through a survey on individual elements of the cards, the deck has been examined in order to get enough level of understanding and take full account of designers' perspective. The results of the survey have shown that the designers understood the different design strategies and how to combine different design strategies.

Chapter 7. Circular Design Tool.

Likewise, the previous chapter, this presents an instrument to accelerate the use of sustainable and circular design strategies when designing circular products. The tool is called Circular Design Tool and is an online and open-source platform of DfX strategies based on the Multi-hierarchical DfX framework mechanism and shape. The platform has been created during the Ph.D. to help designers and students to better-use sophisticated design strategies in the circular economy. This systemic tool can be based on the product life cycle system model. This model breaks the product life cycle into sequential phases in time that can be replicated for multiple loops. The sequence can be useful to un-

derstand step by step all the phases that the product passes through.

This solution can provide two advantages, the first advantage is that, by structuring workflow to describe how and when specific DfX can be applied it is easier to fit specific strategies on the specific phase of the product life cycle. Secondly, it is possible to use a unified measure for all the decision-makers involved in the design of the system. The tool is structured around the five main circular DfX, Maintenance, Reuse, Refurbish, Remanufacturing, and Recycling, for each, multiple DfX have been identified and defined. Unlike the Circular Design Cards that are a physical tool, the Circular Design Tool is interactive and implementable from the community. This has the potential to collect many more DfX from all around the world.

A collaborative and structured way of working may accelerate the circular economy. With this purpose, it is introduced the concept of 'Lean Design' to create products based on multiple design perspectives with more value and less time. Built on the Google Design Sprint, two workshops have been carried out to create a qualitative approach with the aim of comprehending how to manage the complexity in the circular design process. Both workshops have been conducted with students from the University Iuav of Venice. In the first workshop, the agenda was unchanged from the classic Google Sprint, whereas during the second workshop, the agenda was redefined and tailored around the Multi-hierarchical DfX framework.

Chapter 9. Recapitulation of the research and Evaluation Workshops.

After completion of the workshops, feedback, notes, reflections, insights, surveys, and the results have been analyzed, and it has been argued that the modified workshop (the second one) is more suited to the design of circular products, because helps designers to have a more complete vision and control of the product life cycles. This analysis has led to some consideration and opportunities for future work related to critical aspects such as informed decisions, visionary decisions, and systemic decisions that can be implemented in the coming years.

Finally, the main conclusions, limitations, and suggestions for future research are presented. To answer the main research question - What would be a comprehensive design framework that supports multiple design perspectives throughout the design process for effective circular products, thus accelerating the circular economy? - The thesis proposes that, in order to support the development of an effective circular product, a multiple design perspective approach should be accepted and embraced to manage interconnected problems better and dynamically control possible solutions, and at the same time, to balance the multiple requirements for multiple product life cycles. In order to facilitate this, this thesis presents:

Chapter 10. Final conclusions.

- a new collaborative design framework - the Multi-hierarchical DfX framework;
- insight into which design systems product is developed, and how designers design between these systems;
- two new design tools to support multiple design perspectives;
- a modified version of a lean workshop to better tackle the challenges of the circular economy;

insight on new design strategies related to the bike-sharing systems.

The design methodologies for managing multiple design strategies as presented in this thesis offers a new conceptual joint methodology to work with different objectives, stakeholders, life phase of the product, and approaches and their intercorrelations with context and time.

It is highlighted how the decision maker's role, generically named designers in this thesis, is changing in the circular economy. Indeed, in the circular economy, products should last for multiple loops, and, for every loop, the buyer may be a different customer, in entirely different contexts. This thesis attempts to grow a different issue such as the design for the circular economy introducing tools, methods, and directions, however much work is needed and necessary to fight climate change and the waste of natural resources.

Chapter 1

INTRODUCTION: THE USUAL DESIGN PERSPECTIVE AND ITS LIMITATIONS

Synopsis
An overview of the linear economy concept and the problems this way of doing things is leading introduce this thesis and chapter. It is then proposed an overview of the circular economy concept as a possible alternative to the linear one. Along with it, the circular product design approach is introduced as well.

1.1. Linear Economy

Most of the world's economies are based upon the conversion of natural resources into waste. Therefore, these economies are often defined linear. In the linear economy, Stahel states that "the main objectives are to maintain value (not to create value-added), to optimize stock management (not flows) and to increase the efficiency of using goods (not of producing goods)" (Stahel 2019). In the linear economy model, the value is generated by producing and selling as many products as possible. Natural resources coming from all around the world are the basis of the linear economy model. They are taken from companies and transformed to valuable products to be sold. According to McDonough et al., (2010), once products reach the market, 90% become waste almost immediately. As products become waste, the energy and useful materials which are embedded are displaced into landfills, incinerators, or simply in the ocean or one's backyard. For these reasons, the linear economy is usually defined as a "take-make-dispose" step-by-step plan. Thus, the linear economy incessantly demands the input of resources from nature, meanwhile, it continuously deposits large volumes of waste, emissions and pollution of different kinds into air, soil, and water (Fig. 1.1.A).

The IPCC estimates that on current trends, the average global temperature will rise between 2.5 to 7.8 degrees Celsius before the end of the twenty-first century (Fig 1.1.B). The limit of 1.5 to 2 degrees Celsius, in view of sustained growth of global population and the demand of many low-income countries for the living standards of developed countries, represents a huge challenge for the future (Tirole, 2017). According to the Department of Economic and Social Affairs of the United Nations, the current world population of 7.6 billion is expected to reach 8.6 billion in 2030, 9.8 billion in 2050 and 11.2 billion in 2100, as shown in Fig 1.1.C. This incredible growth will require an enormous use of natural resources to support an adequate standard of living for all. But because Earth's resources are limited, this cannot be possible and could lead to an environmental collapse. The entire sequence or trajectory undergone by the population and its environment together is often called 'overshoot-and-collapse'. In 2019, when this book was written, the Overshoot Day happened on July 29th (Fig. 1.1.D). This means that humanity in 2019 was using nature 1.75 times faster than our planet's ecosystems could regenerate. The book Ecological Footprint: Managing Our Biocapacity Budget, describes that the phenomenon of overshoot can only be temporary. Humanity will eventually operate within the means of Earth's ecological resources, and have that balance restored by disaster or by design. "Companies and countries that understand and manage the reality of operating in a one-planet context are in a far better position to navigate the challenges of the 21st century," (Wackernagel et al, 2019).

1.2. Linear Society

Without too many thoughts, most people throw away goods daily. This is made possible by market based growth and technological progress (Wijetunga, 2019) that increased continuously the affordability of most of the products in the market. This type of behavior often defined "throwaway culture" led to an environmental problem that is jeopardizing the entire natural system. While it has been easy to relate this behavior to a sustainability problem, it is also a socio-economic issue

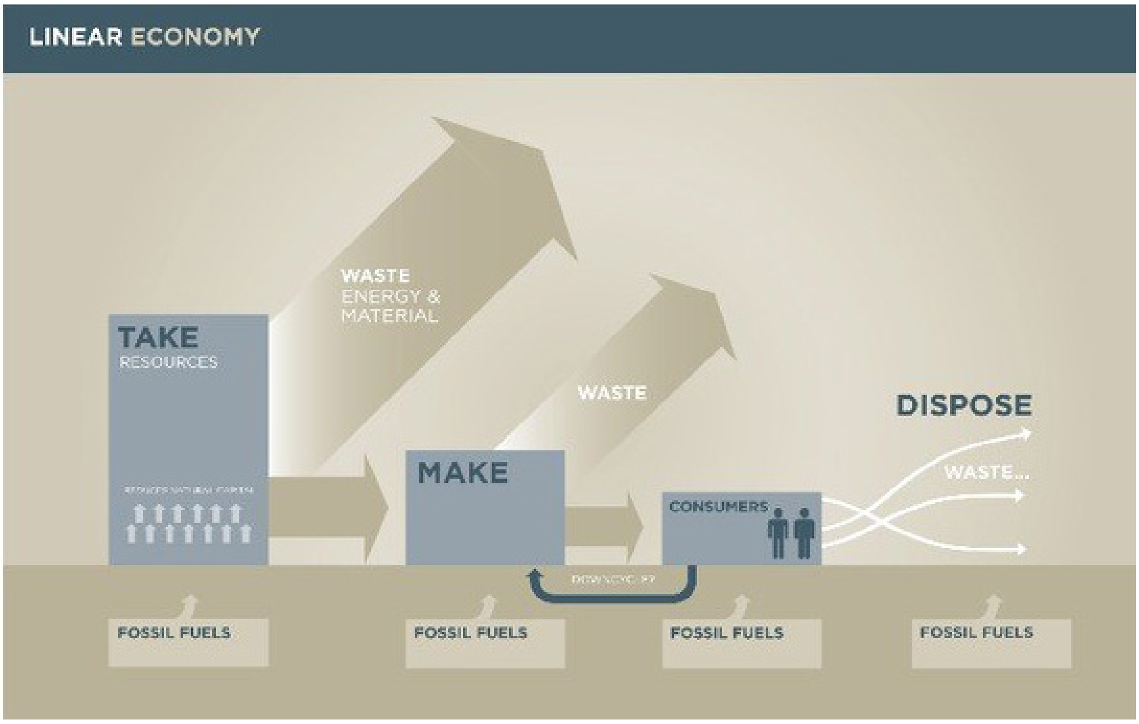
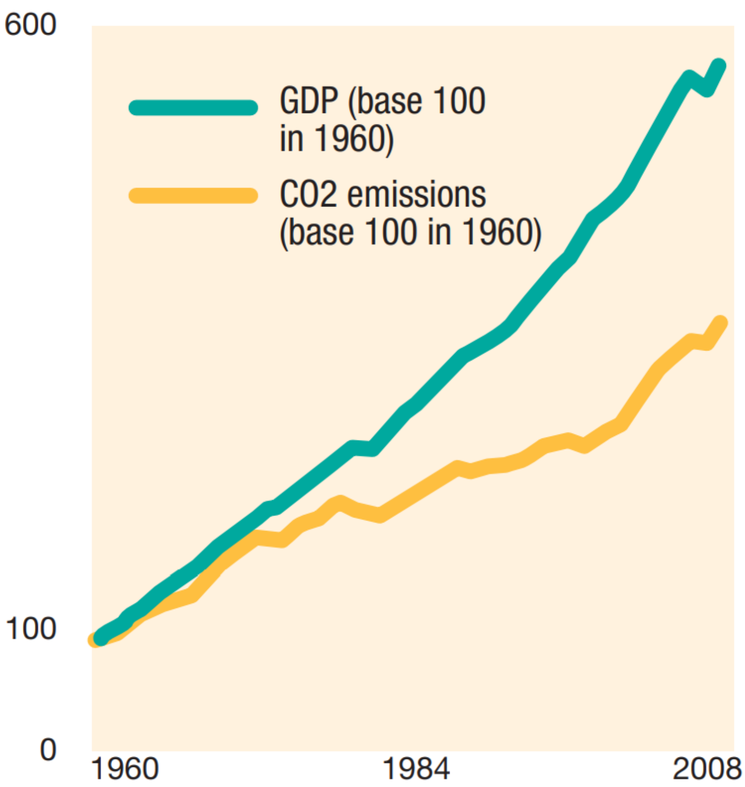


Figure 1.1.A. Linear economy model
Source: Ellen MacArthur Foundation

Figure 1.1.B. Growth of global GDP and CO2 emissions from 1960 to 2010.
Source: Canfin-Grandjean Presidential Commission (2015).



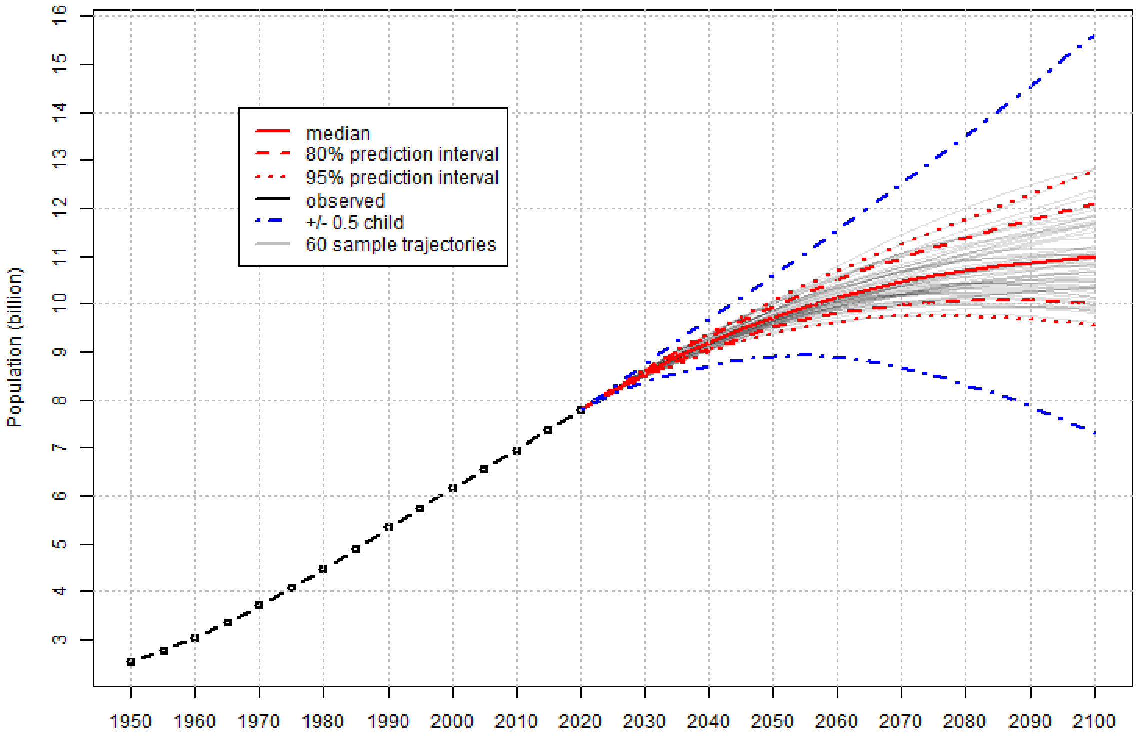
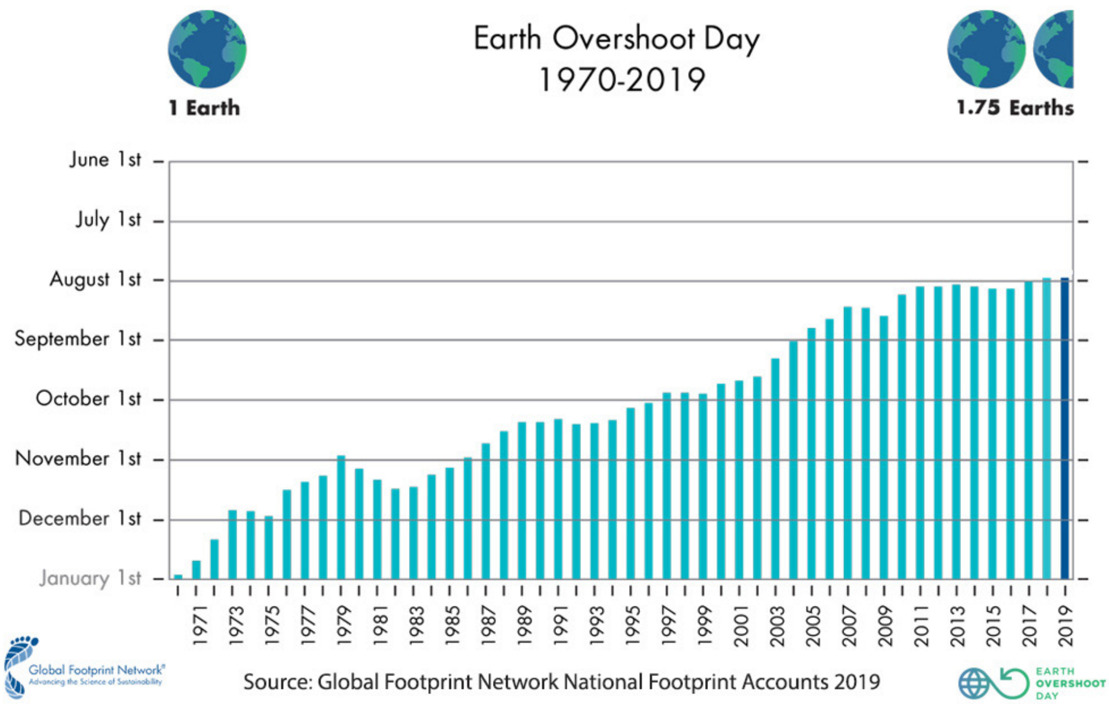


Figure 1.1.C. World Population Prospects from 1950 to 2100.
Source: United Nation, Population Division, 2019.

Figure 1.1.D. Earth Overshoot Day 1970-2019.
Source: Global Footprint Network National Footprint Accounts 2019.



(Ashby, 2015) that should be considered for the future of our society.

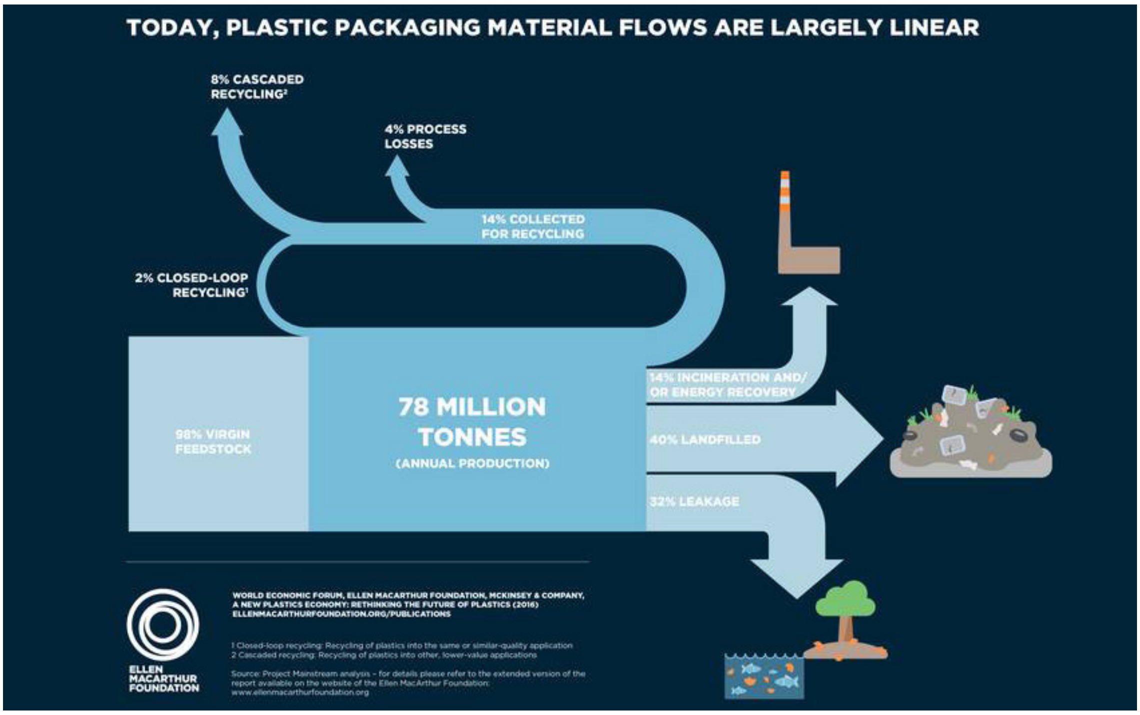
Today's society extracts and use 50% more natural resources than only 30 years ago (SERI, 2009). This increased use of natural resources has terrible social consequences which are paid from populations in Africa, Latin America and Asia where human rights violations, poor work conditions and environmental catastrophes are the norm (SERI, 2009). In Europe, consumption of resources is around 45 kg each day per person, while in Africa people consume only around 10 kg per day. And these numbers are increasing every year due to the increased request for more goods and services from western countries like Europe.

In 2007, for example, the world production of plastics rose, approximately, by 260 million tones. In Europe alone this resulted in the creation of 24.6 million tons of post-consumer plastic waste mostly concentrated in packaging, constructions, car manufacturing and electrical and electronics equipment sectors. Half of this waste was disposed in landfills, 20% was recycled and 30% was recovered as energy (Plastics Europe, 2008). Similar data are shown in the Ellen MacArthur Foundation's report, "New Plastics Economy Rethinking the Future of Plastics" about the packaging material flows (Ellen MacArthur Foundation, 2016). While there have been significant improvements at recycling material flows, it is now clear this is not enough (Fig. 1.2.A.).

1.3. The failure of design

In 1985, Papanek defined design as one of the most harmful professions (Papanek, 1985). After more than 30 years, design has not changed much. Reasons why design disciplines failed to evolve quickly enough are connected to education, as well as the area of research and development, where Europe has a big role to play. However, it would be unfair to attribute this failure to individuals or individual categories, it is a systemic and multi-faceted problem that involves many professions,

Figure 1.2.A. Plastic packaging material flows.
Source: Ellen MacArthur Foundation.



and not just the private sector. Design, as especially interpreted from industrial design schools, is just a bridge between companies and customers, increasingly "good design" is the only thing that differentiates products from one another in the market (Peters, 2005). This led most of the blame to design.

"Design…is an attempt to contribute through change. When no contribution is made or can be made, the only process available for giving the illusion of change is 'styling'. In a society so totally committed to change as our own, the illusion must be provided for the customer if the really is not available" (Packard, 1960, pg. 68).

Through aesthetic, functional, and symbolic dimensions, design can alternate consumers' behavior (Homburg ate al., 2015). The strategy used by most companies in the modern linear economy is to design products that have a short life cycle through tactics including death dating, limited repair, and gradually declining aesthetic. As a response to perceived obsolescence, consumers feel obligated to buy newer versions of the same product, buy new products rather than repair them, and replace perfectly functioning appliances when they are aesthetically worn (Guiltinan, 2009). This strategy is usually defined as Planned Obsolescence.

1.3.1. Forms of Planned Obsolescence

Products become obsolete whenever the user decides that they are no longer useful or valuable for them (Burns, 2010) or when a spare part or a component is no longer available from the original manufacturer (Bartels et al., 2012). Consequently, many products are thrown away (Packard, 1960; Bayus, 1991) or abandoned in the garage and storage closet waiting to be discarded (Packard, 1960; Cooper, 2010), sometimes even if they are perfectly performing. This can depend on a wide range of social, technological, economic and environmental variables (Burns, 2010).

Obsolescence is often used as a strategy by companies to force the user to buy a new product, especially in markets which are saturated by offer. Sometimes this strategy is pushed even further from companies who integrate microchips and software to make their products more fragile and anticipate their death (Packard, 1960). In this specific case, the obsolescence of products is planned. This design strategy, defined "planned obsolescence" occurs when a product is directly designed to have a specific short life expectancy, so that customers will have to make repeat purchases (Bulow, 1986).

Obsolescence is categorized in different typologies. In the early critical design discourse, Papaneck et al., (1977, pg. 122) provided one of the first and comprehensive checklist composed of ten planned obsolescence questions for users.

1. Technological Obsolescence: Will the item you are considering buying be superseded soon by more sophisticated manufacturing methods?
2. Size Obsolescence: Does a smaller, more compact version of what you have really provide better results?
3. Powered Obsolescence: Does it really make sense to have the

device or tool steered electronically or electrified?
4. Additive Obsolescence: Does the gimmick that the manufacturer has slapped on the newer version improve it at all?
5. Marginally Improved Obsolescence: Does the tiny improvement warrant your investing in the newer model?
6. Constrained Obsolescence: has it been tested and proven itself, and have all the “bugs” been ironed out?
7. Instant Obsolescence: Is the product only a poor and shoddy copy of the original? Is it a passing fad?
8. Aesthetic Obsolescence: Are you buying a trendy exterior, or a phony exterior image of quality?
9. “Protective” Obsolescence: Is it just a sales game, or is it really safer?
10. “Easy” Obsolescence: Will it really be more convenient, easier to operate, and are other sacrifices implied worthwhile?

Other authors have approached the planned obsolescence by dividing issues into smaller clusters. For example, Packard (1960) distinguished obsolescence of function, quality and desirability. Whereas, Burns (2010) made a split between aesthetics, social, technological and economic obsolescence. Cooper (2004), discerned two types of planned obsolescence absolute obsolescence and relative obsolescence. The first happens when a product due to structural deterioration is not able to meet the functional standards. The second happens when the product, despite being still able to meet functional standards, is discarded. The latter depends on consumers’ decision to considerate the product insufficient adequate to meet their needs and wants of modern society (Cooper, 2010). Cooper (2004) defined the relative obsolescence into three forms; psychological, economic and technological (Fig. 1.3.1.B):

- **Psychological obsolescence** occurs when new products with cosmetic variations are deployed to market to stimulate and boost new flows of consumption against previous similar products. Fashion trends are a particularly good example. However, many goods typologies such as coffee machines, toasters or washing machines are replaced by customers to meet aspirational needs. In this case, design strategies consist of different color combinations, shape, size, or models, even without real technological improvement.

- **Economic obsolescence** is a form of depreciation caused by technical changes, running cost (fuel or energy) or high repairing costs of the product. This obsolescence occurs especially with product subject to technological change or low-cost products (Cooper, 2010). Example of this form of obsolescence are mobile phones, refrigerators and cars. Here, the design strategy is to make repairing or upgrading difficult or even impossible. The most emblematic case of economic obsolescence was the iPod. In 2003, Apple was sued by a “class action” because of the non-replaceable battery performance of their device which was purposely designed to degrade over time and the die after eighteen months (Latouche, 2013).

- **Technological obsolescence** occurs when a more technological and performing product or a technological change replace the earliest product or when supporting technologies are no longer available. For example, pen-drives, CDs, telegraph, or VHSs outline some historical products surpassed from new ones such as smart phones. This kind of obsolescence is related to fast-moving technology and it is subject to an incremental change.

Of the many different clusters of planned obsolescence, for the purpose of this thesis, it was decided to refer to the classification proposed by Cooper (2004) in the coming chapters because it has been considered the most update.

1.4 Circular economy

The circular economy (CE) is a concept inspired by authors such as Boulding (1966), Pearce and Turner (1989), Stahel and Reday-Mulvay (1981), Frosch (1992), and Pauli (2010), who argued that the traditional ‘ linear ‘ industry model (where raw materials enter and products and waste exit the system) must be transformed into an integrated industrial ecosystem. This closed loop model is inspired by natural systems and proposes the optimization of energy and material consumption, and waste minimization, where the outputs of one process serve as inputs for other processes (Frosch et al., 1989) to create further value (European Commission, 2016). More recently, the CE has been defined by the Ellen MacArthur Foundation as an economic model “that is restorative by intention; aims to rely on renewable energy; minimizes, tracks, and eliminates the use of toxic chemicals; and eradicates waste through careful design” (Ellen MacArthur Foundation, 2013) (Figure 1.4.A).

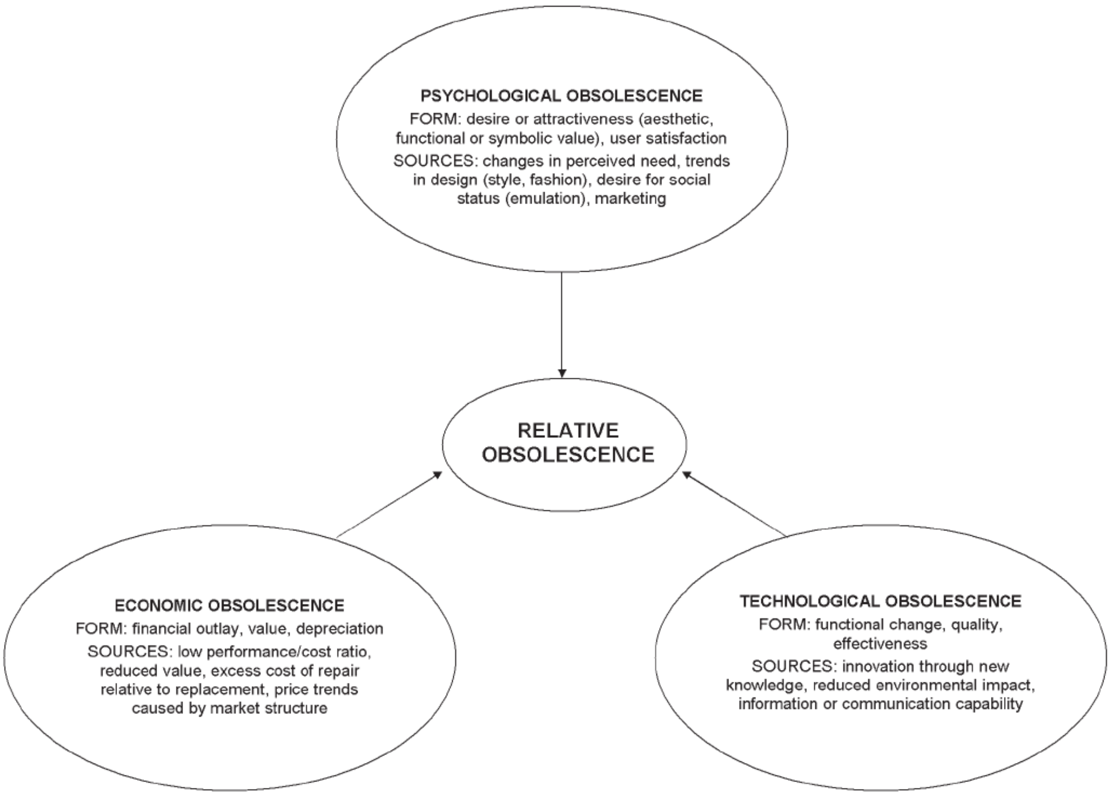


Figure 1.3.1.B. Forms of relative obsolescence.
Source: Cooper (2004).

The CE is an economic model that has been increasingly emphasized from many in contrast to the current linear economy: "take - make - use - and throw away" (Ellen MacArthur Foundation, 2014, Andrews, 2015, Ghisellini, et al. 2016,). The fulcrum of this concept is the closure or slowing down of material and energy flows through multiple technical or biological cycles (Yuan, Z. et al., 2006), with the consequent decoupling of use of materials and economic growth (Ellen MacArthur Foundation, 2014, Ghisellini, et al. 2016). This thesis focuses on the technological cycles of materials with the aim of improving the management of product design strategies. The objective of such system is to maintain the value and utility of products as high as possible as long as possible (Stahel, 2019). To retain the highest value in the system, in the CE five strategies are used: maintain, reuse, refurbish, remanufacturing and recycling (Figure 1.4.B).

Recent legislative regulations[1], concerning the use of chemical substances, reduction of gas emissions and solid waste production (Umeda, et al. 2012), were enacted to stimulate the European transition towards the CE (Bakker, et al., 2014). This change requires companies to make a major effort to transform business models, supply chains and production that not all companies are yet prepared to undertake (Asif, F.M.A et al. 2016). However, numerous case studies (De los Rios IC. Et al. 2016) show that companies could greatly benefit from material savings, risks associated with procurement, customer retention and the development of new revenue streams (Winkler, H. , 2011).

[1]See the regulations introduced by the European Commission in 2015 with the Circular Economy Package.

At this juncture, appropriate business models and design methods could help companies transition to the CE (Stahel, 2010; Tukker, 2004; Ceschin, 2014a; Vezzoli 2018). In literature, a great deal of attention is devoted to the role of the product designer, seen as a key function to close the material cycle and to encourage a sustainable approach throughout the production chain (Bakker, et al., 2014, Bocken, NMP et al. 2016, De los Rios IC. Et al 2016, Moreno, M., 2016, Ordoñez, I., et al, 2013). In this regard Bakker, et al., (2014), reiterates that one of the biggest challenges for design research is to determine when to apply certain methods in relation to certain choices of circular business models.

The only way to give hope to future generations, is by planning a drastically different way of doing things. To achieve this change it is necessary to transform the way we consume, design, build, produce, move, eat and take care of nature (Tirole, 2017) in other words, decoupling the use of materials and economic growth (Ellen MacArthur Foundation, 2012; Canfin-Grandjean Presidential Commission, 2015) (Fig. 1.4.A.). Ellen MacArthur Foundation, (2013) defines four "building blocks" that are necessary to the transition to the CE:

1. **Circular product design and production** - In this block belong all the activities related to the designing phases of the product. For instance, circular design strategies, circular tools, sustainable industrial processes and how the product should be reintegrated in the system to achieve the value-retention process (through reuse, repair, refurbishment, remanufacturing or recycle). Moreover, it is highlighted in this block the collaboration between different local and non-local stakeholders. In this thesis much attention will be paid to this block.
2. **New business models** - This block draw attention to the use of

business models to shift the behavior of users to new and more performance business model (based on the research of Stahel (2010) on the performance economy). From ownership of the product to sharing, collaborative or service models.

3. **Skills in building cascades / reverse cycles** - This block point out all the activities, capacities, tools and infostructures to recapture the value of the product, parts, materials once they have reached the end-of-use or end-of-life.
4. **Cross cycle and cross sector collaboration** - In this block a special focus is identified in the systemic collaboration between all the stakeholders involved in the different lifecycles and in all phases of the product journey. But also, all the interrelations between companies and policy makers.

CE consists of complex and intertwined networks and interlocutors that need to collaborate to obtain economic and environmental benefits. In 2018, the World Business Council Sustainable Development (WBCSD) described four possible levels of approach to address the CE, the macro level, meso level, micro level, and nano level (Tab. 1.4.A.).

1. **Meso level** - refers to eco-industrial parks, industrial symbiosis districts and networks. In these complex industrial systems, the aim is to exchange valuable nutrients such as materials, water, energy and by-products to create multiple cascading flows. By minimizing or eliminating waste and its cost from different types of industries, it is possible to emulate natural ecosystem and obtain an integrated system that works on cascading of nutrients (Pauli, 2010).
2. **Macro level** - refers to strategies that are applied to a bigger scale, for example cities, metropolitan areas or regions. Ghisellini at al., (2015) stresses the attention in this level on the integration and redesign of four systems, industrial system, infrastructure system, cultural system and social system.
3. **Micro level** - refers to the addressing of the CE from the production sector. Within a company's production process, product design is considered the main strategy. Whereas sustainable production process and its copious strategies are defined in the literature, design for the CE is still under discussion with many overlapping terms such as eco-design, green design, sustainable design, environmental design, bio-design, etc. A discussion on the general issue of the "different design approaches" at more length in chapter 4.
4. **Nano level -** refers to the base of pyramid on whichour society is built, hence materials and componentes. This level is not covered by all research and publications as related goals and measures must be taken to higher levels (e.g. Ghisellini at al., 2015)

The complexity and cross-disciplinary in addressing the goal of the CE reflect the need to investigate and clarify who should play which part. The better understanding and juxtaposition of many different intellectual domains could bridge the gap between systems and help to find better tools and design approaches to boost and manage the CE. For this reason, this thesis will focus on specific subject areas related to the general discourse introduced so far better explained in Figure 1.4.B.

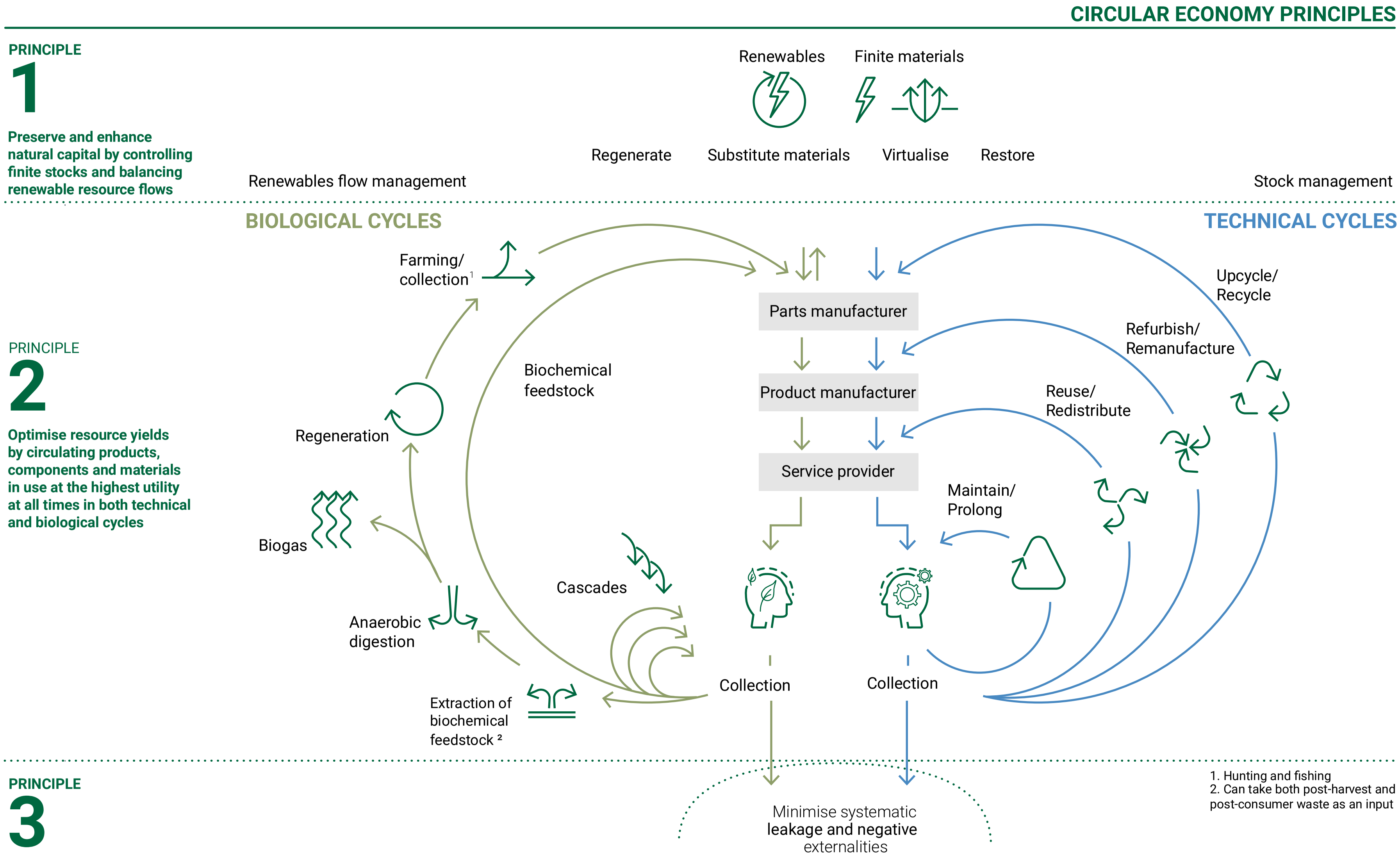
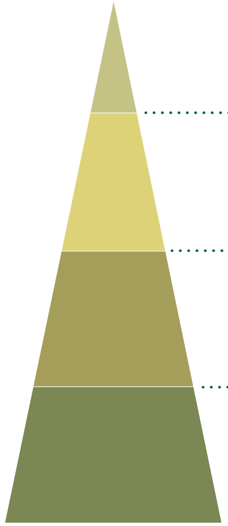


Figure 1.4.A. Circular economy system.
Source: Adapted from Ellen MacArthur Foundation (2012).



	WHAT DOES CE MEAN?	WHAT ARE CE'S POSITIVE IMPACTS?
MACRO LEVEL *(countries, cities ...)*	· Change purchasing habits (favour products & services with low environmental impact...) · Enforce laws, programs frameworks related to CE	· Increase attractiveness thanks to value/job creations · Limit resources rarefaction and dependency on importations
MESO LEVEL *(inter-industries, ...)*	· Create inter-industries/firms networks · Deploy industrial symbiosis where companies exchange flows and mutualize needs	· Increase dynamism & attractiveness of territories · Reduce impact on environment · Create / relocate jobs
MICRO LEVEL *(companies, consumers, ...)*	· Consume green (favour products with low environmental impact, recycling...) · Produce cleaner (eco-conception, offer services instead of products...)	· Reduce impact on environment · Provide competitive advantage (improved business model, new markets available...) · Improve brand image / reputation
NANO LEVEL *(product, component, ...)*	· Use/extract environmental-friendly goods · Increase life expectancy of goods through recycling, reuse, repairing	· Decrease extraction / consumptions of raw materials · Increase value of second-use materials and goods

Table 1.4.A. Levels of circular metrics.
Source: WBCSD (2018).

Figure 1.4.B. Circular Economy Building Blocks / Thesis Focus.

CIRCULAR ECONOMY BUILDING BLOCKS - THESIS FOCUS

3. CIRCULAR ECONOMY DESIGN	3. NEW BUSINESS MODELS	3. REVERSE CYCLES	4. ENABLERS AND FAVOURABLE SYSTEM CONDITIONS
1. Human Dimension in the CE	1. The Classic Long Life Model	1. Maintain / Prolong	1. Collaboration / Network
2. Circular Material Design	2. The Hybrid Model	2. Reuse / Redistribute	2. Tools
3. Circular Components Design	3. The Gap Exploiter Model	3. Refurbish / Remanufacture	3. Circular Skills
4. Circular Product Design	4. The Access Model	4. Upcycle / Recycle	
5. Circular Product System Design	5. The Performance Model		

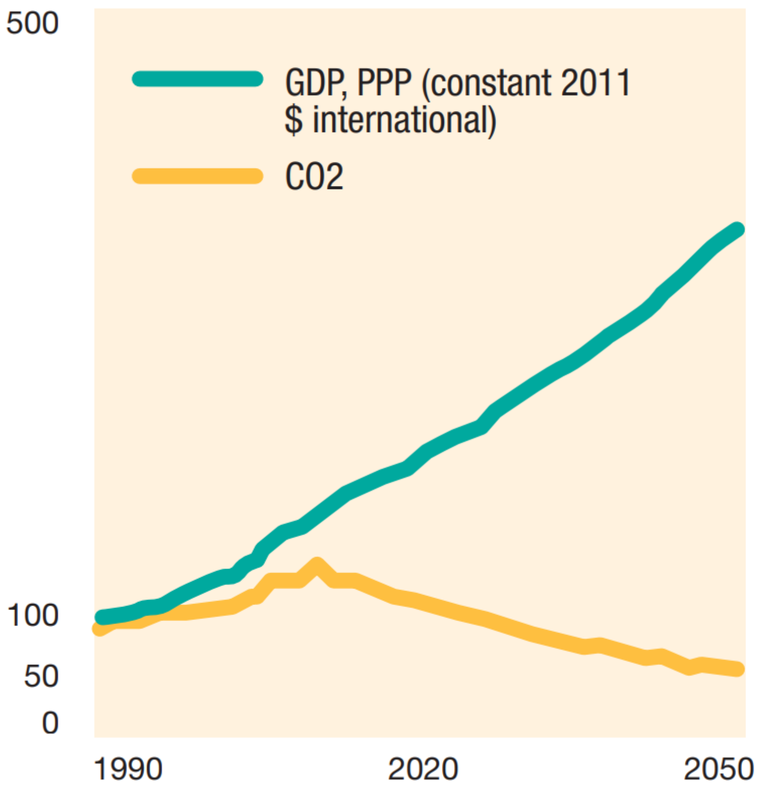


Figure 1.4.A. Projected growth until 2050 of global GDP and CO2 emissions in a 2°C scenario.
Source: Canfin-Grandjean Presidential Commission (2015).

1.4.1. Circular Society

The current European rate of consumption is unsustainable. Developing countries are rapidly on the same path of consumer materials consumption and increased inequality (Lorek et al., 2015). In 1988, the Brundtland Commission published a report which explored the implications of global resource overshoot and they framed an iconic definition of sustainable development: “Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1988). The evidence has since shown that little progress has been made.

Changing the consumption behavior is a crucial element for the success of the CE. However, consumption is part of a complex social and economic system, entering into all aspects of it, to move from a linear economy to a circular one may imply to redefine the entire anthropogenic system. Complex systems are often, due to their non-linear nature, unpredictable at longer time scale. Knowing the interrelations between variables is an essential task to avoid “shock” and create “resilience”. For the purpose of this thesis, to avoid the rise of 2.5 to 7.8 degrees Celsius before the end of the twenty-first century and preparing for the rise of 1.5 to 2 degrees Celsius.

In order to understand the range and characteristics of the existing complexity to achieve a CE, a literature review was performed. This analysis identified and mapped the complexity of different barriers by using the micro (Product/Customers), meso (Business/Network) and macro

CULTURAL BARRIERS OF CE	LEVEL	FOCUS	REFERENCES
Lack of awareness from customers in refurbished products	MICRO	User acceptance	van Weelden, et al., 2016.
The misconception of the refurbishment concept	MICRO NANO	User acceptance Product design	van Weelden, et al., 2016.
Lack of high availability of refurbished products in the market	MESO MICRO	Reverse cycles User acceptance Product design	van Weelden, et al., 2016.
Lack of the thrill of newness	MICRO NANO	User acceptance Product design	van Weelden, et al., 2016.
Lack of design skills to influencing new ownership models	MICRO	New Business Models User acceptance	Bakker et al., 2014; Tukker, 2015.
Lack of inter-sectoral and interdisciplinary tools	MESO MICRO	Collaborative Design Tools User acceptance Product design	Vezzoli 2015; De los Rios et al., 2017; Bokken et al., 2019.
Lack of simple and promptly circular tool	MICRO	Tools	Bokken et al., 2019.
Lack of leadership and management of CE	MACRO MESO MICRO	System System System	Su et al., 2013; Liu et al., 2014; Shahbazi et al., 2016.
Lack of information on CE to companies	NANO	System Collaborative Design	Liu et al. 2009; Su et al. 2013; Dalhammar, et al., 2016.
Lack of design decision for CE	NANO	Material Design Component Design Product Design System Design	Bakker et al., 2014; Pan et al. 2015.
Lack of supportive CE lows	MACRO	Material Design Component Design Product Design System Design	Zhijunet al., 2007; Li, et al., 2009; Su, et al. 2013.
Lack of information to the public on CE. Lacking user interest and awareness in CE.	MACRO MICRO	System User interest	Su et al., 2013; Lieder et al., 2016; van Weelden, et al., 2016; Kirchherr, et al., 2018.

Table 1.4.1.A. Circular cultural barriers on micro, meso and macro level.

level (Region/City) approach. Table 1.4.1.A can be used as an overview of all the principal barriers that may be prejudicial to the transition to a CE society.

The difficulties to move from a linear to a circular design for a social change is undeniable. What remains to be understood now is how all this components and levels will work together to create a "choral way of designing" capable to be sustainable, ethical and resilient.

1.5 Design for Circular Economy

The concept of design for CE lies at the core of the systemic approach to the CE. Environmental impacts occur at all stages of a product's lifecycle. Different types of products have impacts at different stages of their lifecycle. Kitchen utensils, for example, have the greatest environmental impact on their raw materials and disposal. While most environmental effects are expressed in the use of a refrigerator during its lifecycle. Wherever the environmental impact is, however, all the resources used in the first, second, third and after life cycles should be optimized and controlled in the design for the CE. Naturally this control can only be effective if all the decisions are determined during the 'Phase 0' of the design process.

1.5.1. Designers in the circular economy

Many scholars have argued the most important actors in product design for the CE and development of it have been designers (Moreno et al., 2016; De los Rios et al., 2017). Designers such as engineers, product designers, packaging designers, etc., have been the focus of product design and development; however, other internal and external stakeholders are playing an increasingly important role in the transition to the CE. Therefore, the position taken in this thesis is that all the decision-makers that can affect how well the succeed of a circular product goes over multiple life cycles are crucial and bring important competencies to successful circular products and should therefore be considered.

The picture is, however, more complex. Different decision-makers have different skills, terminologies, knowledge and use different approaches and methods to solve problems. If the ambition is to consider and integrate all their perspectives to accelerate the CE, then there is also an essential need to understand and coordinate all the different views and approaches. Therefore, should be important not to give more relevance to one discipline rather than another and examine all the decision-makers essential part of the total circular approach. With this view, in this thesis it has been decided to consider all the decision-makers indistinctly designers.

While in the linear economy every designer focuses on his or her challenge, in the CE the challenge lies on how different design strategies can be used together to better manage the product over multiple life cycles. In particular, this attention should be preeminent in the product recovery phase, when the product will terminate one life cycle and begin another one.

1.5.2. Closed-loop and Open-loop in CE

At the end-of-use, products should be returned to be reused somehow in the system again. At this phase of the product process, designers should decide whether to adopt a closed-loop or an open-loop strategy. In the CE, a loop is closed when products, components or materials remain in the same system loop (it is always the same company that recapture the product value over and over again), while it is open when the product change system loop (different companies from the original equipment manufacturer (OEM) recapture the value of the product). To better understand the difference between these two strategies some examples may be useful.

Xerox is commonly used as an example of closed-loop strategy, by selling goods as a service the property of the product is maintained by the company. When the end-of-use of the product comes, the company recaptures the value from the customer and reprocesses the product in order to reuse the value of it for another loop. Xerox maintains control of the system, and other companies cannot take advantage from it. Conversely, a good example of open-loop system is Apple. Apple sells hardware (smartphones) in the free market but preserve the high value of their product by granting sole rights to access to their hardware to third-party companies in a very controlled manner. By so doing, Apple tries to avoid cannibalization from uncontrolled third-party companies. The third and last example is Vestiaire Collective. Luxury products are usually sold in the market, where customers can buy high end seasonal products. When a product is not attractive anymore, customers can sell their product in secondary markets to companies like Vestiaire Collective that recaptures the value of such product by reselling it into second-hand consumers.

The closed-loop vs open-loop consideration has a profound impact on the success of circularity as well as on the business model. Success lies in the ability of the designers to accurately control how and from whom the product should be reintegrated. In the case of an open-loop approach, this can be much more complicated and collaboration between the OEM and third-party companies is a fundamental aspect to plan. In general, it should be stressed that product will get, eventually, a level of obsolescence in which the product needs to be restored to be kept in optimal conditions of working. For this reason, design for managing product obsolescence is an important part of the design process.

1.5.3. Design for Managing Obsolescence

Aerospace, railway or defense sectors often have products which remain in service for more than 20 or 30 years. During the product life journey, obsolescence is a common stage that all components and structures will face eventually in this sector. In most cases, those products are made from different materials and components which have different expected service-life. Whenever a new product for industrial goods sector shall be designed, designers must define an obsolescence plan that describes when, how and why a part of the product or the entire product should be substituted. Also, by specify how to handle the end of life for any component of the system and list all the factors that contributed to that decision including the criticality and risks of that component being obsolete. This shows that design for managing obsolescence is a common practice in some industrial sectors where the value of the product is high and often owned by the same manufacturer.

From the above enlightenment, it follows that obsolescence is, especially in some industrial sectors, an important component of the design process which has to be considered and managed as an ordinary parameter. Differences between industrial goods sector (B2B) and consumer goods sector (B2C) lies on the fact that the most widespread engagement between the provider and the customer in this B2B is the sale of the performance, whereas in B2B is the sale of the product. Therefore, it would seem worthwhile to analyze and draw attention to characteristics of the two different sales approach on three factors: products, consumer and situational context (Cooper, 2010). See Table 1.5.3.A.

These factors can influence how a product behaves in the market, how it is sold (i.e. rental or sale), how the customer takes care of the product, and when the customer will want to get rid of the product. Design for managing obsolescence means making decisions on the basis of all these factors. It is up to designers decided and manage the multiple obsolescence the product will deal across the multiple lifecycles., and understand it is a key factor to maintain full control of the product.

Table 1.5.3.A. Managing obsolescence in different sales approaches.

	PRODUCT SALE	PRODUCT AS PERFORMANCE
PRODUCT	When products are sold to customers, one of the economical values of the company is to create products with lower quality to economize on materials. In this case products need more maintenance and care that should be provided by the consumers.	Product in this sector are tailor-made for customers. The high quality of products sold as a service can guarantee that the product can be reintegrate for multiple times in the system without suffering from the high rate of use.
CONSUMER	Here, consumers are more interested in the ownership of the product. They should take care of their items to maintain the product in operation. In this case, when the product will fail, consumers had to deal with the recovery of the item and any additional charges must be settled by him/her.	Here, customers are less interested in the product and more interested in achieving the purpose for which they are paying (Stahel, 2010b). Customers can decide between many products which one is best suitable to achieve the desired result and they do not have any responsibility for the maintenance of the product.
SITUATIONAL CONTEXT	Here, the property of the product passes from the provider to the customer (Tukker, 2004). When a product wear and tear, the customer is expected to take care of and fix it. However, when the product is too obsolete, he can decide to give the product to any entity offers more to get back the product, this means that the company does not have any rights to get back the product.	Here, the property of the product remains with the provider, whereas the customer pays just to receive the service of the product (Tukker, 2004). In this case the customer is obliged to give back the product to the provider. The provider can have a better control of the product and decides when there is a need to restore the product for a better service

1.6. Conclusions

This chapter investigated the basics of the linear economy and how it is possible to reverse this unsustainable development, that rely on natural resources, by shifting the current system to a more circular and resilient model. The key findings gathered in this chapter are that pursuing infinite growth -of the economy, the production, the population- on a planet with finite resources is impossible and is creating unrecoverable disruptions for the entire natural ecosystem. It is therefore important to replace the linear narrative of endless growth with circular narratives that remind us that what goes around comes around. In this new narrative, design plays a pivotal role in supporting the transition to a CE. There is a need to develop strategies which provide for a new , often radical and committed approach to minimise the potential environmental impacts of new developments at the the earliest stage possible. If natural resources are harnessed correctly, new economic models may emergence to restore a sustainable balance between economic growth and use of natural capital. Its success depends on the collaboration between different stakeholders in the meso, macro, micro and nano level. Here, designers have a major part to play to respond to the change by integrate all their perspectives and in doing so accelerating the CE. The final choice of product, service and process should relate both to economic and environmental criteria. Managers and designers must therefore collaborate and justify their decision at all stages. This will foster understanding, commitment and support from all stakeholders.

Chapter 2

RESEARCH SCOPE AND QUESTIONS

Synopsis
This chapter introduces the reader to the research by providing the thesis position, describing the purpose, research questions, methodological approaches, and how this work fits into the broader landscape of design research.

2.1. The motivation of the thesis

This thesis, is discussing a different and more integrated approach to design in the context of CE. A variety of systemic problems might lead to irreversible global warming of 1.5% ºC. Industry plays a crucial role in limiting global warming (Ellen MacArthur Foundation, 2012; European Commission, 2016c). As suggested by de Coninck, et al., (2018), such reduction can be achieved through the combination of new and existing technologies and practices. For example, some businesses have already subscribed to a CE to benefit from material savings, reduced supply costs, increased customer loyalty, and new revenue stream growth. However, this is not easy to achieve, since most of the European companies are small and medium-sized inter-sectoral enterprises and have limited access to reliable information about how technical changes in their products and the transformation of industrial systems can contribute to shaping the sustainable models of production and consumption (Govindan, et al., 2018).

The majority of existing concepts and tools employed for dealing with elimination, avoiding, or reduction of environmental impacts such as life-cycle assessment (LCA) or extended producer responsibility (EPR) are usually employed too late during the design process. Many designers are involved throughout the design process to decide all the characteristics of a product, but often these different professionals have different business goals and work in "silos". In other words, companies and their designers find it challenging to integrate systematically circular design strategies from an early design stage (De Los Rio, et al., 2017; Bovea, et al., 2018). The political, economic, social, technological, and ecological complexity makes it even harder; this reveals a general lack of appropriate approach for industries to design for the CE.

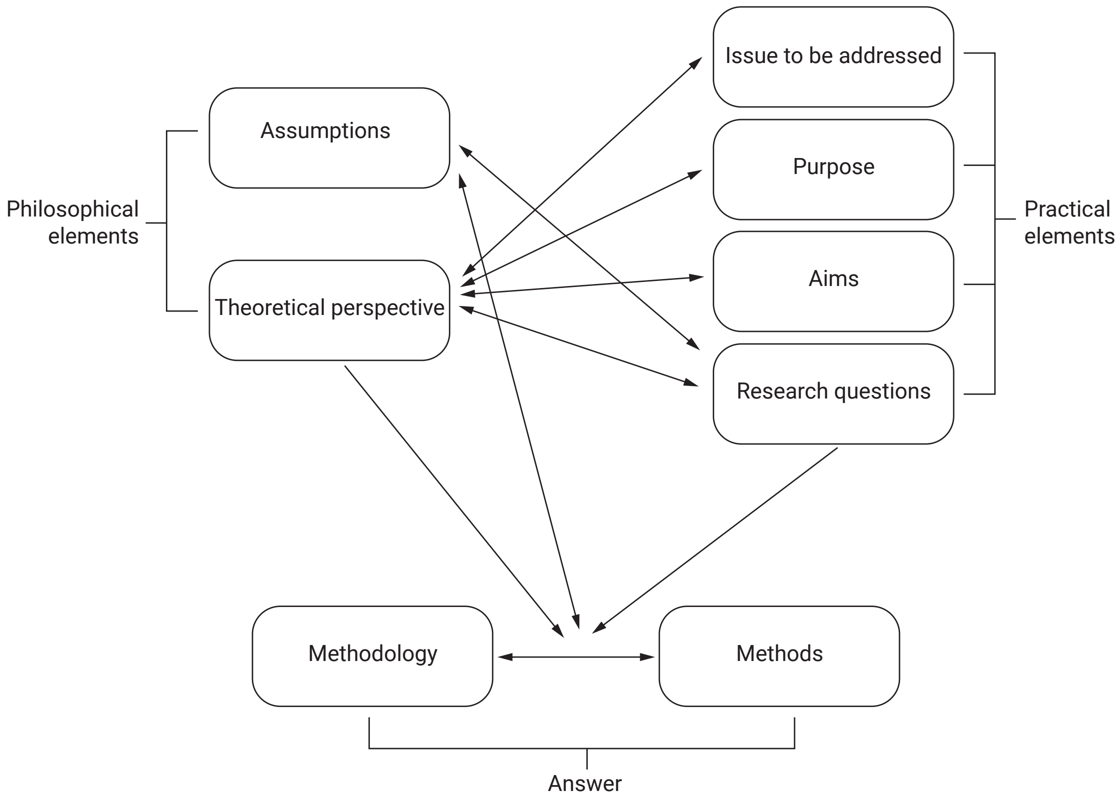
Ideally, an industrial circular system should be able to reintegrate significant products (value) continuously, regardless of type, dimensions, or system of origin, as well as creating economic and employment opportunities (Nasr, et al., 2018). It means to be able to apply the most promising systematic design strategies for the company, context, and customer for many loops over time. Despite the extensive research conducted on the issue, and the considerable progress achieved, the conception and implementation of the usual approach to a circular system do not seem to be easy to achieve soon. For this reason, it is necessary to reframe the design viewpoint in order to create a whole new pattern of new advantages and opportunities, which will be only possible by designing an appropriate methodological approach to finding a relevant final answer.

2.1.1. Methodological approach

There is plenty of knowledge about the practice of social research. The general message that can be taken is that the choice of methodologies and methods for the study is motivated by various philosophical (ontological and epistemological principles, and theoretical perspectives) and pragmatic elements (as to be dealt with and purpose, goals, and questions related to research). Because social research starts with "a real-life question to be addressed and a problem to be solved or answered" (Crotty, 1998), and that all knowledge is knowledge from some point of view (Toraldo di Francia, 1978) philosophical assumptions are 'inescapable' (Carter et al., 2007), theoretical and practical considerations are important for social research design.

Practical elements are straightforwardly present and influence when designing social research; the goals and objectives of the research are underlined, and help to answer questions of the study. However, the relevance of philosophical elements should be considered because, even if it is not always clear in social research, these elements influence whether explicitly or impliedly all the methodology and practical elements are chosen for research use (Crotty 1998). Hence, this research is based on the researcher's awareness and understanding of his philosophical assumptions and theoretical perspective. The interrelationships between the important elements in social research design were considered, and a framework (Cunningham, 2014) was followed to incorporates such elements and defines their interactions and relationships (Figure 2.1.1.A). This promotes consistent research design, including the use of congruent quality assurance methods, and makes good and meaningful results possible (Crotty, 1998; Silverman, 2000; Morrow, 2005). In the following paragraphs the philosophical and practical elements that characterize this thesis will be explained in detail.

Table 2.1.1.A. Framework integrating philosophical and practical elements in the process of social research design.
Source: Figure adapted from Cunningham, 2014.



2.2. Theoretical perspective

The functional and implementation of the issue to be addressed led to a realistic conceptual view; in other words, the theoretical perspective of this thesis is a pragmatic theoretical perspective. Pragmatism means a research methodology that emphasizes the practical effect of information (Schuh et al., 2008). It considers knowledge as an 'instrument of practice', and the question shifts from 'Does this knowledge accurately reflect the underlying reality?' to 'Does this knowledge serve our purposes?' (Cornish et al., 2009). The goal of a pragmatic theoretical view is to choose the methodologies and methods most suitable to answer the questions posed by the analysis and achieve the goals of the study - be they qualitative, quantitative, or a combination of them (Cornish et al., 2009).

At the beginning of this research, understanding the theoretical perspective formulation has been complicated, probably because of the abstraction of topics involved and their relations with the pragmatism theory. Alongside this process many reconsiderations and adjustments have been made to acquire a solid theoretical position and increase the reliability of the final result.

2.3. Aims of the Research

The general purpose that this thesis wants to address is the acceleration of the CE through the adoption of a more systematic and collaborative approach to strategic design. Thus, the issue to be addressed is the lack of available tools and frameworks that can enable this systemic and collaborative approach. For this reason, three aims have been defined and highlighted:

The **first aim** of this research project is to provide a new comprehension among multiple circular designers. Such framework should establish a common perspective between designers involved throughout the entire lifetime of the product across different loops. The driving force for the implementation of a new circular design framework is mainly the lack of agreement about circular strategy and the role of design in the whole system.

The **second aim** of the research is to develop circular design tools that can facilitate the management of design strategies between different phases of the product lifetime. Based on the first aim output, the tool can support collaborative decision making by organizing strategies more coherently and highlight the links between phases. The driving force for the implementation of a circular tool is to clearly visualize multiple design perspectives to order the set of possible opportunities and frame the circular goal as an integrated whole.

The **third aim** of the research is to define a possible process where all the multiple design perspectives can be analyzed and elaborated concretely. Based on the two previously aims, the process can support collaborative strategic innovation through design. The driving force for the implementation of a new circular process is the urgency of the transition to the CE.

2.4. Research questions

2.4.1. Main research question

Design methodologies can be a powerful resource for designers to accelerate the design process and implement specific goals. In many companies, where time and decision making are standardized and already implemented, the introduction of variables such as CE is often seen as problematic. Today, where education in industrial sustainability and CE is still in its infancy, the implementation of good circular strategies in the real world is a chimera. CE adds too much complexity to an already complex industrial setting.

For the reasons above this research intends to focus on:

What would be a comprehensive design framework that supports multiple design perspectives throughout the design process for effective circular products, thus accelerating the circular economy?

2.4.2. Sub-research questions

Product design evidently has links with a lot of other areas (Lutters et al. 2014). This causes complexity that designers should manage during the design process. In the CE this complexity can become even more oppressive due to the fact that product should circulate in loops. Some circular approaches exist and can be used by designers to implement their products circular flow, however the application of such approaches tend to be unbalanced towards one or a relate close group of views (i.e. business model creation, change behavior of users, etc.). For this reason, the first sub-research question of this PhD' research is:

How could a multitude of heterogeneous decision-makers (designers) and their strategies be organized for a collaborative design approach in the context of CE?

For designer is hard to have a holistic view of the entire design process, especially after the end-of-life. Even when products are designed to be circular, sometimes is hard to manage all the single design steps within the industrial process. Additionally, corporate internal conflicting goals, may interfere and dilute the objective of an increased circularity of products. For this reason, the second sub-research question is:

How design strategies can be systematized and organized more efficiently to help designers to cope with cross-system, cross-loop and multi-phase perspectives over multiple product life cycles?

Circular design is a network of correlated activities that designers should apply in order to get a product in the loop. There are several design opportunities in the CE, but time and effort for corporates to evaluate those are limited and expensive. Because of that, many opportunities are often overlooked as the cost and risk of innovation feel overwhelming as opposed to incremental linear models. Starting from this point, the third question that this research wants to achieve is:

How might multiple design perspectives be integrated into an agile and fast process to developed circular products?

2.5. Methodology and methods

The approach and methods should be chosen based on their ability to answer and achieve research questions (Miles et al., 1994). In this thesis, it is assumed that the most efficient way to address the research questions is by using a qualitative method. The decision is based on the particular complex challenge and the lack of quantitative studies on this topic. For these reasons, such study employed the design-based research approach. Herrington et al., (2007) listed three parameters why design-based research may be preferred:

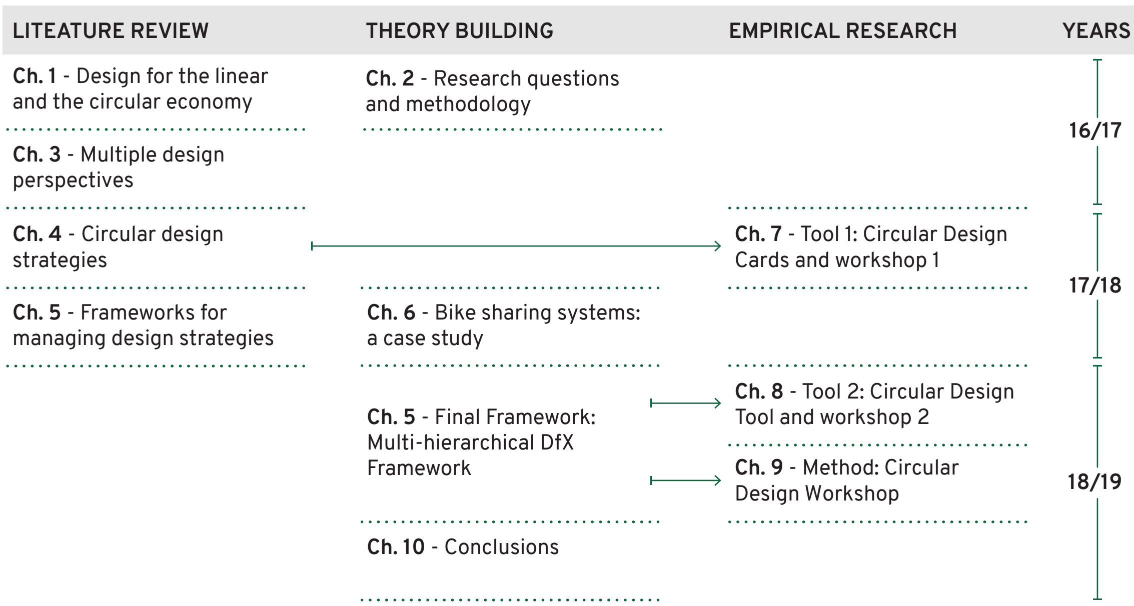
- addressing complex problems in real contexts in collaboration with practitioners;
- integrating known and hypothetical design principles with technological affordances to render plausible solutions to these complex problems;
- conducting a rigorous and reflective inquiry to test and refine innovative learning environments as well as to define new design principles;

This methodology was chosen for the following reasons:

- in the main question, the aim is to find a comprehensive framework to facilitate collaboration between multiple design perspectives, the field of design for CE is in its early stage of development, and not enough experimentation and research have been conducted, for the time being, this methodology may facilitate trial and error approach to investigate and expand the knowledge;
- in the first sub-research question, the aim is to design a collaborative design approach for multiple design perspectives; this makes design for CE a particular complex subject where multiple disciplines continually overlap each other. This kind of complexity is a new matter in research that force to think to alternative and innovative, practical approaches that should be tested with real participants;
- the second sub-research question aims to systemize and organize design strategies, this question targets designers both in their professional or educational careers to create tools that can support both design for real challenges, and design for conceptualization and learning, changing the roots of the linear system towards more circular one;
- the third aim is to find how multi design might be integrated with an agile method; this sets the foundation of an explorative research that should be further investigated through additional iterations.

Several methods have been used to find possible answers to the research questions, to guide the reader the chapter were clustered in three groups, literature review, theory-building and empirical research (Figure 2.5.A). In general, terms, to understand and to develop the knowledge of this thesis, the method used was the literature review, so chapters 1, 3, 4, and 5 are based on this method. Fink (2014) defined a research literature review as “a systematic, explicit, and reproducible method for identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars, and practitioners”. Once the theoretical foundations are set, the research attempted to create its theory in chapters 2, 5, 6, and 10 through different methods for each chapter. Chapter 2, developed a theory-building through a deductive process, chapter 5 and chapter 6 are based both on a semi-structured interview with users and experts, and then chapter 10 tried to develop its theory based on the analysis of the previous chapter. In the empirical research group, chapters 7, 8, and 9 are based on field methods. In chapter 7, a design tool was developed and tested in a first workshop with students, in chapters 8 and 9, after iterating from the previous chapters, an online design tool (Chapter 8), and a new workshop (Chapter 9) have been developed and tested with students. Chapters follow a semi-chronological order that reflects the doctoral period of the author (Figure 2.5.A).

Figure 2.5.A. Research methods.
Source: Figure adapted from Ceschin, 2012.



2.6. Philosophical assumptions

Philosophical assumptions were the final item to be considered. These are inherent in research design and guide and influence all research phases (Mesel, 2013). The researcher should identify them clearly and look at them to prevent them from being fooled by their hidden influence (Hammersley, 1992). It also helps others to consider and appreciate the conclusions and, therefore, not to misjudge the research results and findings (Crotty, 1998).

Through a consideration of the research questions and methods, it is assumed that to design for the CE; it is a requirement that many different perspectives from several professionals have to collaborate and organize design strategies to implement a successful CE design. This may not seem much different from plenty of literature on CE, which argues the necessity of collaboration to create real opportunities for the CE. However, collaboration is often taken from only a certain number of perspectives, and not all. Besides, a solid understanding of the collaboration network is often missing, probably due to the impossibility to define the inter-relationships between different decision-makers, their design strategies, and how they can collaborate to create products where both circular and sustainable design strategies are applied.

2.7. Outline of the research project design

In a doctoral thesis, where multiple research elements intertwine and overlap, it is essential to define the interactions and relationships for extra clarity. The final and general outline of this research is presented in Figure 2.7.A.

2.8. How and Where Does this Research Fit into Design Science

It is now important to define how and where this thesis fits into design science, especially because it embraces a really holistic vision of design. Love (2002), defined three key elements of designing, “humans”, “objects” and “context”. Together with their relationship they form the following nine headings:

- Humans;
- Objects;
- Contexts;
- Human to human interactions;
- Object to object interactions;
- Human and object interactions;
- Human and context interactions;
- Object and context interactions;
- Interactions involving human(s), object(s) and contexts together;

The nine areas above, provide a structure for establishing a relationship between design theories and designs and theories from other disciplines (Love, 2002). In this research, the European context and world influence on it is analyzed in Chapter 1. By contextualizing the current anthropogenic system it is possible to identify and integrate the different perspectives to build the foundation of the thesis. The object dimension in this thesis is investigated in Chapter 3. By visualizing all the possible elements that constitute an object from a different industrial perspective, it is possible to define the correlations and actions for CE. Finally, the human dimension is analyzed in Chapter 4. Only by understanding the connection between time and design and the relative consequences on human behavior, it is possible to transit for a linear economy to a circular one. The sum of “human”, “object” and “context” elements are presented in Chapter 5. Here, an attempt of building a unified and coherent cross-disciplinary framework for the design for the CE is proposed and tested.

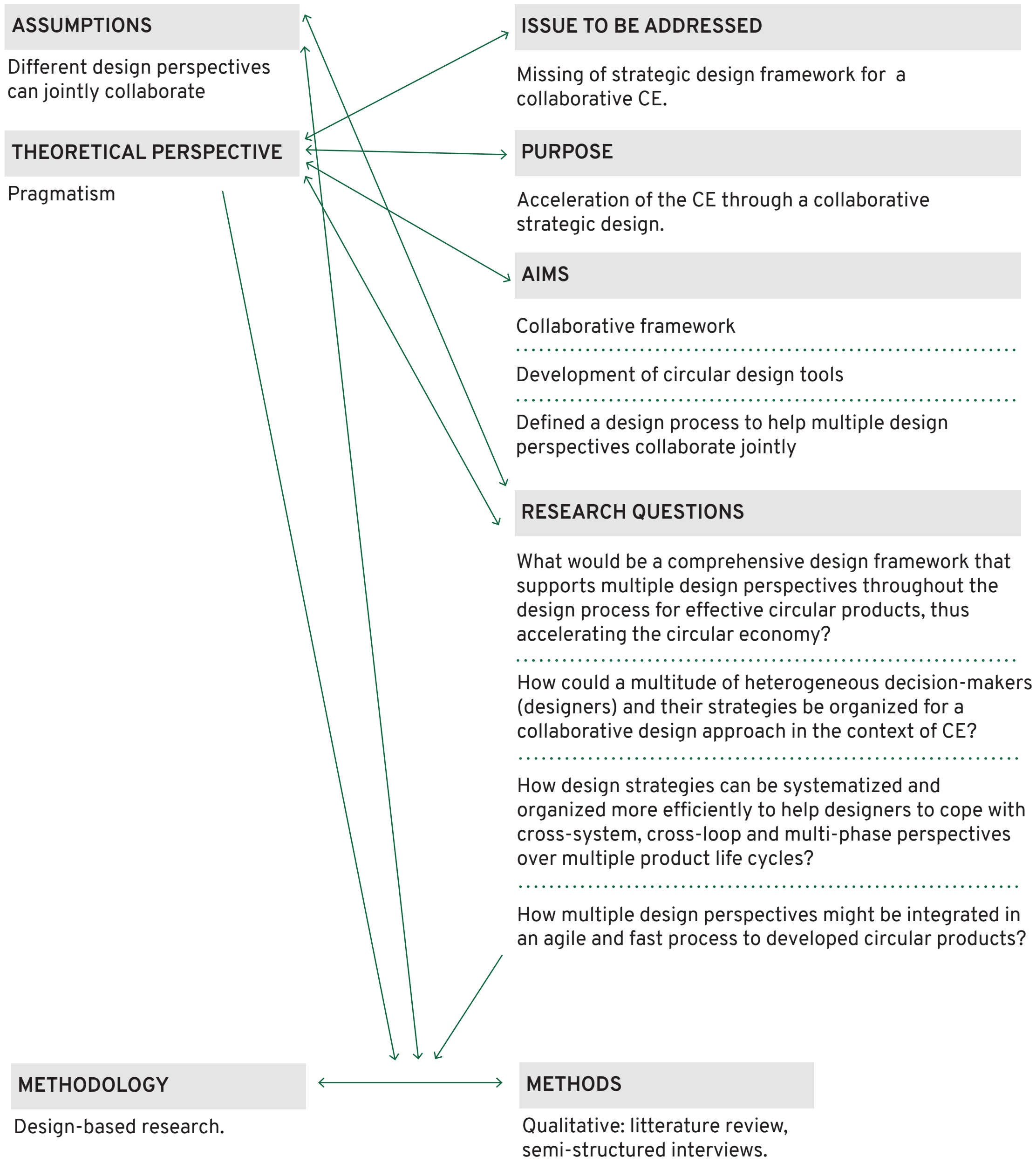


Figure 2.7.A. Outline of the research project design.

Chapter 3

MULTIPLE DESIGN PERSPECTIVES

Synopsis
In the CE, in order to solve complex problems, it is useful to see solutions from different perspectives. For the designer, it is vital to see and understand the different elements and sizes which make up the challenge, leading the part the designer should play among other designers. By doing so, different perspectives can be the link, conflicts can be solved, and the bigger picture may be unveiled. This chapter deals with the difference between “what the designer looks at?” and “how the designer looks at it?”. This differentiation of “what and how to look at” is something that was initially proposed by Linstone in 1984. For this thesis, the same approach was used and reapplied in the context of design for the CE.

3.1. What the designer looks at?

The entire anthropic system, to work correctly, involves different elements: nature, man, society, and technology. By combining these elements, it is possible to define four different levels that describe the system (Ceschin et al., 2016).

- Socio-technical system level;
- Spatio-social level;
- Product-service system level;
- Product level;

In literature, various categorizations of system levels can be found, in addition to the categorization made by Ceschin et al., (2016) presented in Fig. 3.1.A. However, it was decided to use and combine the classifica-

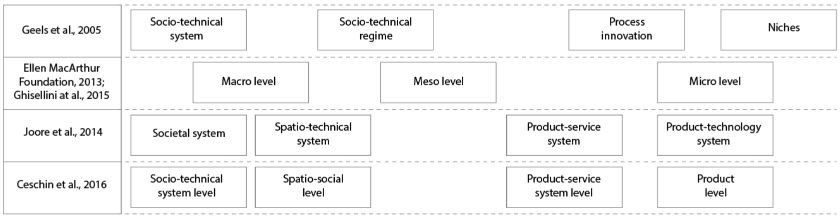


Figure 3.1.A. System levels classification.

tions of Ceschin et al., and Ellen MacArthur Foundation (2012).

This thesis mainly focuses on the last two elements of the system. However, it takes always into consideration all levels of the system, because "sustainability is a system property and not a property of individual elements of the system" (Ceschin et al., 2016). In the system, design represents the everyday activity for all the four-levels to innovate and improve and each of this system can be considered a design perspective. If until recently, design was seen as a narrow space where different designers could operate together, often with imbalances between roles, decision power, and duties, now it has become increasingly clear that all the design functions should be operating across multiple perspectives with the same emphasis to innovate and improve the system effectively. By having in mind the entire picture, it is easier for each designer involved to tackle interconnected problems.

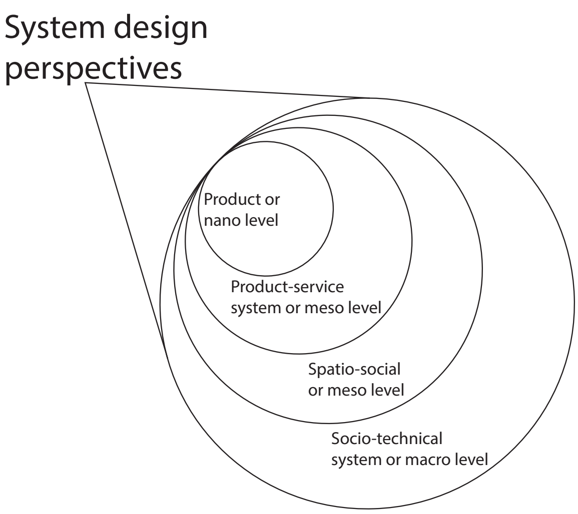
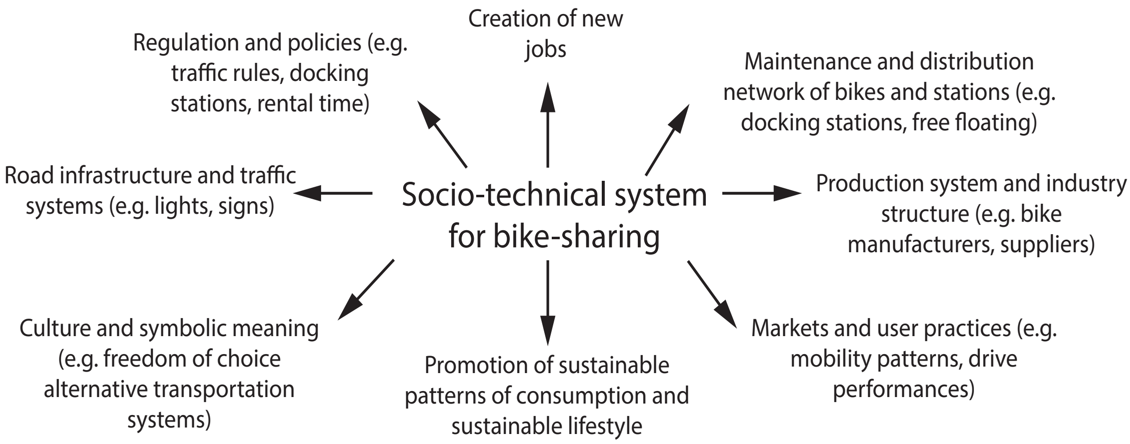


Figure 3.1.B. Design perspectives of the anthropic system.

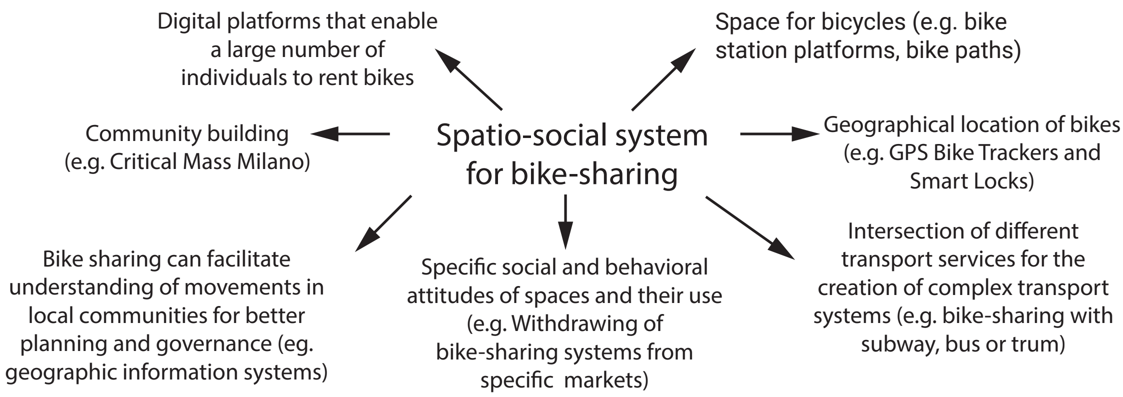
Socio-technical system level - can be described as a network of technology, activities, administrative organs, maintenance networks, and supply networks, among many others, which are needed to fulfill a societal function (Geels, 2005). Geels also added that "these social groups have their vested interests, problem perceptions, values, preferences, strategies, and resources (money, knowledge, and contacts) (Geels, 2005). Ceschin et al. defined the design approach in this system., (2014) as the design for system innovation and transition (more information about design in the socio-technical system level can be found in Ceschin 2012, Gaziulusoy et al., 2015 and Irwin, 2015). An example of the socio-technical design perspective for bike-sharing is illustrated in fig. 3.1.B.

Figure 3.1.C. Socio-technical system for bike-sharing.



Spatio-social level - refers to the coordinated activities that enable social innovation. In other words, all of these activities should be continuously supervised, monitored, and recorded by designers in order to support groups of individuals or companies to develop products and services for a given geographic area. The operational approach to this system takes place through digital platforms or, less often, by meeting people of the same community (Manzini, 2019). Some examples of this design perspective relate to activities designed for social innovation (Manzini, 2019), systematic design (Barbero et al., 2010). An example of a spatio-social system for bike-sharing is illustrated in fig. 3.1.D.

Figure 3.1.C. Spatio-social system for bike-sharing.



Product-service System (PSS) - can be defined as “the result of an innovation strategy, shifting the business focus from designing and selling physical products only to selling a system of products and services which are jointly capable of fulfilling specific client demands” (UNEP, 2019). Compared with the first two system perspectives, the PSS is a well-defined system. In this system, users can be better satisfied because they do not concentrate on the product itself but on the core activity of the product, which is the function of the product. Companies can build multiple touchpoints with clients and obtain customers’ loyalty creating more space for innovation (Tukker, 2004). In this way, the producer has an economic advantage in designing products that are more robust, durable, and that can be reused for multiple life cycles (Vezzoli, 2007). In the linear economy, the production of goods, consumption, and a company’s profit are all directly proportional. Whereas in the PSS, companies profit from the number of times goods are used.

The PSS is based on the school of thought of the Performance Economy by Stahel. In his book, Stahel argued how the Service Economy could uncouple revenue and wealth creation from resources, increase wealth and welfare, and create more jobs (Stahel, 2010). Here, the concept of value becomes increasingly important as the objective of the PSS is to maintain the value of the product along with the product (Mont, 2004). On the other hand, in a linear economy, value is destroyed when users get rid of their products. However, PSS is not always synonymous of sustainability; the product given as a service should be explicitly designed to be used as a service; otherwise, it may not be reintegrated multiple times in the system. For instance, in the case of bike-sharing, Mobike designed and produced their bikes. When a bike fails, they can remanufacture the bike many times and continually recapture the value of it. However, unlike Mobike, Ofo uses a third party bike that was not designed to be repaired or robust enough to be remanufactured. These different design and business approaches to PSS will, most likely, determine a very different sustainability score.

PSS can be classified into three categories, with related subcategories (Tukker, 2004; Vezzoli, 2007, Ceschin, 2014).

- Product-oriented PSSs. In this case, the service provided is not the product. The provider sells ownership of the product to the user and offers services related to the product. These services may vary from maintenance, repair, upgrading, substitution, product take-back, etc. (UNEP 2002). Here, the value for the user lies in the fact that the user’s accountability is reduced and for the company that the value of the product can be somehow recaptured. Tukker (2004), identified two different subcategories in the Product-oriented PSSs.
- Product-related services - it is characterized by the presence of additional services during the use or the end-of-life of the product. In the example of bikes, this service can include a financing scheme, a maintenance contract, an upgrading contract, a take-back agreement, etc.
- Product-related advice/consultancy - is characterized by the fact that the provider offers information/advice concerning the

product. Advice under the case of the sale of a bike may be bike classes on how to use the bike for kids.

Use-oriented PSSs. In this case, the provided does not sell the product, but access to it. Consumers receive the required service but do not own the products that supply the service and pays only for the time the product is used. According to the specific typology of access, users can use the products several times for a defined time. In this sense, the company's most significant value is to satisfy the client at best for the time, either short or long, they will use the product. However, in this system, the user knows that other users may use the product, and because they accept this condition, it is easier for the company to apply circular strategies. Tukker (2004) identified four different subcategories possible in the Use-oriented PSSs:

- Product lease - occurs when the user keeps the product for extended periods without changing it. Here the client pays a regular fee for unlimited and individual access to the leased product. The company offers supplementary services in addition to the principal product service.
- Product renting or sharing - occurs when the user keeps the product for a limited time having a defined usage. Other users can reserve the use of the product immediately after the previous user. In this case, the provider should take care of all the additional costs related to the product, such as maintenance, repair, and disposal.
- Product pooling - occurs when the product is shared between different people simultaneously. Like the product lease and product renting and sharing, the user has limited access to the product; meanwhile, the provider should maintain the product in perfect functional conditions.
- Pay-per-service - occurs when the customer has the temporary use of a product in order to obtain predefined services. The provider has full responsibility for the maintenance of the product. The difference of this last typology is that users will operate the product by themselves.

Result-oriented PSSs. Here the provider offers specific customized results to the customer, and the product fades into the background of the service. Here the user does not have any responsibility for the product or the service but pays the provider to obtain a specific service. Tukker (2004) identified two different subcategories possible in the Result-oriented PSSs:

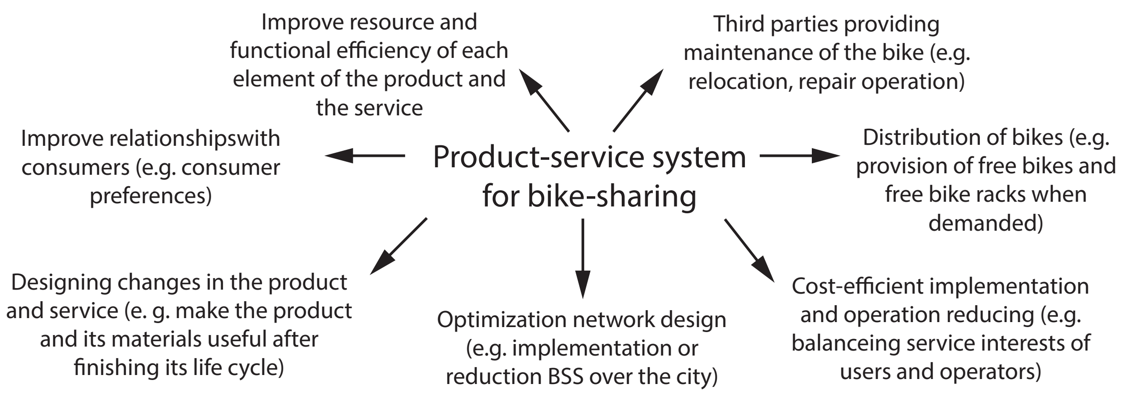
- Activity management/outsourcing - occur when a provider outsources third-party operations, deciding on performance indicators to test outsourced operation efficiency.
- Functional result - occurs when the user has access to a service without the direct use of any product or technology. In this case, the parties agree on the final result (e.g., reach point B). Providers maintain the products and equipment needed for the use of the product.

There are several vital elements of which the PSS is composed, and all of them should be considered in the design for PSS (the following bullet point is quoted from Mont, 2002).

- Designing a PSS requires close integration of all actors within the life cycle of a product-service. Tight integration, especially between the service and manufacturing organizations, is more likely to permit the clear "transmission" of the economic incentives, allowing service activities to drive manufacturing or design changes.
- Schemes for taking back products at the end of their life, as well as all necessary arrangements with business partners, should be focused on ensuring maximum closing of the product flow and reduction of transport distances.
- Alternative scenarios of product use could be analyzed, and the range of these scenarios may be presented to the consumer, providing information on the economic and environmental features of offers.
- Marketing strategies could be developed in ways that teach and promote an environmentally and socially acceptable way of function fulfillment. They could include communication campaigns during which the producer would provide consumers with information and presentations about utilizing her/his products most efficiently.
- Alternative scenarios of servicing the products could also be given at the point of sale to ensure proper product handling during the use phase.

An example of a Product-Service System for bike-sharing is illustrated in fig. 3.1.E.

Figure 3.1.E. Product-service system for bike-sharing.



Product level - refers to the coordinating activities that are related to the product and the use of the product. Many designers have to coordinate technical, functional, and behavioral dimensions to create products and services that fulfill the needs of users. This system specifically concerned industries and all the intersectoral stakeholders that interface with them. Products created from these industries can be both industrial and biological products, and the sustainable operation depends not only on one of the phases of the system but on the overall aspects of the entire system. Some examples of this system related to design activities can be: emotionally durable design, design for sustainable behavior, and nature inspire design (Ceschin et al., 2014). An example of a product system for bike-sharing is illustrated in fig. 3.1.D.

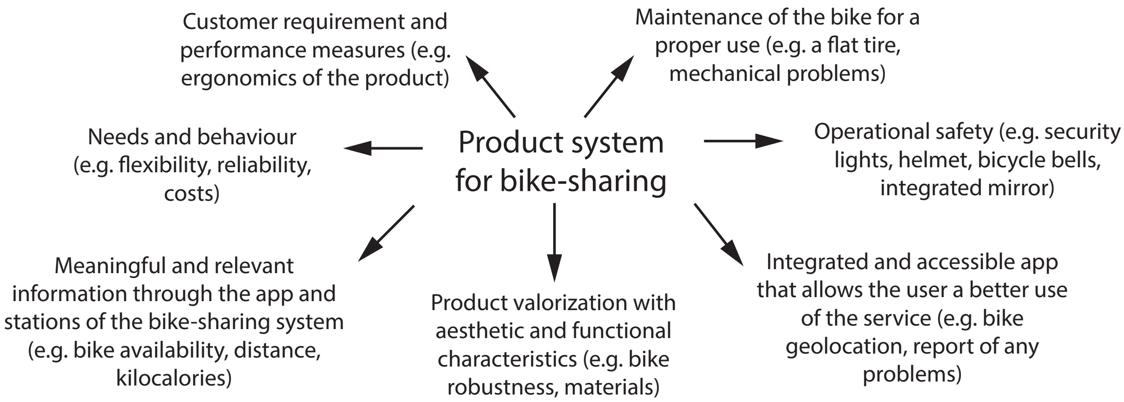


Figure 3.1.F. Product system for bike-sharing.

3.2. Relationships between system approaches

It is relevant to highlight that all the systems presented so far are strictly connected to each other, this is clear in figure 3.2.A. However, from the example of bike-sharing, not all the connections that exist between systems emerge, indeed, many more could be visualized and listed. We could argue, though, that this example is good enough to visualize the intricate relationship between systems. Relationship between systems may also have different levels of relevance, for this reason a hierarchy of objects could facilitate the work of the designer in understanding systems. In design for the CE it is vital to understand the relationships between different systems perspectives, this because as in all systemic environments, decisions and actions are related and the better understanding of consequences for each major design choice may positively, or negatively, affect all the others.

As Ceschin et al. demonstrated, several design approaches address different points of the varied perspectives, such as Design for Sustainability, Design for Sustainability Behavior and Design for Sustainable Transition (Ceschin et al., 2016). Nevertheless, it is not yet clear how to manage all this interlinks and how to cope with them to create a CE. Next paragraphs will illustrate how a collaborative approach to sustainability could facilitate the aggregation and handling of complex projects by understanding how the designer should look at the entire system.

3.3. How the designer looks at it?

As mentioned above, this thesis will only focus on the last two system levels of the entire anthropic system, Product Service Systems and Product Level. Building on the work of Brezet and van Hemel (1998), and Vezzoli and Manzini (2008), the way the designer should look at these systems is aligned with the product life cycle. This decision was taken because the product life cycle approach is multidisciplinary, cross-sectional, and systematic, where multiple perspectives are taken into consideration. This heterogeneous view widely considers activities related to how products are made and used (product-level) and interlink with business, marketing, and logistics (PSS). In the product life cycle approach, the full consequences of the product development are thus identified, and upstream and downstream effects for the environment considered (Vezzoli et al., 2008), so circular objectives within this approach can be better targeted.

Different design systems can be observed from many points of view

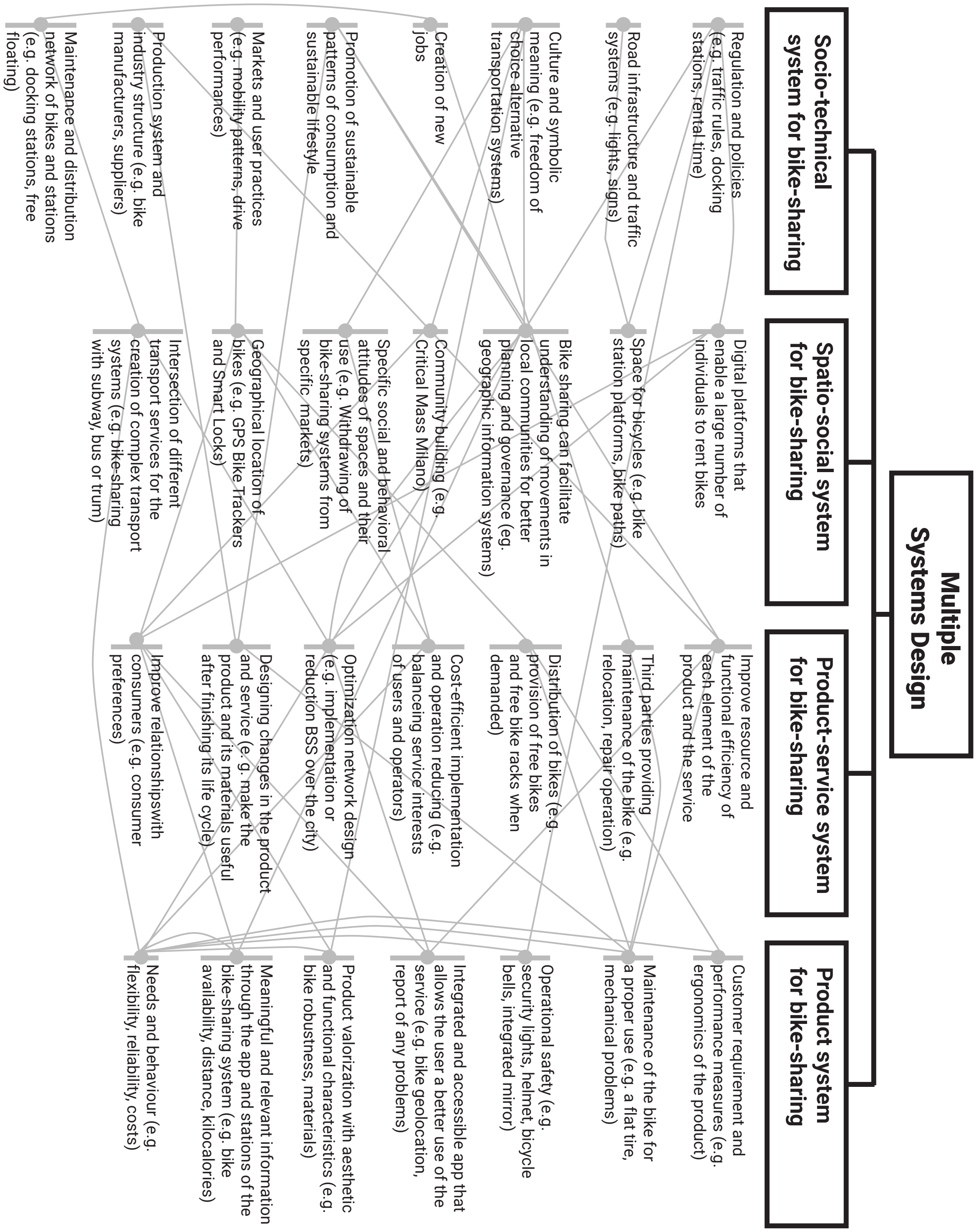


Figure 3.2.A. Multiple Systems Design.

within the product life cycle. It is crucial to balance these multiple perspectives to create the most efficient and circular product possible. At the beginning of the design process, many assumptions are made by designers with the intent to reach an adequate product definition (Lutters eta la., 2014). In this phase, often defined phase "0" of the design process, many possible alternatives are compared to move on to the next phase of the design process. In the linear design process, most decisions are made by a narrower range of decision-makers based on several circumstances such as technological innovation, data available, markets where the company is present, and so on. Usually, this phase is considered strategic, and decisions taken here will influence all the sub-departments of the company and stakeholders.

The present literature on CE does not clarify who should take such strategic decisions in this phase of the design process and how knowledge should be managed between many possible alternatives. On the one hand, many academics focus on circular business models (Bocken et al., 2014; Bocken et al., 2016; Geissdoerfer et al., 2017), on the other hand, many other academics increasingly emphasize the role of designers, and how they can lead to a more efficient CE by understanding material flows and how to encourage strategic design break. As an example, sufficiency in user behavior (Ammons et al., 2001; Ellen MacArthur Foundation 2012; Bakker et al., 2014; Peck et al., 2015; De Los Rios et al., 2017; Sumter et al., 2017; Bovea et al., 2018).

There is no question that any perspective may clarify any element. The business model design part of the business can not be understood without business designers' perspectives. On the flip side, it is not straightforward to make business decisions on the cyclability of the product without an expert who can confirm or deny the technicality related to maintainability, reusability, refurbish-ability, remanufacturability or recyclability of the product. Moreover, how a product should flow from one part to the other? How might the company appeal to the user when the product is second-hand, third-hand, or fourth-hand? It is inconceivable that one person may be able to offer all these perspectives without compromising his or her impartiality on one dominant perspective. Moreover, in the CE, many technical decisions are involved in each loop. Therefore, it is considered appropriate to balance all the different perspectives and analyzing the product life cycles under multiple perspectives (Figure 3.3.A).

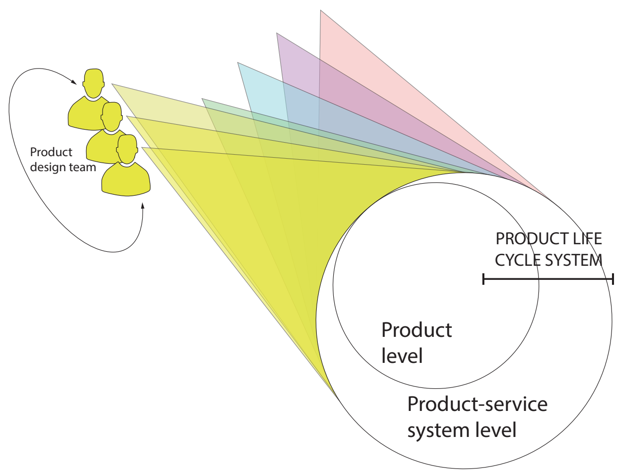


Figure 3.3.A. Multiple design perspectives.

3.4. Product Life Cycle System

Product life cycle system (PLCS) is the set of commonly identified phases of the product life, from the early product concept to the recovery (Keys, 1990). The phases which a product cycles through during its lifespan are dynamic and complex and with many levels of detail (Pugh, 1990). Design for the product life cycle means planning during the earliest phase of the design process the entire life cycle of the product. In the PLCS, the designer needs to identify for each phase proper planning that is balanced with the other phases; this forces designers to keep in consideration the bigger view of the system. In the literature, several PLCS frameworks have been proposed to have a complete picture of the sustainable design approach (Breast et al., 1998; Vezzoli et al., 2008). These frameworks have been a critical resource for many companies so far. Each framework combines different phases of product journey from the raw material acquisition and includes all activities through the final dispersal of residuals. For example, in the Eco-design Strategy Wheel proposed by Brezet and van Heme in 1998, eight strategies for product development where combined: (I) selection of low impact materials, (II) reduction of materials usage, (III) optimization of production techniques, (IV) optimization of distribution systems, (V) reduction of impact during use, (VI) optimization of initial lifetime, (VII) optimization of end of life system, and (VIII) new concept development (Fig. 3.4.A.).

In 2008, Vezzoli and Manzini proposed the Product Life Cycle system. The framework introduced the notion of input-output of energy, resources, and emission flows throughout its entire lifetime (Vezzoli et al., 2008). This framework included five activity stages which the product goes through, pre-production (acquisition of resources, delivery, and transformation into raw materials or energy), production (processing of materials, assembly, completion) distribution (packaging, transportation and storing), use (utilization or consumption and service) and disposal (reuse, remanufacturing, recycling, compost, incineration, and landfill) (Fig. 3.4.B.).

Based on both frameworks, this thesis presents a new PLCS framework where the typical phases of the production process have been updated. At the beginning of the PLCS, a new phase of Business & Network was added to help designers understand the relationship between the PSS and the Product-level system. Design for business and network means many decision-taking in this phase, for example, business designers can decide the product's values or stakeholders for each phase and loop of the process, and so on. Usually, this part of the design is kept separate from other processes, but this may negatively influence the full understanding of the product design. Moreover, the last phase of the PLCS was changed from "Disposal" to "Recovery". Theoretically, circular products and their components should remain in the system for as long as possible, so it is better to define the last phase as the "recovery phase".

PLCS can help the designers to dominate the complexity of the system. For each stage of the PLCS, one or more designers (design teams) have to define objectives, activities, and deliverables to/for the next stage (Keys, 1990). In the PLCS framework presented, the criteria used for each stage match primarily with the criteria presented by Breast et al., (1998). However, it was decided to integrate some new stages to fulfill the overall picture of CE (Fig. 3.4.C.).

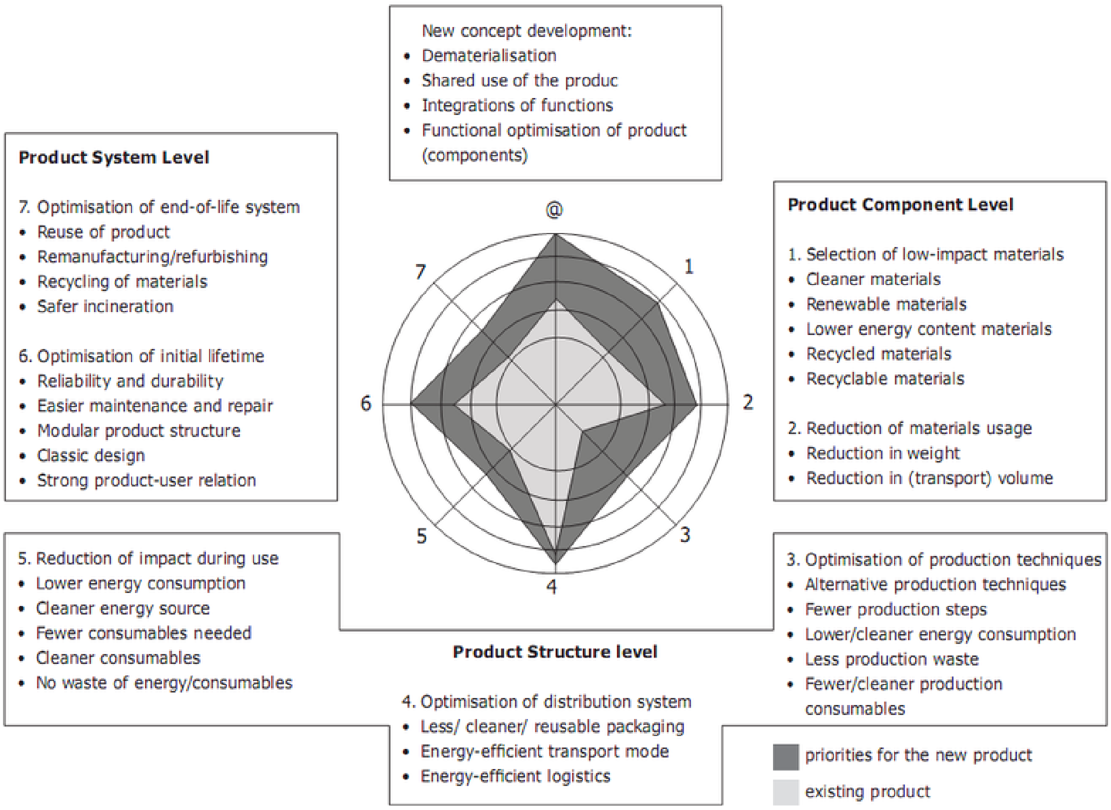
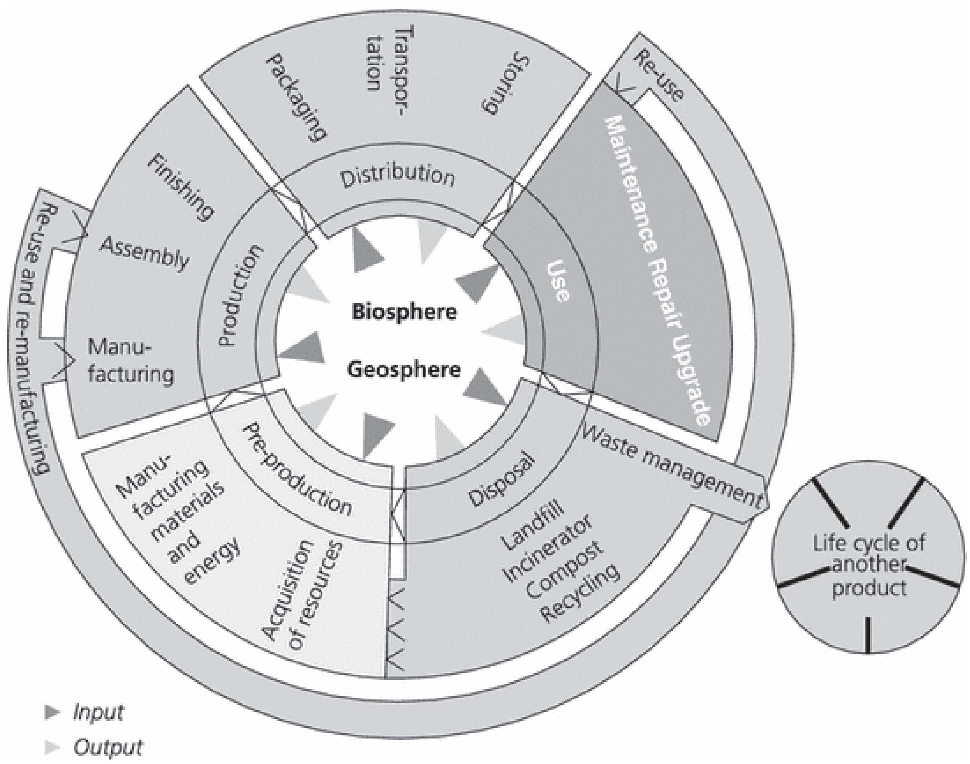


Figure 3.4.A. The Eco-design Strategy Wheel.
Source: Brezet and van Hemel, 1998

Figure 3.4.B. Product Life Cycle System.
Source: Vezzoli et al., 2008



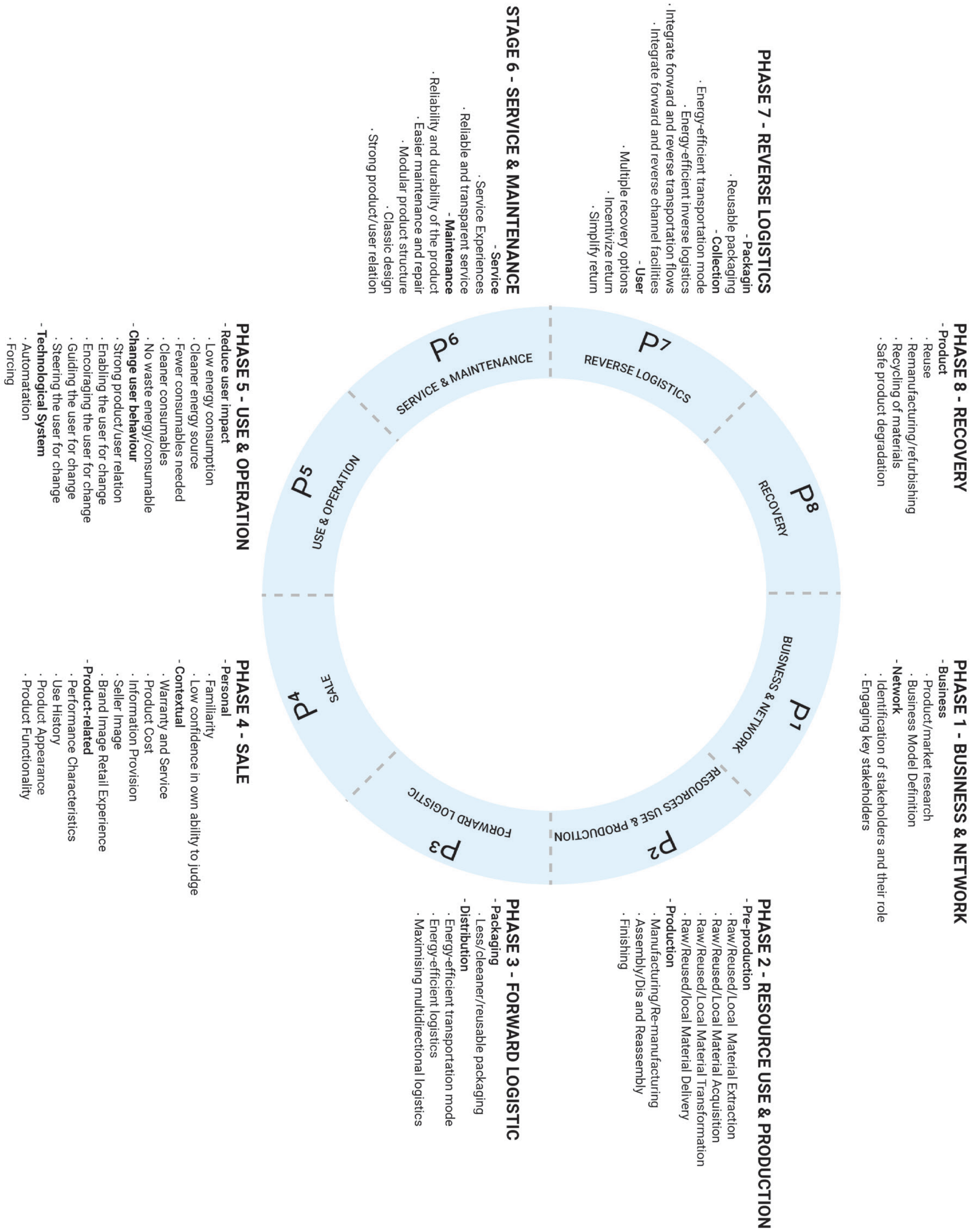


Figure 3.2.A. Circular strategy Wheel.
Source: Modified from the Eco-design Strategy Wheel, Brezet et al., 1997.

Figure 3.4.C. represents the structure of the product life cycle overview in the circular context. It summarizes the possible strategies to help designers to imagine new opportunities. Each phase is a clusterization of strategies according to the phase of the life cycle of the product. Designers can use those clusters to identify links between problems and solutions, objectives for each phase, and focus on a specific point of the list. It may now be useful to define each phase of the wheel and highlight the correlation between designers. It may sound redundant to draw attention to collaborative design as this is key for any business, even in the current linear economy. Even so, in the CE, new forms of collaborations are necessary to obtain a common objective. For this reason, to better analyze this circumstance, the phases were divided into three dimensions:

- design dimension;
- systemic dimension;
- professional dimension.

Each of these can better define the general aim of a designer in a determinate phase, the systemic relationship with other phases, and the roles involved. Each phase's group was added to possible design questions for designers as a way to get started with a circular design project.

3.4.1. Phase 1 - Business Design & Network

The design dimension in this phase involves the selection of business decisions to create, capture, preserve, and re-employing value on multiple loops (Nasr et al., 2018). This activity consists of the interdependent decision-making process between the firm and other suppliers, partners and customers that are going to define the business model of a company or a network of companies (Zott, et al., 2010). Here, it is decided which business model should be applied in order to slow, close, or narrow resource loops and generate value and profit from the flow of materials and products over time (Bocken et al., 2015).

Systemic dimension aim at the management of the effective transition of costs of goods in the system and stakeholders network for value recapture between phases of each loop. In this phase, the customer segments that will influence all the consecutive phases (i.e., market, aesthetics, etc.) is defined. Decisions may change between different loops, and each choice in this crucial phase will have implications on all the other phases accordingly.

The professional dimension might involve, but is not limited to, experts such as business managers, business analysts, economists, information system managers, business model designers, marketing departments, behavioral finance, applied engineers, engineering managers, project engineers, systems engineers, systemic designers, service designers, operations managers, business process managers, etc.

Possible design questions for designers:

- Which is the strategic objective (X^2) for this phase?
- Who are the stakeholders for this phase? What values will be exchanged?
- Who are the key partners?
- How might we expand and diversify the business model to recap-

ture value in this phase better?

- How might we transform the product into a service to be leased?
- How might we create a business which is based on a collaborative consumption model? How to profit in a collaborative consumption system?
- How might we provide services around long-lasting products to improve the business model?
- What is the best business model to support X^1?
- Can a product be transformed into a service or leased?
- What is the network of partners and stakeholders to maximize the value captured in L(n+1)?
- Can a secondary revenue stream generate revenue other than selling products?

3.4.2. Phase 2 - Resources Used & Production

The design dimension in this phase deals with the technical decisions regarding functionality, quality, and cost of the product. This activity consists of the selection of materials, methodologies, and tools that will be used in order to realize the product. This is when the actual product is manufactured, and all the activities must be carried out in an environmentally friendly manner and following the highest environmental standards to avoid the waste of resources (Tempelman, et al., 2014). For all the product lifetimes, time and energy are the primary agents that should be considered in this phase to create profitable loops.

The systemic dimension of this phase is critical to the success of the entire circular process. In this phase, it is defined how the product should be engineered to remain in-business for many loops. The product must fulfill the business model, and the functional parameters of circularity should be linked with parameters of aesthetic for the marketability for products.

The professional dimension might involve, but is not limited to, experts such as mechanical engineers, manufacturing engineers, industrial engineers, chemical engineers, electronic engineers, materials engineers, environmental engineers, power and water resources engineer, computer engineer, textile engineer, architectural designers, etc.

Possible design questions for designers:

- What is the strategic objective (X^2) for this phase?
- Who are the internal and external stakeholders for this phase?
- How might we improve the resource production efficiency for each product's component?
- Can this product be dematerialized?
- Are the resources used for re/manufacturing energy efficient? Can renewable energy be used instead?
- What material can be reused from the material flow? Are the materials used locally? What are the valuable residual resources from the production flow that could be offered to partners? What is the residual output of neighbor companies that could be bought as raw materials?
- Is there a way to shorten or simplify the supply chain?
- How might we design products that can be reintegrated in technical cycles endlessly?
- Are the right processes and capabilities in place to achieve X^2?

Is there a need to upskill the workforce or technology for this objective?

3.4.3. Phase 3 - Forward Logistics

The design dimension in this phase deals with the optimization of operations from a broader perspective. Forward logistics takes into account the design of the supply chain network and deals with all the movement of materials, technical resources for the production of goods, and finished goods as well either to or from different stakeholders.

The systemic dimension of this phase is strongly connected with operations of the Resource Use & Production and Reverse Logistics. The design of product flows, such as the occupancy of the storage spaces and transportation capacity between forward and inverse logistic, should be integrated (Lee et al., 2010). Sustainable logistics design should also take into consideration the design of the products as well as the decision related to the materials used.

The professional dimension in this phase might include, but is not limited to, experts such as transport engineers, industrial engineers, product designers, etc.

Possible design questions for designers:

- What is the strategic objective (X^2) for this phase?
- Who are the internal and stakeholders for this phase? What values will be exchanged?
- Can we use renewable energy for the logistic or choose energy-efficient logistics partners?
- Is there a way to remove excessive/unnecessary packaging from b2b and b2c flows?
- Can single-use, disposable packaging be avoided across the value chain? Could new revenue streams or services be created from long-lasting packaging?
- Can technology be used to avoid logistics altogether?

3.4.4. Phase 4 - Sale

The design dimension in this phase deals with the acceptance of circular products at the point of sale (Stahel, 2010). In this phase, and in particular, from the second life cycle onwards, the product must be reliable, qualitatively acceptable, and attractive (aesthetic, functional or symbolic valuable) in line with its costs. The sale phase is becoming increasingly dominant in the concept of PSS and how companies are shifting from traditional selling of goods to selling customer satisfaction. Specific design strategies related to the product's shape and interactions between the firm and its users (touchpoints) become central. This phase is not adequately taken into consideration within the CE literature, and a broader understanding of factors that influence consumer acceptance (i.e., re-purchase) of circular products should be widely considered (van Weelden et al., 2016).

The systemic dimension in this phase should deal with how to nudge users towards second-hand, refurbished, remanufactured, or recycled products alongside new products at the point of sale. Within a systemic view, all the earlier phases of the life cycle of the product are connected to the Sale perspective and should ensure that everything came off on schedule.

The professional dimension might involve, but is not limited to, experts such as marketing, product designers, psychologists, service designers, graphic designers, interaction designers, user experience designers, user interface designers, etc.

Possible design questions for designers:

- What is the strategic objective (X^2) for this phase?
- Who are the stakeholders for this phase? What values will be exchanged?
- How will sales and marketing strategies affect sourcing and logistics?
- How may we appeal to the consumer so that circular products are perceived as the best option?
- What is the best pricing strategy to access circular products and services?
- Could we leverage tailor-made products and on-demand local production as marketing propositions to increase the desirability of circular products? Is it sustainable from an operational and cost perspective?

3.4.5. Phase 5 - Use & Operation

The design dimension of this phase is related to the use of products by customers. All the design strategies adopted during the design process on the relationship between the user and the product will take place here. Under the Use & Operation perspective, product experience comes into play and can create rational and emotional engagement with the product (Chapman, 2005). In this phase, Use is related to the direct and continuous use of a product by the same user. Operation, instead, is related to the products that are not owned by a single user (e.g., bike sharing); however, users may still establish a relationship of trust with such products. In this stage, many improvements can be defined by reducing users' impact, change users' behavior, and technological systems (Zachrisson, et al., 2012).

The systemic dimension in this phase is related to the aesthetic and symbolic aspects of the product, together with the functional one.

Professional dimension might involve, but is not limited to, experts such as product designers, industrial designers, psychologists, service designers, user experience designers, interaction designers, ergonomic designers, interior designers, fashion designers, graphic designers, etc.

Possible design questions for designers:

- What is the strategic objective (X^2) for this phase?
- What is the audience the product is designed for? Why is it serving them better? Can trend cycles and obsolescence be managed?
- How long will the product last in the use cycle? Can products' failure be anticipated to design the best uptime for clients? Can the products' value be recaptured at the point of failure?
- What happens when the product use cycle ends?
- How might we design the behavior of users so to maximize the resilience of the product or/and service? How can we nudge them towards energy efficiency through our offering?
- How might we persuade the customer to reuse products? Can we think of secondary revenue streams from second-hand use?

3.4.6. Phase 6 - Service & Maintenance

The design dimension of this phase is intended to improve and simplify the maintenance of product functions during use. This phase is a critical one because it may imply several handling processes to and from the company.

The systemic dimension in this phase is related to the business model the company decides to use and how the company controls the product. The academic literature draws attention to three basic types of maintenance programs, including reactive, preventive, and predictive maintenance strategies (Bateman, 1995). In the first strategy, only when the product fails are then repaired, but little maintenance is performed during the operation. The preventive maintenance strategy includes preventive and predictive maintenance, which decreases the chance of unforeseen product failures. The predictive maintenance strategy is similar to the preventive strategy but is scheduled and fixed in time (Swanson, 2001).

The systemic dimension in this phase is related to the attitude of customers and the considered product, market and customer segment. Companies may consign third-party companies the maintenance of their products, but this is a critical touchpoint that may undermine a company's reputation and hence the loyalty of the user. Reverse Logistic plays a part in the maintenance as products could be sent back to the company, fixed, and given back to the user. So, a good sustainable strategy should also consider the movements of the product between points.

The professional dimension might involve but is not limited to experts such as product designers, interactive designers, graphic designers, etc.

Possible design questions for designers:

- What is the strategic objective (X^2) for this phase?
- How might we design products that can be maintained or replaced with minimal adjustment or on-site modifications?
- How might we preserve the desirability or products so that users will experience a consistent quality of service over time?
- How might we maximize the product uptime? How might we implement predictive maintenance?

3.4.7. Phase 7 - Reverse Logistics

The design dimension of this phase is crucial to determine how goods are recovered. Here, there is a specific focus on the design of products, returns forecasting, data, and information collection, product returns handling, warehousing, and aggregate production planning in terms of returns' recovery (Mahaboob Sheriff, et al., 2012).

The systemic dimension in this phase is connected to the operation of the Forward Logistics. An essential factor in the systemic approach of Reverse Logistic is related to the retrieval of products from customers or third parties. In focusing on recapturing value or proper disposal, costs, and effectiveness of operations play a significant role in understanding and managing each phase and life cycles of the product dynamically.

The professional dimension might involve, but is not limited to, experts such as logistics engineers, transportation engineers, product data managers, systems engineers, industrial engineers, computer engineers, product designers, etc.

Possible design questions for designers:

- What is the strategic objective of this phase?
- Is the cycle open (third parties will capture products and parts) or closed (we will recapture our products and parts)?
- Is there a way to facilitate dis- and assembly for users so to simplify the reverse logistics of whole products and components?
- How might we design products and services so that returning items is the best option for users?
- Who are the stakeholders that could be leveraged to create efficient return flows? How might we scale this in multi-region businesses?
- How may we ensure that recapturing techniques are energy efficient?
- How might we maximize the value stakeholders extract from recapturing products so to incentivize a forward loop market?

3.4.8. Phase 8 - Recovery

The design dimension in this phase should consider how products and their components can be optimized to be reusable from other loops. Designers should focus on a solution that is both environmentally friendly and cost-effective. Much in this phase depends on the product and the markets the product comes from; however, in general terms, the designer should pay attention to the inertia principles where the less the product needs treatment to re-enter in a new loop, the better it is.

The systemic dimension of this phase is connected with the Business Design & Network and the Resource Use & Production. To maintain the highest value of products, designers should be more intentional with the selection of materials for products that will be used for many loops and products' structures that make it possible to upgrade and change the aesthetic and technology continuously. Flexibility and quality play an important role from the beginning of the product life cycle, but only in this phase, this will be confirmed.

Professional dimension might involve, but is not limited to, experts such as waste managers, mechanical engineers, manufacturing engineers, industrial engineers, chemical engineers, electronic engineers, materials engineers, environmental engineers, power and water resources engineers, computer engineers, textile engineers, architectural designers, etc.

Possible design questions for designers:

- What is the strategic objective of this phase?
- Who are the stakeholders for this phase? What values will be exchanged?
- How can weak components of the product be maintained in use, reused, refurbished, remanufactured, or recycled for the next cycle?
- How might we design products that are easy to dis-reassemble for professionals practically?
- What skills and technologies are needed to reprocess the products? Could technologies be provided to third parties for those

processes?

- How might we design products so that reprocessing is more energy-efficient than producing new ones?
- Is the process scalable and operationally feasible?
- How can we maximize the recapture of the value of each component?

3.5. Time dimensions in design

The management of time in the design for circular products is a complicated and challenging matter. Time depends on the product's type, the technology used (and its obsolescence), and the context in which the product is used. Perhaps, the most significant complexities and challenges when implementing products for the CE are mostly connected to time and its influence on products. In literature, many terms overlap with similar concepts such as lifetime, product life cycle, or time horizons. Nevertheless, all terms have a specific function, and designers need to know the nomenclature to understand each other better, and also how to cope and manage those. Figure 3.5.A. introduces a guide of terms based on the product life cycle concept described above, and then a reference for each term is explained below.

3.5.1. Product life cycle

As explained above (see 3.4), the product life cycle embodies all the phases that a product crosses during its life. The strategies followed by companies and designers are significantly dependent upon the type of product involved. In a preliminary classification, three categories with varying time scales and strategies may be defined. The first category is the beginning of a life where all the design processes, production, and forward logistic take place. The second category is the middle life, where the product is sold from companies (online stores) or bought from third parts (physical or online stores) to be sold to the user that will use and maintain it until the useful life of the product will end. The third category is the end of life of the product, where the product is brought to a facility to be recovered and begin another life (Vadoudi et al., 2014). In the CE, the product life cycle can be repeated and may change through different product's lives. Designers must understand how many prod-

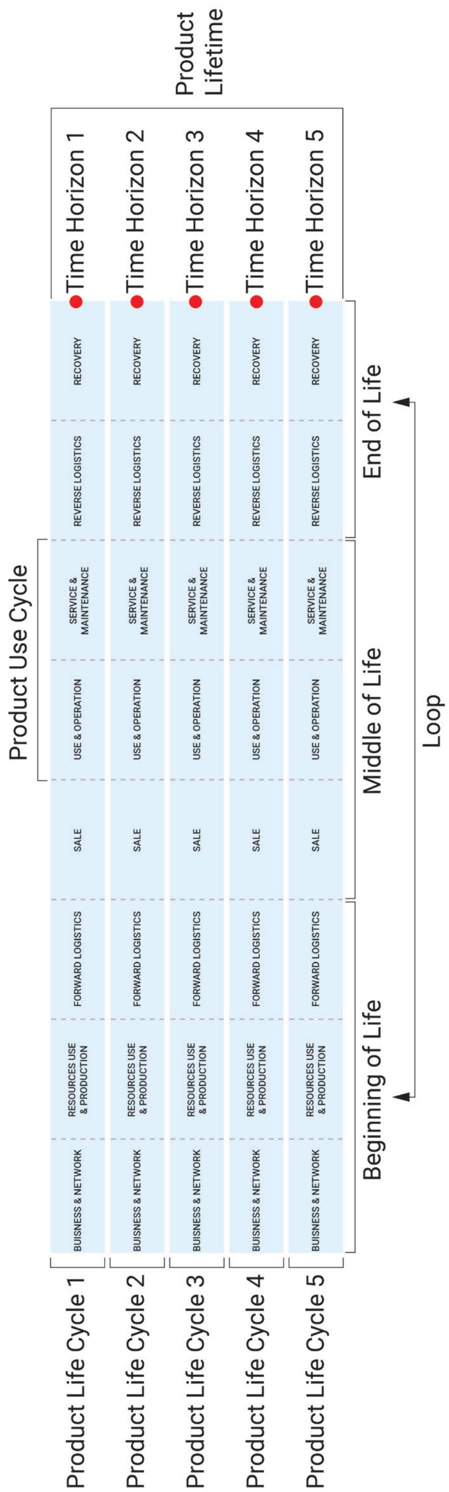


Figure 3.5.A. Time dimensions and time segments for the design for the CE.

uct life cycles the product will pass through to design the product accordingly.

3.5.2. Time horizon

Ebert and Piehl defined time horizon as: “that distance into the future to which a decision-maker looks when evaluating the consequences of a proposed action” (Ebert et al., 1973). The exact definition of when the product will terminate its life is important in order to coordinate the design strategies and stakeholders in a specific product life cycle or between multiple product life cycles. The definition of time horizons can help companies and designers to identify possible alternative scenarios, such as where the product can be sold. Hence potential new contexts and stakeholders that were not considered before. Moreover, the horizons can be an essential factor in understanding technological, ecological, social, political, and economic changes that may influence the product. Depending on sectors, some goods can live in a single life cycle up to 10-15 years (e.g., washing machines), so understanding the time horizons can help the long-term planning of multiple product life cycles, it is a significant activity to control the value and its possible variations over time.

3.5.3. Product lifetime

Product lifetime is meant as the total lifespan of the product. The product can have multiple life cycles but only one lifetime. Under this definition, product lifetime is considered as long as the product maintains the original characteristics provided from the original equipment manufacturers (OEM) through the different loops and until the product lifetime ends.

3.5.4. Loop

At the end of a product life cycle, another product life cycle begins, when this happens, the product is looping in the system. Every time the product makes another loop, the product lifetime stretches into the system, and more resources are saved.

3.6. Summary and founding of this chapter

This chapter provides an overview of the relevance of multiple design perspectives and tried to answer the questions: “what the designer looks at?” and “how the designer looks at it?”. It argues that the anthropic system can be divided into four levels: subsystems socio-technical system, spatio-social, product-service system, and product. In all these systems, design is a significant action to improve the entire system. The connections between designers and actions in each system relate to all the other systems. In order to promote systemic changes, could be useful for the designer to have a comprehensive view of the system and understand the connections, influences, and effects between systems and actions. Having a complete perspective of the entire system from a design point of view can facilitate the transition to a CE.

Then, a more specific analysis of the product-service system level and product level systems were made in order to understand how designers look at the systems. It has been suggested the use of the product life cycle scheme as a good classification to represent both the perspectives of designers in the product-service system level and product level systems. Then, by studying product life cycle wheels in literature, a more appropriate new life cycle system was introduced and described phase-by-phase. This work aims at improving the yet limited understanding of phases and correlation between designers of different phases. From it, a designer may better understand how to improve the design process and system.

Finally, each phase and product life cycle correspond to a different time dimension, which the designer must understand to manage the system. In this chapter, different terms were described to clarify the nomenclatures and characteristics of products within time and space.

Chapter 4

DESIGN STRATEGIES FOR THE CIRCULAR ECONOMY

Synopsis
Having introduced the reader to the multiple design approach in the previous chapter, the following chapter presents the definition of design strategy, Design for X, and Value in the circular economy. Through a literature review, two main hierarchization of design strategies are analyzed along with different case studies based on material flows classifications. The two hierarchization are criticized and additional factors of circularity are proposed.

4.1. Introduction to the chapter

The fulcrum of value creation in the CE is the closure or slowing down of material and energy flows through multiple technical or biological cycles, with the consequent decoupling of use of materials and economic growth (Ellen MacArthur Foundation, 2014, Ghisellini P., et al. 2016). Recent legislative regulations, concerning the use of chemical substances, reduction of gas emissions and solid waste production (Umeda, et al. 2012), intended to stimulate the European transition towards a more performing CE (Bakker et al., 2014). This change requires companies to make a significant effort related to the transformation of business models, design, reintegration of materials, and production that not all companies are ready to undertake (Asif F.M.A., et al. 2016). However, numerous case studies (De Los Rios IC., Et al., 2016) show that industries could benefit significantly from material savings, achieving a reduction in supply-related risks, increased customer loyalty, and the development of new revenue streams (Winkler H., 2011).

At this juncture, appropriate business models and design methods could help companies transition to the CE. In literature, a great deal of attention is devoted to the role of design, seen as a pivotal element to close the material cycles and to encourage a sustainable approach throughout the production chain (Bakker C., et al., 2014, Bocken et al., 2015, De Los Rios IC., Et al., 2016, Moreno M., 2016, Ordoñez I., et al., 2013). In this regard, Bakker C., et al., (2014), emphasizes that one of the biggest challenges for design research is to identify when to apply specific design strategies concerning certain circular approaches.

In the literature, various circular models have been investigated to understand the role of the designer in the context of CE (Asif FMA, et al. 2016, Bocken NMP et al., 2015, De los Rios IC, et al., 2016, Moreno M. , 2016). These models are based on decision-making hierarchies within different business areas (Asif F.M.A et al. 2016). Nevertheless, design often refers to similar concepts and strategies in different ways; those are likely to be misinterpreted and generate conflict between design departments; therefore, some work is necessary to establish consensus to unifying the terminology (Pieroni et al., 2019).

For these reasons, this chapter first defines the appropriate terminology to which this thesis refers, then introduces how the CE value is created, and last, it links the two main hierarchization of design strategies (or DfX). This chapter also provides an overview of other DfX and shows the way design strategies were used through real case studies. Finally, all the paragraphs are discussed and criticized to implement a collaborative design approach and prepare the field for a better multiple design perspectives approach.

4.1.1. Definition of design strategy

This paragraph defines design strategy and explains why it has been decided to work with this topic, and how this thesis embraced it. Unexpectedly, after a literature review focused on the term design strategy, not many results, nor many discussions on the topic or detailed analysis have been found. However, in broad terms, the literature describes design strategy as a cross-border problem-solving activity to deal with complexity.

In 1999, Manzini described design strategy as “an activity that opens up new markets and calls for different mixes of products and services”.

If it is successful, it is only because its results are recognized as better than existing solutions or because they meet a previously unanswered demand. For these reasons, the strategic design results may be seen as real win-win solutions: entrepreneurial initiatives in which "everybody wins" - the maker, the user, and the environment. On the other hand, accordingly to Meroni (2008), "design strategy is about presenting to social and market bodies a system of rules, beliefs, values, and tools to deal with the external environment, thus being able to evolve (and so to survive successfully), as well as maintaining and developing one's own identity. Moreover, in doing so, influencing and changing the environment too".

In 1990, Ackoff made a distinction between strategic decisions, operational decisions, and tactical decisions.

- Operational decisions consider short-term decisions in a highly dynamic environment.
- Tactical decisions aim at rational and efficient management and allocation of resources among the network to improve the system's performance over medium-term time horizons.
- Strategic decisions, network design, involves significant capital investments over long-term horizons.

In other words, strategic attitude is more related to the longer view toward the future, operational attitude concerns with the immediate future, and tactical attitude is interested in what happens now (Ackoff, 1990). Also, "strategic decisions focus on prior (anticipatory) and posterior (after the fact) responses to such potential and actual change in an organization's environment can affect its performance significantly" (Ackoff, 1990). This description provides a compelling account of the way designers may work and plan with different degrees of decisions over time, but for this thesis, it has been decided to prioritize the attention on the strategy, as a proactive approach that looks at the bigger picture ahead to anticipate and adapt.

Uncountable design strategies are possible, and each of them can be integrated and create unique business models. In the CE, these strategies should be planned carefully in advance and consistently adjusted to be functional and effective. Additionally, because our premise is that collaboration of multiple design perspectives is the primary remedy to deal with the complexity, it is crucial to use a common language where many different typologies of design can understand each other. Many trustworthy authors in the field of design have used the terms Design for X (DfX), to describe a design strategy (Huang, 1996; Stuart, 1996; Bralla et al., 1999). Typically, X is a variable that can have one of many possible values (Huang, 1996; Arnette et al., 2014; Ceschin, 2016; Moreno, et al., 2016; De Los Rios, et al., 2017). Huang (1996) argued that the use of this approach could facilitate the design decision through the compartmentalization of specific actions concerning a specific DfX.

4.1.2. Definition of DfX

The term DfX, as a model definition, can give continuity to the extensive work which has already been done. While Huang (1996) have primarily investigated DfX as a tool for engineering, he outlined the need for a basic DfX pattern for different reasons:

1. A basic pattern would help understanding how DfX works and what DfX does. Much unnecessary confusion can be avoided.
2. A basic pattern would help to select the most appropriate DfX tool for a problem at hand from a large toolbox.
3. A generic DfX model would speed up the development of specific DfX tools dramatically; this can be explained by the effect of the learning curve factor because different DfX tools share similar constructs that can be reused.
4. The learning curve factor can also be gained during DfX implementation if multiple DfX tools follow a general pattern. Once the team becomes familiar and experienced with one DfX tool, other members can easily adapt to new DfX tools that share a common basis.
5. A generic DfX model can provide a platform for integrating multiple DfX tools to facilitate the flow of data and decisions between them.
6. A generic DfX model can provide a common basis on which tradeoff can be carried out among competing issues when multiple DfX tools are used.
7. A generic DfX model can provide a platform for integrating a DfX tool with other decision support systems used in product development such as CAD/CAM (computer-Aided Design and Manufacture), CAPP (Computer Aided Process Planning), and CAPM (Computer Aided Production Management), to facilitate the flow of data and decisions between them.

The DfX approach is becoming a broader concept that encompasses many more disciplines. If, in the past, the DfX approach was only used in engineering as a performance metric for competitiveness, today, this approach is seen as a much more flexible term to define a specific design strategy. For instance, many scientists refer to DfX, or at least with the words "Design for", in business and change behavior design approach (see for example Chapman 2005; Bakker, 2014, Bocken, et al., 2015, Ceschin, et al., 2016, Moreno, et al. 2016, Lilley, et al., 2016) or even referring to the socio-technical system level and spatio-social level (see Norman et al., 2015), making this approach tangible and understandable for all.

4.1.3. Definition of Value

It is not very easy for designers to define which one is the ideal design strategy. In the CE, the value is no longer only about economic gained or customers' needs and wants. New forms of value should be defined and incorporated into the previews ones to create successful products that are capable of flowing multiple times in the system.

The Ellen MacArthur Foundation defined the CE as a system "that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles". In this standard definition of CE, value is created when there is a reverse cycle of materials. Similarly, in the Stahel's Inertia Principles introduced in 2010, it is pointed out that: "Do not repair what is not broken, do not remanufacture something that can be repaired, do not recycle a product that can be remanufactured. Replace or treat only the smallest possible part in order to maintain the existing economic value of the technical system" (Stahel, 2010). Both the definitions stress the fact that the circular value is created when the product is maintained in the same configuration, as provided by the Original Equipment Manufacturer (OEM), over multiple life cycles (Ellen MacArthur Foundation 2012; Stahel, 2010, Nasr et al., 2019).

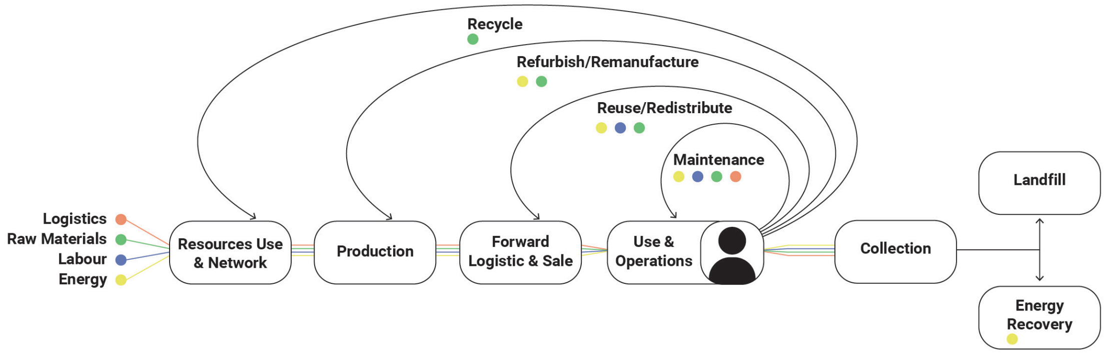


Figure 4.1.3.A. Representations of possible values in the CE.
Source: Stahel, 2010

This principle represents the new general "vademecum" for a circular approach and redefines the concept of value in general terms. In the CE, all the values added during the manufacturing process should be preserved, limiting the handling of the product at the end-of-use (EOU). This approach depends very much on what products are considered. To simplify the concept for the reader, a diagram (Figure. 4.12.A) highlights the values lost or maintained in the various loops.

On a similar perspective, Nasar et al., (2018) extended the same concept to the value-retention process (VRPs). VRPs points to all the activities necessary to enable the completion of the reverse cycle, referring to the process. These activities concern arranging direct reuse, repair, refurbishment, and remanufacturing (Nasar et al., 2018). The added value in VRPs is to be found in the development of innovative process solutions that, on the one hand, reduce environmental impacts of production, on the other hand, do not jeopardize economic opportunities and consumer satisfaction and needs (Nasar et al., 2018).

4.2. Research method

The analysis of scientific literature, through the use of online databases, represents a systematic, explicit and reproducible method for the identification, evaluation, and complete synthesis of the set of results produced by academic researchers (Fink A., 2010). This research is based on the concept of systemic research approach proposed by Fink A., (2010). The research was conducted through two digital databases: ScienceDirect and Google Scholar.

To define the literature, only those articles published in English after 2002 were considered, the year in which the concept of Circular Economy was formally accepted (Yuan et al. 2006 in Geng B., et al. 2008). The selection took place in June 2017 through the evaluation of the qualification and possible abstracts. The keywords used for the research were: "circular economy", "method", "product design", "Design for", "DfX", "design strategy" and "circular design strategy". ScienceDirect provided 9,952 articles, a result further refined with the "design", "material", "product", and "process" filters, with an outcome of 150 articles. From the results obtained, 16 relevant articles were manually selected. Performing the same search in Google Scholar, 27,100 results were obtained instead, of which only the first 250 were revised, and 13 articles were manually selected. The selection of abstracts led to a total of 29 relevant articles. In addition, five additional studies have been added (Badalucco L., 2014, Ellen MacArthur Foundation, 2012, Fink A., 2010 and Geng Y., et al., 2008, Lutters E., et al., 2014) for their relevance to the research, for a total of 34 articles.

4.3. Material and product flows

The notion of CE develops around different currents of thought. In large industries, this concept is receiving much attention because it is perceived not only as a realistic ecological possibility but also as a means of change and innovation for new possibilities and value creation. Concepts such as the end of life product or end-user are replaced by a new circular vision such as multiple product life cycles and multiple users. Products and materials remain in a continuous cycle, and anyone involved in the production process must be considered and managed to maintain the control of the value throughout the product life cycles (Ellen MacArthur Foundation, 2012; Lewandowski, 2016). The design process is not altered in the CE, but designers must equip themselves with additional methods in order to explicitly analyze significant variables that may affect the recovery of products and materials for future life cycles.

For a better understanding of the issue, it was useful to review the state of the art of "circular product design". Particular attention was given to the DfX hierarchization of Bocken et al., (2015) and Moreno M., et al. (2016) that, through their considerations, have provided a clear description of usable DfX based on value creation through the regulation of material flows. Bocken et al., (2015) distinguished three different ways in which materials flow in the system - slowing resource loops, closing resource loops, and narrowing resource flows (Figure 4.3.A.). For each of these ways, several design strategies are presented. Below, every circular flow and possible DfX to achieve that objective is described:

- **Slowing resource loops:** The development and/or extension of long-life products (i.e., maintenance loops to improve product life, e.g. repair, reprocessing) increases and/or intensifies the usable duration of products, resulting in a reduction in resource flows.
  - Designing long-life products
  - Design for attachment and trust
  - Design for reliability and durability
  - Design for product-life extension
  - Design for ease of maintenance and repair
  - Design for upgradability and adaptability
  - Design for standardization and compatibility
  - Design for dis- and reassembly

- **Closing resource loops**: The loop between post-use and production is closed through recycling which results in a circular resource flow.
    - Design for a technological cycle
    - Design for a biological cycle
    - Design for dis- and reassembly

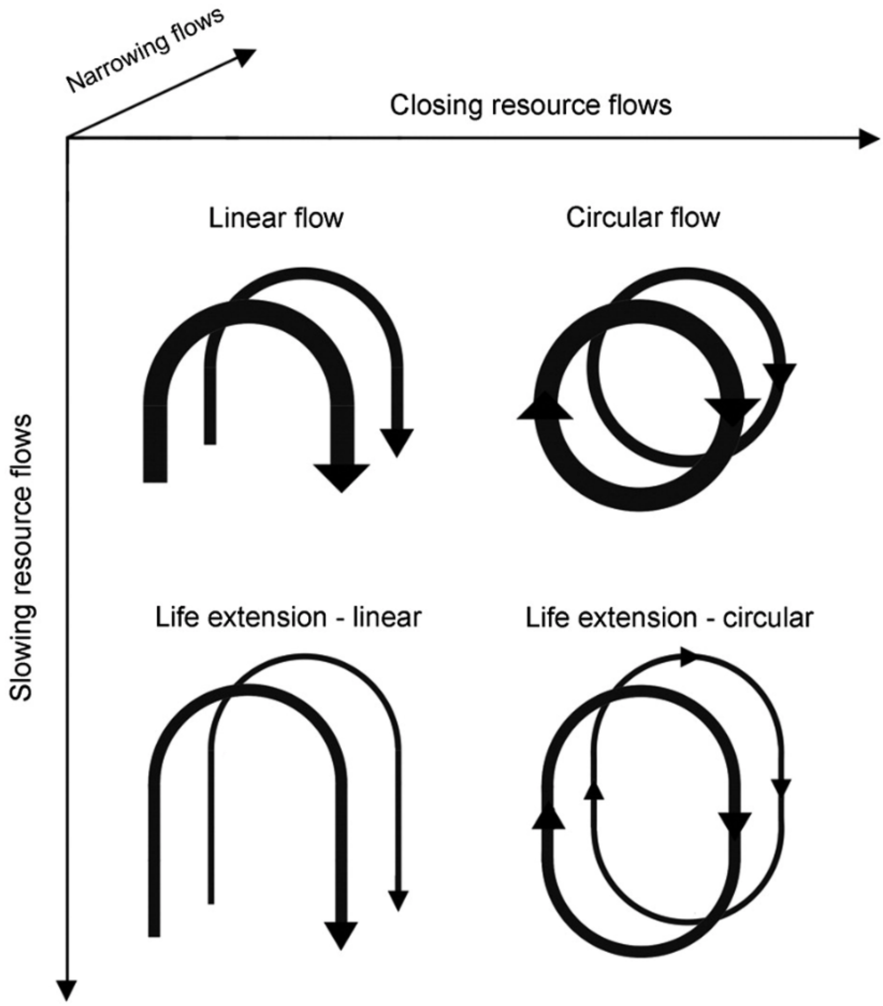


Figure 4.3.A. Categorization of linear and circular approaches for reducing resource use.
Source: Bocken et al., 2015

On the other hand, Moreno, et al., (2016) hierarchized design strategies on three very close categorizations compared to Bocken et al., (2015); Design for resource conservation, Design for slowing resource loops, Whole Systems Design. The two categorizations are both based on material flows and drawn attention to the role which design, and "circularity" play in the economy in order to create circular values. However, in the classification of Moreno, et al., different DfX are presented and analyzed. Below, it is presented a short overview of the classification of materials flows and possible DfX to achieve that objective:

- **Design for resource conservation**
    - Design for circular supplies
    - Design for resource conservation
- **Design for slowing resource loops**
    - Design for long life use of products

    - Design for multiple cycles
- **Whole Systems Design**
    - Design for systems change

Through an analysis of the literature, this chapter aims to expand and review the design strategies or DfX approaches to increment the ways of interpreting this phenomenon.

4.4. Circular design strategies

To minimize the loss of any form of energy and matter one must intervene in the earliest stages of design (Badalucco, 2014). It is inherently necessary for designers to apply a series of methods and methodologies to dominate the entire design process. This is true more than ever in the CE because of the complexity of the decisions that the designer is called to take (Rossi M., et al. 2016). For this purpose, the introduction of DfX methods can be useful to facilitate the designer's work and completely close the resource cycle. It is essential, however, to clarify that it is not easy to map the behavior of designers and therefore we cannot be strict and limited in describing a range of methodologies, but rather, as Lutters E., et al., (2014) argues, it will be the designer who based on his creativity, experience and value in the choice he will be able to weigh his decision in the best way. For this reason, based on real case studies and the classification of Bocken et al., in the following sub-paragraphs different and complementary DfX will be presented.

4.4.1. Design strategies to close resource cycles

In designing, several DfX methods can be useful to close the resource cycle. Methods like Design for Technical Cycles (DfTC) and Design for Biological Cycles (DfBC) define the first choice that the designer makes. Subsequently, strategies like Design for Reduction of the Chronic Risk of materials (DfCRR) can help the designer in the conscious choice of "critical" raw materials (Peck D., et al. 2014).

The approach Design for Technical Cycles (DfTC) requires the designer to use synthetic materials that can be upcycled within the same cycle without losing technical properties or value (McDonough et al., 2010; Bocken N.M.P., et al. 2015). The example of SS17 Parley (Fig. 4.4.1.A.) helps to understand the concept of "upcycle", a joint project between Adidas and Aquafil for a collection of swim apparel made of 100% upcycled[2] synthetic fiber from old fishing nets and carpets (Fig. 4.4.1.B).

On the contrary, by using the approach Design for Biological Cycle

[2] Upcycling is described by McDonough et al., 2010 as reusing a material without degrading the quality and composition of the material for its next use.

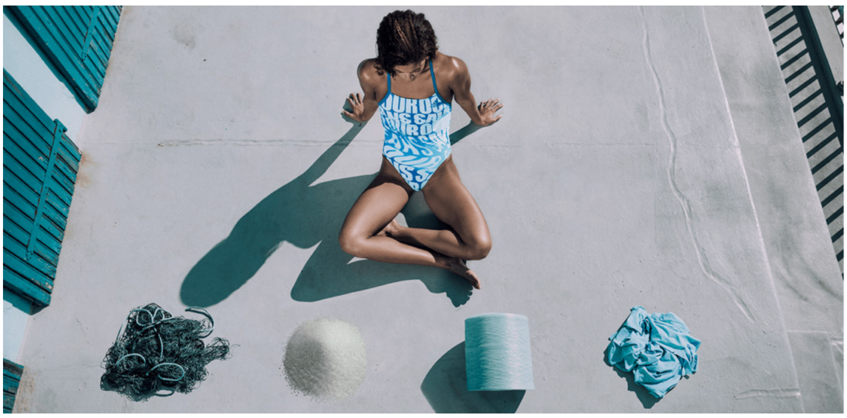


Figure 4.4.1.A. SS17 Parley swimsuit.
Source: Econyl S.r.l.

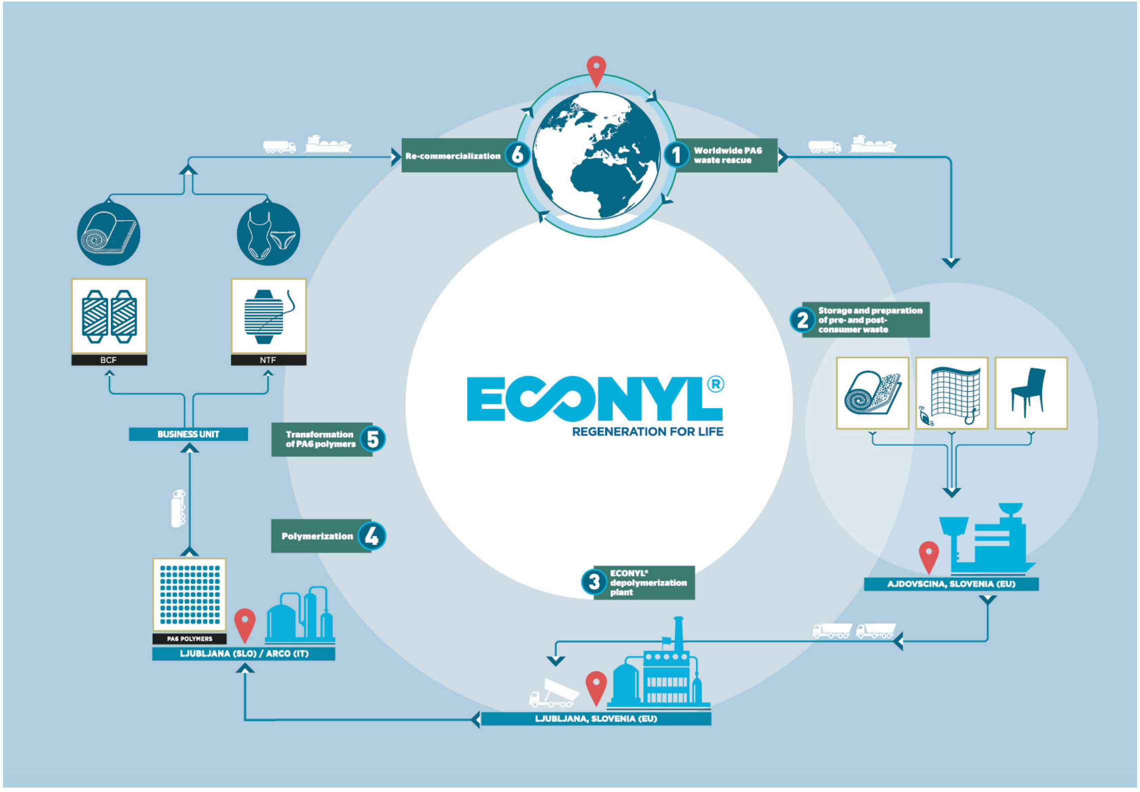


Figure 4.4.1.B. ECONYL system process.
Source: Econyl S.r.l.

(DfBC) the designer is obliged to use 100% biodegradable materials (McDonough et al., 2010), which, once the useful life cycle of the product is over, can be composted and undergo a process of decomposition thanks to microorganisms such as bacteria and fungi (Pauli, 2010; Bocken, NMP et al. 2015). An example of this approach is MOGU from Mycoplast, a biodegradable material deriving from the growth of mycelium on straw-based substrates. This material can be used by designers to create furniture and packaging products (Figure 4.4.1.C).

Bakker et al. (2014) also reemphasize that the Design for Product

Figure 4.4.1.C. Examples of two mycelium based products.
Source: Mogu (mogu.bio)

Service Systems (DfPSS) can facilitate the closing of resource cycles, extending the use of materials, thanks to approaches such as Design for Disassembly (DfD). Unlike Moreno, et al. (2016), Bakker classifies the DfPSS as a suitable method to slow down the life cycles of resources. Tukker A., (2013) validates this theory by clarifying that the system of service products is not yet sufficiently developed, but that, through the work of designers and the application of methods such as Design for Product Safety (DfPA), Design for Trust (DfT) and Design for Experiences (DfPE), this strategy could potentially close the resource cycles.

4.4.2. Design strategies to slow resource cycles

In order to slow down the cycle of resources, Ordoñez, and Rahe, (2013) suggest focusing on Design for Ease of Cleaning at the End of Life Cycle (DfEEoLC) of the products, especially considering the Design for the Reassembly (DfR) and Design for Disassembly (DfD), thus facilitating the work of the workforces, who will have to deal with the recovery and reintegration of the product after the end of the useful life of it. They also add that a collaboration between waste management experts and designers could facilitate the work of both parties (Ordoñez et al., 2013).

An example of a product aimed at slowing down the use of resources is the Cameleon[3] buggy from Bugaboo (Figure 4.4.2.A). This stroller is designed to be a versatile and flexible product. The customer can rent or buy the modules according to their needs and change them in the stages of the child's growth (Sumter et al., 2018). Design for Ease of Maintenance (DfEM), Design for Updating (DfU) and Design for Flexibility (DfF) are approaches that seek to reduce the consumption of the product by the user. The designer can use these methods to encourage sufficiency and the reuse of the products (Bocken, et al. 2015).

It is essential to highlight how Design for Remanufacturing (DfRem),

Figure 4.4.2.A. Bugaboo Cameleon[3] disassembled.
Source: Bugaboo (Bugaboo.com)

Design for Regeneration (DfRef), Design for Ease of Maintenance (DfEM), Design for Reuse (DfReu), Design for Updating (DfU) and Design for Flexibility (DfF) are adapt to be used when the aim is to extend the product life cycle, Design for Extending Product Life (Bakker, et al., 2014, Bocken, et al. 2015). These methodologies support the extended use of products, prolonging their useful life. Design for Updating (DfU) and Design for Flexibility (DfF), otherwise, would undermine the principle of progressive obsolescence, that is, the need for consumers to regularly replace products, such as smartphones and cars (see section 1.3).

As in design to close resource cycles, even in design to slow down resource cycles, the designer must pay particular attention to consumers. Considering emotions, needs, and desires, the designer should pay particular attention to all those DfXs such as Design for Trust (DfT), Design for Experiences (DfPE) and Meaningful Design to understand how to prolong the life of products through emotions, needs and wishes of users (Hinte, 1997; Chapman, 2005). These steps are likewise essential in the Design for Product Service Systems (DfPSS), to move the attention from the sale of products to the sale of services (Tukker A., 2013). Finally, quality, durability, and transformation of products and materials over time can positively or negatively influence the consumer experience (Lilley D., et al. 2016). The designer should deal with the matter of Design for Repair (DfRep) and Design for Ease of Maintenance (DfEM) to maximize the use of the product.

4.5. Critical review of previous work

This section provides a critical analysis of the 34 articles reviewed and discussed in this chapter. The methodologies of these approaches are analyzed in terms of:

- value
- collaboration

5.5.1. Circular value creation

In the previews work analyzed, the DfX and company's value strategies were mainly associated with the concepts of keeping products, components, and materials at their highest utility and value over time. Although this is a fundamental concept in the CE, the understanding of circular value should be expanded and improved.

Defining values in determining the design strategy of a company is more important than deciding how the product will be recaptured. Economic values are crucial in defining how the company should move forward; nevertheless, it is almost impossible to execute a CE in isolation. Hence, the fundamental notion of circular value creation should include more aspects of how to collaborate with other stakeholders to make the CE possible.

Stakeholders can have various meanings; the Cambridge English Dictionary defines stakeholders as:

- a person or group of people who own a share in a business;
- a person such as an employee, customer, or citizen who is involved with an organization, society, etc. and therefore has re-

sponsibilities towards it and an interest in its success;
- a person who is in charge of the prize money given by people betting on the result of a game or competition and who gives it to the winner;
- an employee, investor, customer, etc. who is involved in or buys from business and has an interest in its success.

In the CE, many parties must be included in decision-making. This systemic emphasis should be focused on stakeholders' interests because their values imply the reason why the decision is made. Different stakeholders may have different values, which may indicate variations in their lists of objectives, target hierarchies, characteristics, and objective functions. Hence, in structuring the values for a circular project, the designers must consider different values for each stakeholder.

In such circumstances, together with how to maintain the existing economic value of the technical system, it is essential to make explicit the value for the stakeholders to be pleased (Stahle, 2010). For example, if a company wants some product back for remanufacturing it in a new cycle, and the customer owns the product, how can the company exchange value by negotiating with the customer? Why should the customer give back the product instead of throwing it away or giving it to a third party company which pays more? In a similar case, if an OEM needs a third company to deal with the remanufacturing of a product in a specific context, but it does not have enough workforce to complete the task, why should this company invest in new employees for the OEM? Understanding these dynamics is imperative since each circular value exchange between stakeholders will be part of the success or failure of the final objective of the OEM.

4.6. Conclusions

This chapter provides a review of the literature concerning the definition of design strategy, DfX, hierarchization of DfX based on material flows, a discussion of multiple DfX for different circular approaches, and a redefined concept of value in the CE, according to scientific literature.

The first step in organizing the design strategies is to identify which of the different circular approaches a given product could fit in. As highlighted in this chapter, the literature shows that several circular models can be identified, and designers should decide which direction is the most appropriate to extend the useful life of the product, hence, its value in the market. For each model, many DfX can be applied and combined to respond to the needs and wants of users. It was clarified that different design strategies are possible and that designers should evaluate, depending on given contexts and products, how to implement a systematic design strategy able to extend or close the resource loop. Because of the high reference in literature to the term DfX, in this thesis, design strategy and DfX are understood as the same concept and used in the same way. Moreover, this chapter provides a general overview of the possible DfX applicable to the design of circular products. A complete overview of DfX strategies is available at www.circulardesign.it.

Ultimately, it has been criticized the current scientific literature on the topic of value understanding and the missing relationship between value and stakeholder in the CE. In the next chapter, a detailed hierarchy of design strategies and correlation between DfX, stakeholders and values are introduced and can be used from designers to better manage the DfX strategies in complex systems.

Chapter 5

ACCELERATING THE CIRCULAR ECONOMY THROUGH DESIGN

Synopsis
Having proposed some new possible ways of interpretation of circular design, the following chapter provides a more detailed picture of the multiple design perspective approach: by proposing three new DfX hierarchies. The meeting of these three hierarchies creates a new DfX framework that can be used to structure a collaborative design process. The framework is evaluated with experts and different activities are described to accelerate the circular economy through a better design approach.

5.1. Multi-Hierarchical Framework

Circular product design is a complex and interdisciplinary process. At the early design stages, a variety of designers must make decisions not only about the first lifespan of the product, but also forecasting where, when, for whom and how the product will be reintegrated in the following life cycles, as well as mitigate concomitant objectives in business, engineering, product and service design. Indeed, in contrast to today's linear economy, CE presupposes a constant resourcing cycle aimed at preserving natural assets, maximizing the use of natural capital and decreasing human impacts on nature (McDonough, et al., 2010; Stahel, 2010; Bakker, et al., 2014). This new vision implies a substantial change not only on the product design but in the entire organizational system of our society. Hence, it is de facto unlikely that an optimal transition will occur if there is an imbalance between disciplines and the system could not be considered as a holistic, complex structure, to be designed and managed (Murray, et al., 2017).

The collaboration between so many fields has always been fundamental to respond to the exponential complexity of systemic thinking for sustainability. Some frameworks, such as Eco-design Strategy Wheel (Brezet, H., & Van Hemel, C. 1998), Product-system lifecycle (Vezzoli, et al., 2008), Whole System Design (Charnley, 2010) are well known to take in consideration the bigger picture for sustainable and interdisciplinary decision-making. However, these frameworks tend to neglect the different design approaches for the different life cycles of the product, which are essential factors to consider in designing for the CE. For this reason, it is necessary to review these existing frameworks on which the design is often based today and reframe a new and up-to-date framework that also tackles multiple loops.

In this chapter, through the theoretical application of DfXs, it is presented a framework by which it is possible to hierarchy circular strategies that cover the life cycle of products across temporal dimensions. Furthermore, this chapter introduces how the framework could be used to mapping stakeholders and create values for different phases and life cycles of the product.

5.2. Methodology

To build robust bases capable of supporting the complexity, information volume, overlapping concepts and the wide scope of design disciplines, a methodology has been structured, in line with Friedman (2003) that comprises of four steps outlined below.

Friedman states that theoretical construction cannot be based on practice. Indeed, it is questionable how critical and systematic thinking can be established based on case studies, which meet specific contextual, productive and temporal requirements. Practice can, however, provide a validation of the questions that were created via theory (Friedman, 2003). Theory can be based on a general structure that can be revised, reformulated and reorganized, according to very precise logic, allowing one to develop a resilient theoretical framework (Webster, et al., 2002).

Therefore, this chapter is developed on the following four steps: (1) Discover - an exploratory review of the literature, after which a (2) Define - concept map was defined and developed (3) Develop - three initial hypotheses and finally (4) Validate - the hypothesis was validated through 5 guided interviews (Fig. 5.2.A.). In this thesis this methodological process has been completed only one time, however, more iteration loops from step 4 back to steps 1, 2 and 3 are needed in the future to provide the proper functioning evaluation.

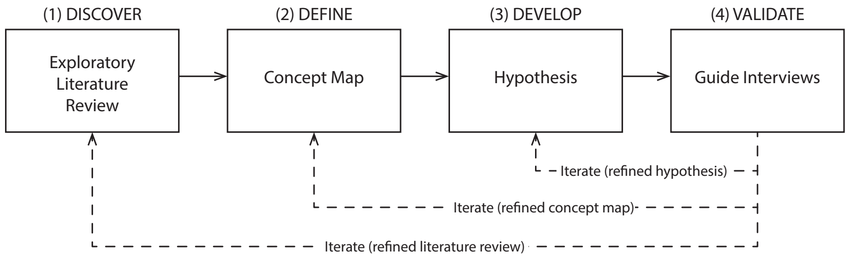


Figure 5.2.A. Methodological steps.

5.2.1. Discover - Exploratory Literature Review

To understand and define the main DfX strategies and try to create continuity between them in the various phases of the design process, it was decided to undertake a first research on the most common design practices with respect to the circular economy according to Webster, et al., (2002). The tool used for this research was Google Scholar, the keywords used in multiple combinations were "Design Theory", "Design Disciplines", "Circular Product Design", "Circular Economy", "Design Process", "Systemic Design ","Design for X", and "Design for Collaboration". All the terms were first searched individually and then combined using AND as a conjunction between the different keywords. Along with the material found through the review of the literature, some texts reputed fundamental were added (such as Brezet, et al., 1998, Vezzoli et al., 2008; Stahel, 2010 and Nasr, et al., 2018). All literature generated was considered.

5.2.2. Define - Concept map

To group and view the findings of the exploratory literature review, the concept map methodology was used. This methodology allows the interdependencies of the different concepts to be connected through logical reasoning (Novak, et al., 2008). Because the goal of the research was to define an interdisciplinary framework, the concept map developed around the word "Design for Collaboration". Subsequently, to give importance to all the design phases, the word "Design for Collaboration" was connected with every single phase of the life cycle of the closed-cycle product readapted based on the frameworks of Brezet, et al. (1997), and Vezzoli, et al. (2008).

This step helped to connect the main influences of different design disciplines with each phase of the product life cycle. For some of the phases of the life process of the product, a DfX was assigned in order to establish the possible disciplines which are able to deal with this design phase. The map presented in Fig. 5.2.2.A does not intend to be a map that includes all the strategies identified, but only an analysis of key aspects.

5.2.3. Develop - Hypothesis

From Fig. 5.2.2.A, a series of observations can be made.

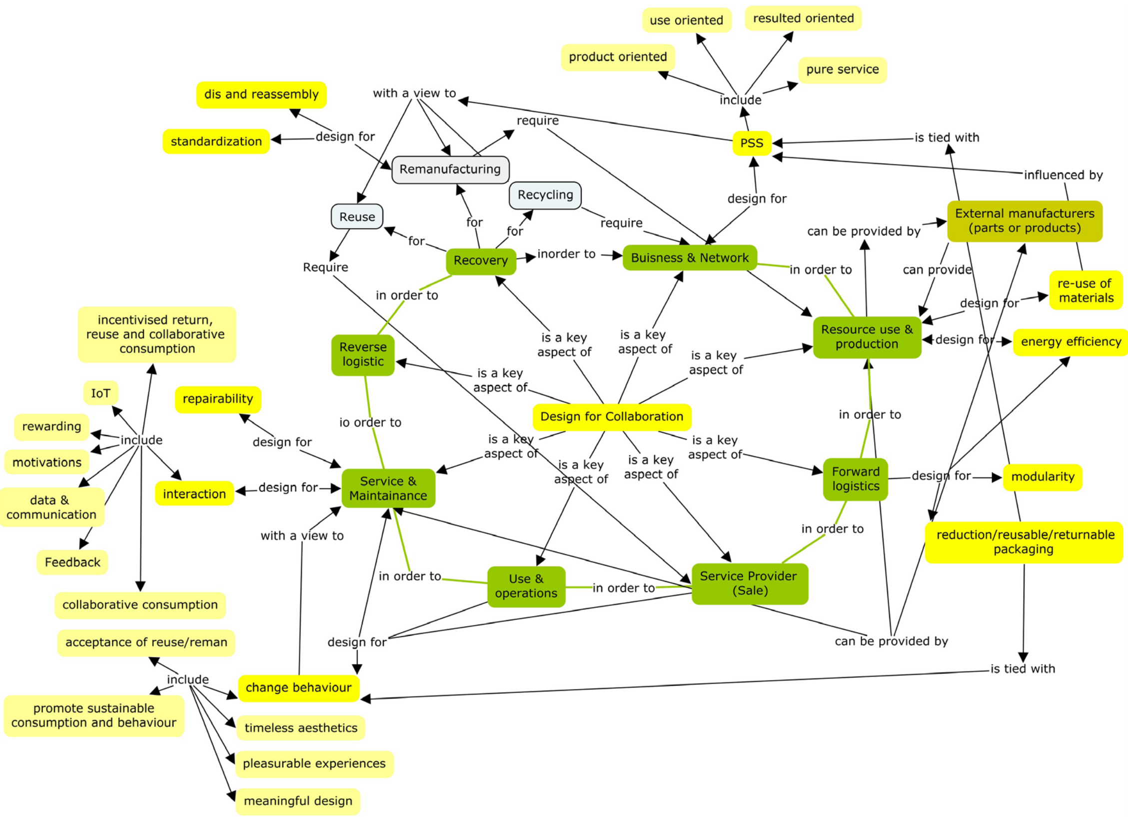


Figure 5.2.2.A. Concept map.

- Some DfXs can be applied by different disciplines/designers simultaneously (Kuo, et al., 2001)
- Some DfXs are applicable exclusively in specific disciplines/designers
- Some DfXs are the consequence of hierarchical decisions (Huang, 1996)
- Some DfXs are mutually non-exclusive
- Some DfXs are mutually exclusive
- Some DfXs are complementary (Van Weelden, et al., 2016; De los Rios, et al., 2017; Moreno, et al., 2017)
- Some DfXs are applicable across time dimensions
- Some DfXs follow different processes in different contexts and times
- Some DfXs are applicable in single and different phases
- Some DfXs can be applied consequently
- Some DfXs can be applied in parallel
- Some DfXs can take effect after the first loop of the product
- Some DfXs may progressively increase or decrease in effectiveness in different loops
- Several DfXs have variable effects on different products

The synthetic DfXs list of observations highlights the complexity of the hierarchization. Consequently, it was hypothesized that a hierarchy of DfXs should follow a multi-hierarchical approach. While a detailed verification of the entire conceptualization presented in Fig. 5.2.2.A. goes beyond the scope of this study, this has been useful to formulate three hypotheses which are the interpretation that resulted from it.

Three distinct hierarchies for DfX are conceivable. The first hypothesis relates to the hierarchy of the priority orders of the 'X' strategies. For example, with a view to implementing a design strategy for refurbishing (X^1) it is essential, in sequential order, work on design for disassembly (X^2) and then in more detail on design for maintenance (X^3), etc. (Van den Berg, et al., 2015), respectively X^1, X^2, X^3. 'X' may vary in detail in the applied design strategy. The X^1 determines the main circular strategy or in other words Maintenance, Reuse, Redistribute, Refurbish, Remanufacture, and Recycle, whereas X^2, X^3 the possible design strategies to reach X1. Hence, the first hypothesis is:

H1

To achieve the first-degree DfX (X^1) a hyperbolic tree hierarchy diagram, which describes each sub DfX strategy, can be used (Fig. 5.2.3.A.).

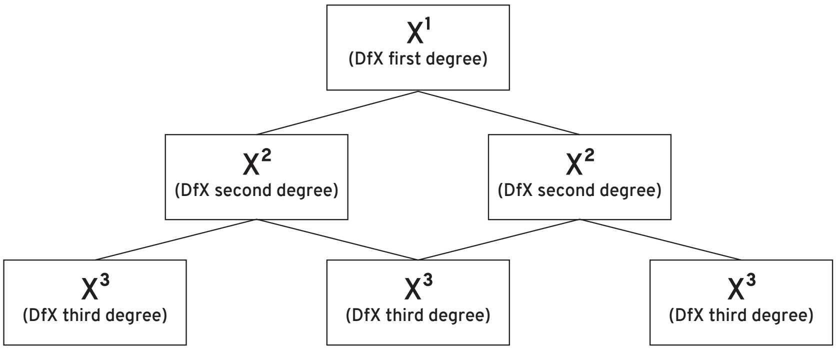


Figure 5.2.3.A. DfX hierarchization based on degrees of priority and design specifications.

Companies organize product development based on the phases of product lifecycle. The choices made during each phase (P) of the process can influence the subsequent phases (Cataldo et al., 2006). In order to achieve X^1, a variety of designers in different design phases, should coordinate their own DfXs effectively using specific X^2 and X^3. Hence, the second hypothesis is:

H2

Through a circular life cycle phase diagram, it is possible to position any DfX for each phase (Fig. 5.2.3.B).

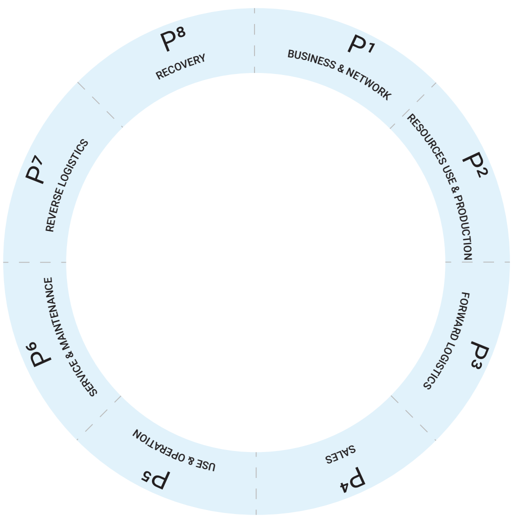


Figure 5.2.3.B. DfX hierarchization based on the phases of the product life cycle.

CE aims at recovering products for many loops by using as less energy and materials as possible for each loop (Bakker et al. 2014). In business terms, the life cycle of the product should last for many loops (L) by using specific combinations of strategies in order to make the business last longer. With that aim, designers should foresee which X1 should be applied for each product lifetime (L^1, L^2, L^3, etc.) in order to then decide in a hierarchical configuration X^2 and X^3. Hence, the third hypothesis is:

H3

In a spiral loop diagram, DfXs can be applied over multiple product life cycles (Fig.5.2.3.C).

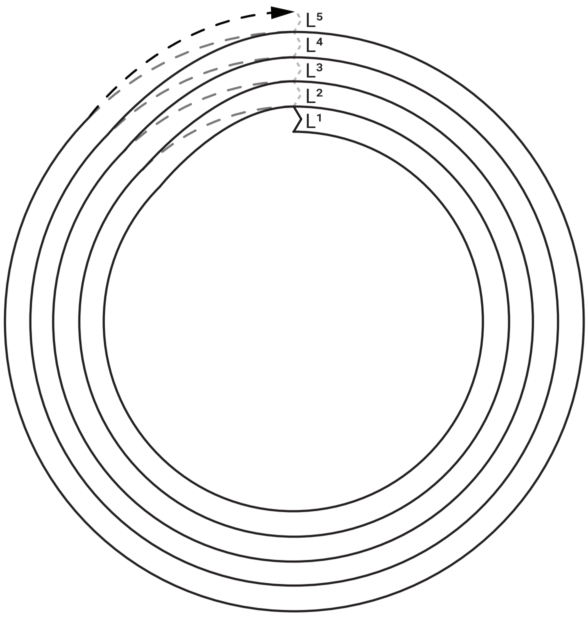


Figure 5.2.3.C. DfX hierarchization based on the different loops / temporal dimensions.

5.2.4. Validation - Interview Guide

In the last step of the methodology, an interview with experts from the academic and industrial world through a guided face-to-face interview was undertaken. This methodology consists of asking all the interviewees the same questions, leaving them free to explore specific issues (Patton, 2002) to validate the proposal.

Table 5.2.4.A. Specification on the competences and origin of the interviewees.

No.	AREA OF CE EXPERTISE	SECTOR	FROM
1	User experience and product design	Academia	USA
2	Transportation and mobility systems	Academia	USA
3	Consumer electronics, nanomaterials, and lithium-ion batteries	Academia	USA
4	Policies supporting energy technology, energy systems and information technology	Academia	USA
5	Product lifecycle design and remanufacturing	Industry	USA

In 1993 Nielsen et al., suggested after an empirical analysis of his studies, that a good consistent result can be gathered only after 5 interviews. Thus, in this research it was decided to interview only five experts. A brief description of the profiles and skills of the interviewees has been provided in Tab. 5.2.4.A.

5.2.5 Framework Validation

Respondents were informed of the methodological process described above. First, the interviewees were asked whether they found the three hypotheses, Fig. 5.2.3.A./B. and C. interdependent and whether a simultaneous use of these hierarchies would have favored interdisciplinary decision-making on multiple temporal dimensions. Subsequently, the specific requirements of the hierarchization of the three dimensions and the potential of a possible tool on the basis of hierarchization were examined. The areas considered in this phase included the requirements related to the application of different strategies in terms of application, relations and management of the different DfXs by different designers. The interviews provided valuable information on the possible hierarchy of DfX, validating all the processes which led to formulating the final framework (Fig. 5.2.5.A). Some key comments can be summarized in two categories, multi-hierarchies and use of the future tool.

Multi-hierarchies' considerations:

- The choices made in L1, P1 influence all the remaining choices;
- The design process always begins with L1, P1 but may not proceed in sequential order;
- X1 is the only objective of each phase (P) and each loop (L);
- X1 varies with the variation of Ls;
- X1 should be the only target, while X2 and X3 may vary in both number and importance depending on the product;
- The common denominator from which to select the DfXs is the cost, to then refine the selection of subsequent strategies;
- X2 represents the specific strategy for each phase;
- The hierarchy of contents should be standardized to the various disciplines and easily integrated within different companies;
- The choices of the DfXs is influenced also for each loop by external factors such as politics, technology, society, and culture;

During the interview, some questions were asked to the interviews for the considerations of a possible future tool (Ch. 8):

The tool must be able to simplify the vision but at the same time to maintain a scientific rigor;

- The tool should help to manage the overhead of designing alternatives by defining basic objectives to focus on;
- The tool should help the designer to establish the priorities of the different DfXs in a dynamic and intuitive way;
- To facilitate control by system designers, there must be a mechanism capable of showing quantifiable information flow for prioritizing different DfXs;
- Through case studies, it is possible to facilitate an immediate understanding of the strategy applied in reference;
- The hierarchy is not only direct but also indirect between the

different disciplines, so the relationships between different DfXs should be emphasized jointly;

- Different companies could have variable departments and structures and not have complete control of the design process; the tool should be able to be used cross-companies;
- Companies may be able to tailor their approach to different needs;

5.2.6. Multi-hierarchical structure

X1 - Main circular strategy objective. The X1 strategy represents the only and the first strategy that the company and stakeholders need to define when designing for the circular economy. This decision corresponds also to the circular value or inertia principle defined in Ch. 4. It identifies the general circular business approach for each Loop (L). Therefore it will define all the other design strategies (X^2 and X^3) for each phase of the design process of the same Loop. Designers can substitute X^1 with one of the following design strategies:

1. Design for Maintenance;
2. Design for Reuse;
3. Design for Refurbish;
4. Design for Remanufactured;
5. Design for Recycle.

P^1 - Business & Network. The P^1 represents the Phase (P) in which the business model is determined. In this phase is defined how the company/ies and the stakeholders should create, deliver and capture value in each loop (L). For each loop, in X^2 same or different stakeholders may be defined and involved in the design of the product.

X^2 in P^1. The X^2 in P^1 strategy represents the main strategy or strategies business designers can use in order to make X^1 possible.

X^3 in P^1. The X^3 in P^1 strategy represents the strategy or strategies business designers can use in order to make X^2 possible.

P^2 - Resources use & Production. The P^2 represents the Phase (P) in which the resources use and production is determined. In this phase is defined how the company/ies and the stakeholders should create, deliver and capture value in each loop (L). In P^2 same or different stakeholders may be defined and involved in the design of the product in each product life cycle. For example, if the place of remanufacturing/reassembly is arrange every loop at several places (context), different values and negotiation should be considered for each stakeholder in advance. They can also be involved in the design of the product.

X^2 in P^2. The X^2 in P^2 strategy represents the main strategy or strategies industrial engineers can use in order to make X^1 possible.

X^3 in P^2. The X^3 in P^2 strategy represents the strategy or strategies industrial engineers can use in order to make X^2 possible.

P^3 - Forward Logistics. The P^3 represents the Phase (P) in which the forward logistics is determined (from raw materials to end-user). In this phase is defined how the company/ies or stakeholders organize the infrastructural movement of the value in each loop (L). In P^3 same or different stakeholders may be defined and involved in the design of the

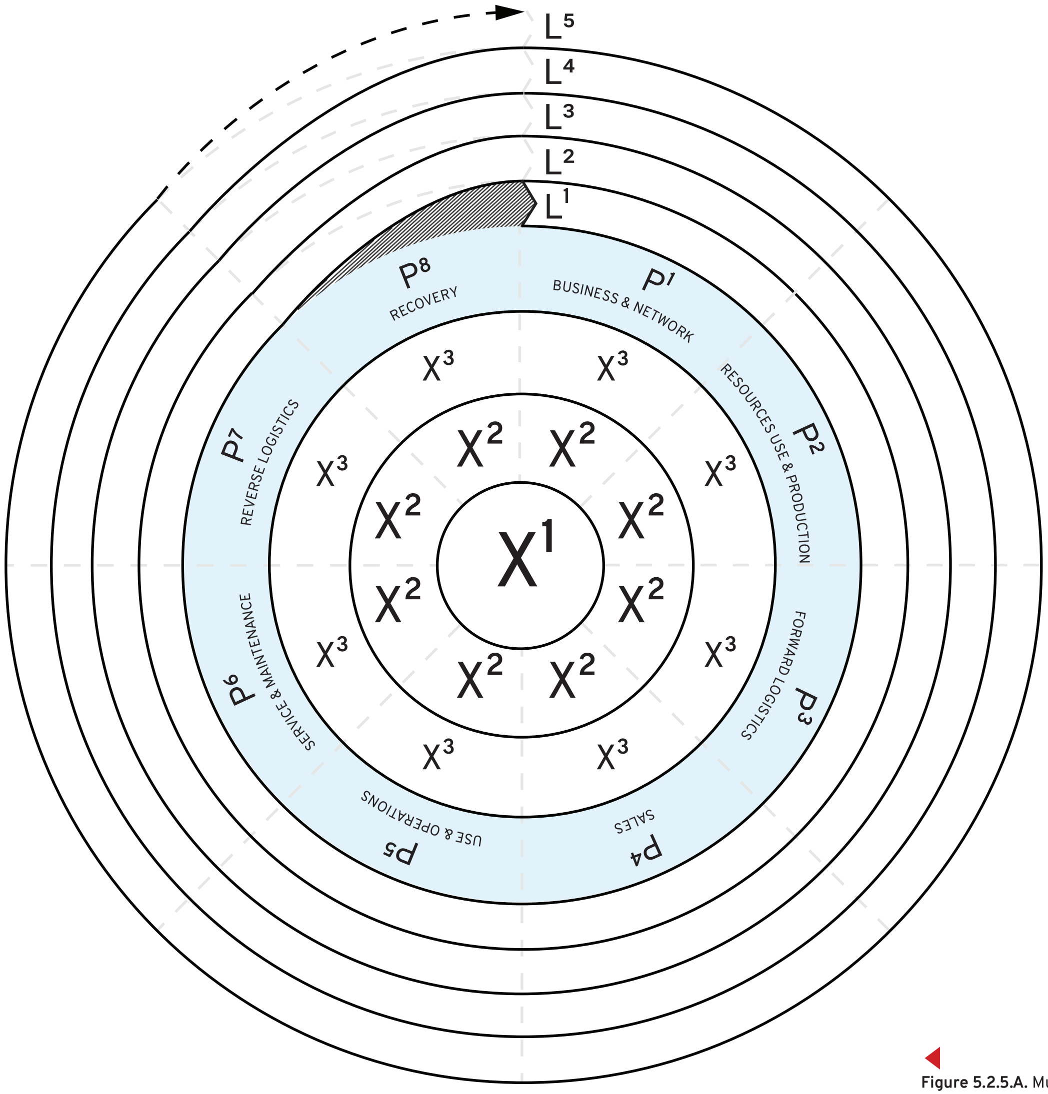
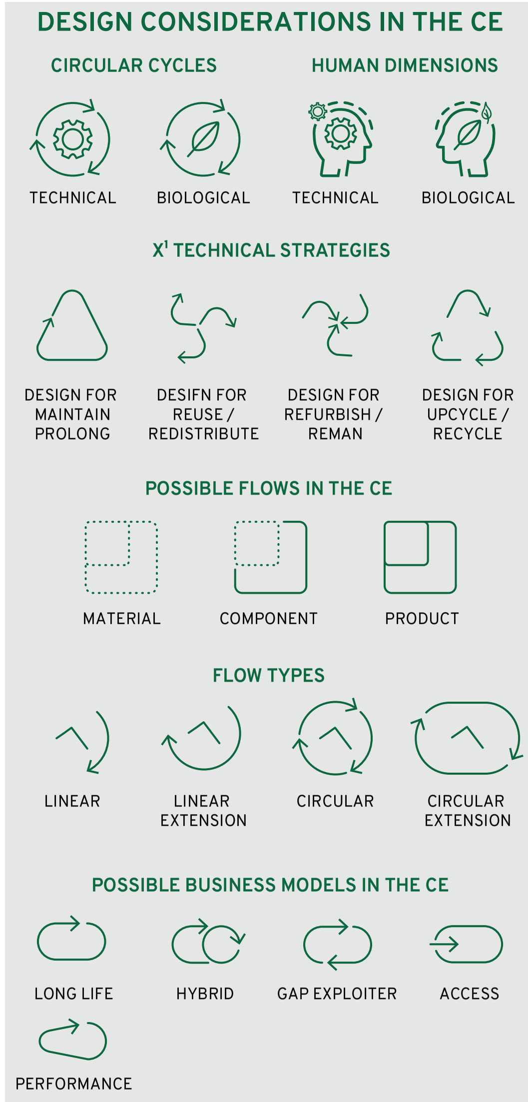


Figure 5.2.5.A. Multi-hierarchical DfX framework.



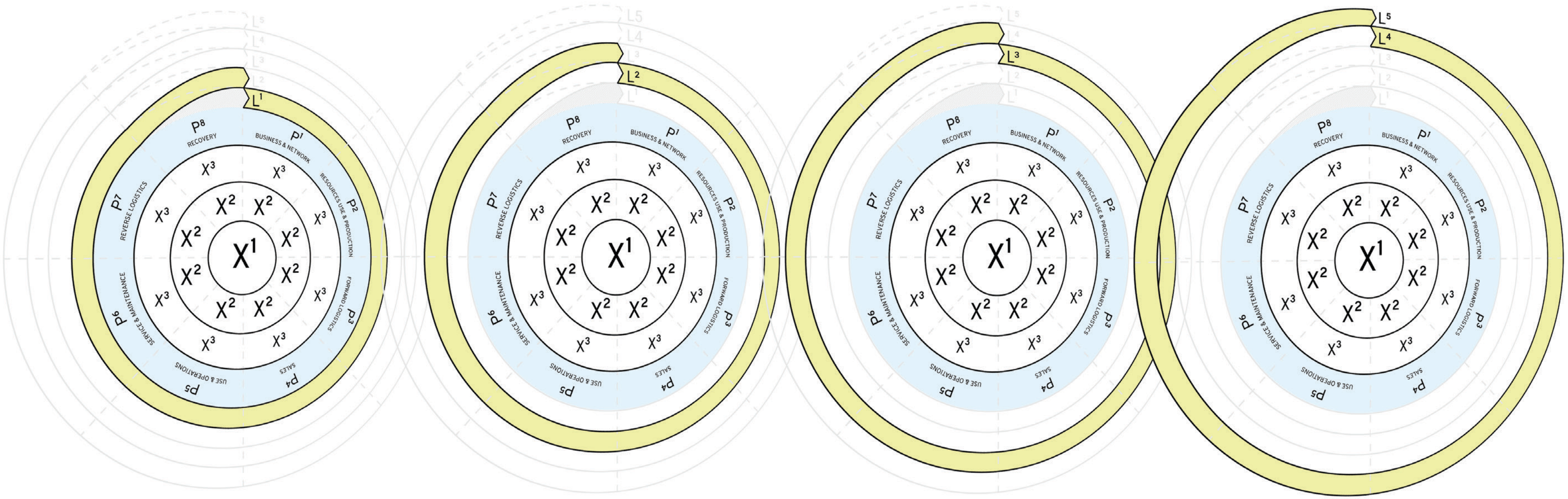


Figure 5.2.7.A. Multiple loop visualization.

CASE STUDY - BUGABOO BABY STROLLERS (Based on Sumter et al., 2018)

X^1 = Refurbishment
L^1 = First lifecycle

PHASE	DESIGN STRATEGY
X^2 in P^1	Design for Access Model
X^2 in P^2	Design for Modularity Design for Quality
X^2 in P^3	Design for Local Logistics Network
X^2 in P^4	Design for Social Media Marketing
X^2 in P^5	-
X^2 in P^6	Design for Modularity Design for Product Upgradability
X^2 in P^7	Design for Inverse Local Logistics
X^2 in P^8	Design for Ease Disassembly Design for Components Recycle Design for Modularity

X^1 = Refurbishment
L^2 = Second lifecycle

PHASE	DESIGN STRATEGY
X^2 in P^1	Design for Access Model
X^2 in P^2	Design for Ease Re-assembly
X^2 in P^3	Design for Local Logistics Network
X^2 in P^4	Design for Social Media Marketing
X^2 in P^5	-
X^2 in P^6	Design for Modularity Design for Product Upgradability
X^2 in P^7	Design for Inverse Local Logistics
X^2 in P^8	Design for Ease Disassembly Design for Components Recycle Design for Modularity

X^1 = Reuse
L^3 = Third lifecycle

PHASE	DESIGN STRATEGY
X^2 in P^1	-
X^2 in P^2	Design for Ease Assembly Design for Spare Parts Replacement
X^2 in P^3	-
X^2 in P^4	Design for Refurbish Market
X^2 in P^5	-
X^2 in P^6	Design for Product Upgradability
X^2 in P^7	-
X^2 in P^8	-

X^1 = - (unknown)
L^4 = Fourth lifecycle

PHASE	DESIGN STRATEGY
X^2 in P^1	-
X^2 in P^2	-
X^2 in P^3	-
X^2 in P^4	-
X^2 in P^5	-
X^2 in P^6	-
X^2 in P^7	-
X^2 in P^8	-

product in each product life cycle. For example, if the place of remanufacturing is arranging every loop at several places (context), the forwards logistics should be designed accordingly with it. Different values and negotiation should be considered for each stakeholder in advance.

X^2 in P^3. The X^2 in P^3 strategy represents the main strategy or strategies logistics engineers can use in order to make X^1 possible.

X^3 in P^3. The X^3 in P^3 strategy represents the strategy or strategies logistics engineers can use in order to make X^2 possible.

P^4 - Sales. The P^4 represents the Phase (P) where it is determined how to sell the value. In this phase is defined how the company/ies or stakeholders will sell the value to the final user for each loop (L). In P^4 the same or different stakeholders may be defined and involved in the design of the product in each product life cycle. For example, if the location of sale happens in different places (context), different typologies of users should be considered accordingly.

X^2 in P^4. The X^2 in P^4 strategy represents the main strategy or strategies marketing designers can use in order to make X^1 possible.

X^3 in P^4. The X^3 in P^4 strategy represents the strategy or strategies marketing designers can use in order to make X^2 possible.

P^5 - Use & Operation. The P^5 represents the Phase (P) where it is determined how users will use the value. In this phase is defined how the company/ies or stakeholders design the value for the different final-users for each loop (L). In P5 same or different customers may be defined and involved in the design of the product in each product life cycle. For example, if the location in which products are used is different among loops (context), the product should be designed accordingly. Different values should be considered for each customer in advance.

X^2 in P^5. The X^2 in P^5 strategy represents the main strategy or strategies industrial designers can use in order to make X^1 possible.

X^3 in P^5. The X^3 in P^5 strategy represents the strategy or strategies industrial designers can use in order to make X^2 possible.

P^6 - Service & Maintenance. The P^6 represents the Phase (P) in which the value is maintained through related services. In this phase is defined how the company/ies and the stakeholders should provide the maintenance of the value in each loop (L). In P^6 same or different stakeholders may be defined and involved in the design of the product in each product life cycle. For example, if the location of repair is different at every loop (context), the interactions and maintenance systems should be designed accordingly. Different values and negotiation should be considered for each stakeholder in advance.

X^2 in P^6. The X^2 in P^6 strategy represents the main strategy or strategies service designers can use in order to make X^1 possible.

X^3 in P^6. The X^3 in P^6 strategy represents the strategy or strategies service designers can use in order to make X^2 possible.

P^7 - Reverse Logistics. The P^7 represents the Phase (P) in which the reverse logistics is determined (from end-user to recovery or to a new user). In this phase is defined how the company/ies or stakeholders coordinate infrastructural return of the value in each loop (L). In P^7 same or different stakeholders may be defined and involved in the design of the product in each product life cycle. For example, if the place of taking back is arranged differently for every loop (context), the reverse logistics should be designed accordingly. Different values and negotiation should be considered for each stakeholder in advance.

X^2 in P^7. The X^2 in P^7 strategy represents the main strategy or strategies reverse logistics engineers can use in order to make X^1 possible.

X3 in P7. The X^3 in P^7 strategy represents the strategy or strategies reverse logistics engineers can use in order to make X^2 possible.

P^8 - Recovery. The P^8 represents the Phase (P) in which the recovery of the value comes about. In this phase is defined how the company/ies or stakeholders coordinate the recovery of each part of the product each loop (L). In P^8 same or different stakeholders may be defined and involved in the design of the product in each product life cycle. For example, if the place of disassembling is arranged differently at every loop (context), the recovery workforce in the facility should have the skills and capabilities to perform such task.

X^2 in P^8. The X^2 in P^8 strategy represents the main strategy or strategies recovery designers can use in order to make X^1 possible.

X^3 in P^8. The X^3 in P^8 strategy represents the strategy or strategies recovery designers can use in order to make X^2 possible.

5.2.7. Multiple loops (or lifecycles) of the product

L^1 - First product lifecycle. In L^1 the product is new and usually, this is the easiest design process to design. However, from the good management of this loop depends on the success of the next loops (L^2, L^3, etc.).

L^2 - Second product lifecycle. In L^2 the product is in its second lifecycle. From this loop on out, the product may have been reused, refurbished, remanufactured, or recycled. All the loops after the first are more difficult to manage because the company should take into consideration different factors for each of the different loops, such as recovery, market, target, etc.

5.3. X^1 objective

The choice of multiple X^1 objectives is a considerable time-consuming process as it implies the understanding of multiple design perspectives. It is possible to identify several X^1 strategies for the product lifetime, one for each product life cycle. X^1 objectives should be one of the most important aspects to be considered in design for the CE in order to create evaluate alternatives, identify decision opportunities and guiding the entire decision-making process between phases and loops. To be possible, the objective should have the six properties listed below:

1. Crosswise, to define a central objective and guide designers into multi criteria decision analysis;
2. Achievable, to define a feasible and manageable objective that create values and revenues for the company and stakeholders across phase and loops;
3. Controllable, to address an absolute circularity of materials, components and products;
4. Detailed, to understand the risks and opportunities that the company and stakeholders are ready to embrace;

5. Understandable, to create a clear path where all the designers can share valuable information between different skills
6. Integrated, to include all fundamental aspects of the product lifetime.

Consider a specific product lifetime, the multiple X^1 objectives should take into consideration different times, contexts and political situations as a requirement to complete all the life cycles planned during the design process. The set of X^1 objectives can be change during the design process in case of difficult design decisions, and will only become final once all the X^2 objectives has been defined and accepted by all the stakeholders and designers.

5.4. Conclusions

In a circular context, the good organization of the different DfX strategies, stakeholders, and values are the keys to increase profitability across multiple loops. This paper presents a Multi-hierarchical DfX Framework that will shape the basis of an interdisciplinary tool. The tool will help designers to identify for each loop (L) a circular objective, defined here as an X^1 strategy, which might be maintenance, reuse, redistribute, refurbish, remanufacture, or recycle. All appropriate DfX strategies to directly pursue the achievement of the X^1 can be considered X^2 strategies. The same principle applies to the X^3, X^4 and so on. When designing for a new loop, the X^1 strategy may change. If so, X^2 and X^3 strategies may change accordingly. Different designers (e.g. business, engineers, product or service designers) should be able to set an appropriate combination of X^2, X^3 in order to achieve X^1.

Through this framework, designers will be able to dynamically compare and identify DfX strategies from the early stages of the design process. Along with DfXs, it is possible to define stakeholders and related values for each of them. In order to make the management of the complexity easier, a framework can be arranged for each loop (Fig. 5.2.7.A). This could help designers in coordinating relations between design strategies for three reasons; the first reason is to manage the interdependencies between different strategies. For example, if the designer decides that X^1 in the L^1 is Design for Refurbishing, in L^2 P^4 a consequential logical X^2 is Design for Change Behavior and X^3 could be Design for Consumer Acceptance of Refurbished Product (Pazhani, et al., 2014; Van Weelden, et al., 2016). The second reason is to exclude the strategies that conflict one another. For example, if the designer decides that X^1 in the L^1 is Design for Recycling, in L^2 P^5 the X^2 cannot be Design for Attachment and Trust. The third and last reason is to help to monitor and forecasting crucial DfX strategies. For example, if the designer decided that from L1 to L^4, X^1 is Design for Remanufacturing, the designer should define if X^2 in P^8 is Design for Closed-Loop Supply Chain Networks, or instead Design for Open Loop Supply Chain Networks (Ene, et al., 2014). These decisions could completely change consequential strategies in the other loops.

Chapter 6

ANALYSIS OF THE MULTI-HIERARCHICAL DFX FRAMEWORK IN THE LIGHT OF PRACTICAL APPLICATION

Synopsis
Having described the Multi-hierarchical DfX framework and how to defined DfX strategies, stakeholders and values in the previous chapter, this chapter presents the analysis of three bike sharing systems, this case study will highlight in detail how to define specific DfX strategies for Use & operation phase of the framework.

6.1. Introduction

The sharing economy (SE) is a collaborative consumption model where the use of products is shared between multiple users. “Collaborative consumption” is defined as “the set of resource circulation systems which enable users to both obtain and provide, temporarily or permanently, valuable resources or services through direct interaction with other users or through the mediation of a third-party” (Ertz et al., 2016).

From a wider technical perspective, the use of materials in the SE is maximized in the system for a longer time between multiple users (Stahel, 2010). However, SE does not always secure a circular flow of materials, or even a circular economy (Webster, 2017). Circular Economy (CE) is positioned to address the challenges posed by the current linear economy, which is based on the take-make-dispose, fossil fuel based, consumption model (Ellen MacArthur Foundation, 2012, European Commission, 2018). Different strategies such as reusing, repairing, remanufacturing or recycling can be applied in multiple-level ways in order to lower environmental impacts, reduce waste, enhance economic prosperity and improve social equity for present and future generations (Ghisellini, et al., 2016; Kirchherr, et al., 2017). Thus, in order to boost a resilient system, the SE and CE concepts should always be considered together.

This chapter takes the Design for Sharing notion as a main X2 strategy applied for multiple loops in P1. Indeed, as Webster (2017) proposes, design is crucial to balance business design strategies with economic values (Webster, 2017). To develop the work in this direction there is a need for more evidence upon which to position the parameters and determine the options and opportunities that designers can take to accelerate the transition towards a resilient system (Morelli, 2006).

To achieve this understanding this chapter proposes an assessment of Milan’s bike-sharing, where three alternative Bike Sharing Systems (BSSs) have been adopted by the municipality. The general aim of this chapter is to understand how to collect and define multi-phase perspectives over multiple product life cycles by analyzing the coexisting Milan’s BSSs. This will make an initial theoretical contribution to the field of multiple design perspectives. It will start by examining the theoretical foundations of Product Service-System, and bike sharing. Subsequently, the scientific method based on three design dimensions: functional, aesthetics and symbolic will be presented. For each design dimension, it will share what is relevant from a design perspective in relation to the business model take into consideration. And finally, the chapter will present the discussion, limitations and future research directions and conclusion of the research.

Relatively few detailed studies have attempted to determine which design strategies might lead to the CE starting from the analysis of potential product issues (e.g. Bakker et al., 2014). Moreover, as far as can be ascertained, no scientific research has been conducted to analyze the link between design dimensions such as functional, aesthetical and symbolic factors for a wider systemic approach (Homburg, et al., 2015 and Candi, et al. 2017). Results can be used to inform how design can influence users’ behaviors, habits, and actions, contributing to an increase user acceptance rate in P5 of the Multi-hierarchical DfX framework.

6.1.1. Product Service System and Bike Sharing

A Product Service-System (PSS) is described as “tangible products and intangible services designed and combined so that they jointly are capable of fulfilling specific customer needs” (Tukker, 2004). Tukker, (2004) defined three categories of PSS, product-oriented, use-oriented and result-oriented (Ch. 3).

- In the product-oriented service, the product is sold to the customer and some services are provided with it;
- In the use-oriented service, the provider retains the ownership of the product and sells its service to final customers instead;
- In the result-oriented service, the provider and the customer agree on a specific final result without pre-determined products involved.

Bike-sharing, together with mobility services infrastructure (such as buses, trams and subway), offers a service of access and belongs to the category of result-oriented services (Ceschin et al., 2010, A). When well integrated with public transportation, bike sharing provides a great and sustainable urban mobility to satisfying transportation needs (Ellen MacArthur Foundation. 2015). The development of additional mobility infrastructures such as bike-sharing improves not only traffic congestion, air quality, and physical well-being (Midgley, 2011) but also reduces demand for new goods as it maximizes product utilization rate, therefore being a good option to solve the typical problems of increased global urbanization (Midgley 2011, Saibene and Manzi 2015).

6.1.2. Design for X and the functional, aesthetics, and symbolic factors

The role of designers has become increasingly complex and systemic over time (McDonagh et al., 2003). This because, as society evolves, designers should take into consideration, during the entire design process, more and more new factors in order to prevent design failures. This is particularly true for circular and service-products. As it was already stressed, one way to simplify the complexity of the existing design into something more manageable and understandable is the Design for X (DfX) (Moreno, et al., 2016; De Los Rios, et al., 2017; Radziwill et al., 2017). A better understanding of possible design strategies leads to a better understanding of complex systems, and consequently to more careful circular decisions.

Huang, (1996) proposed the first study on a cross-sectoral approach of the DfXs. Although this research was not specifically intended for the CE, it built the foundations of a larger theory of DfX. Go, et al. used DfXs to provide a detailed guideline to develop Multiple Life-Cycles products (Go, et al., 2015). While Moreno et al., offered the most comprehensive taxonomy of DfX approaches for CE with more than forty design strategies (Moreno et al., 2016).

In order to adopt a consistent approach with the previous research, the present study reviews DfX strategies following the Multi-hierarchical DfX framework, and in particular it will only focus on a product design perspective (P5). Homburg, et al., (2015) defined and described product design as a “set of constitutive elements of a product that users perceive and organize as a multidimensional construct comprising the three dimensions of aesthetics, functionality, and symbolism”. Based on this definition, for each dimension (functional, aesthetics and symbolic) this chapter classifies strategies in X^2, X^3 and X^4.

6.2. Method

This chapter explores how designers can implement and improve acceptance of bike-sharing taking into account not only function but emotional and aesthetic dimensions in a service context (Bakker, et al. 2014; Homburg, et al., 2015; Planing, 2015; Candi, et al. 2017). By using bike-sharing as a case study, this chapter presents the specific approach of designers in the Use & Operation phase of the Multi-hierarchical DfX framework (Figure 6.2.A), presented in Chapter 5.

Understanding all the dimensions of acceptance of bike-sharing from users' perspective is important especially for product designers in order to scale-up sustainable mobility in urbanized cities, but also to understand the relationship between Design for Sharing approach and

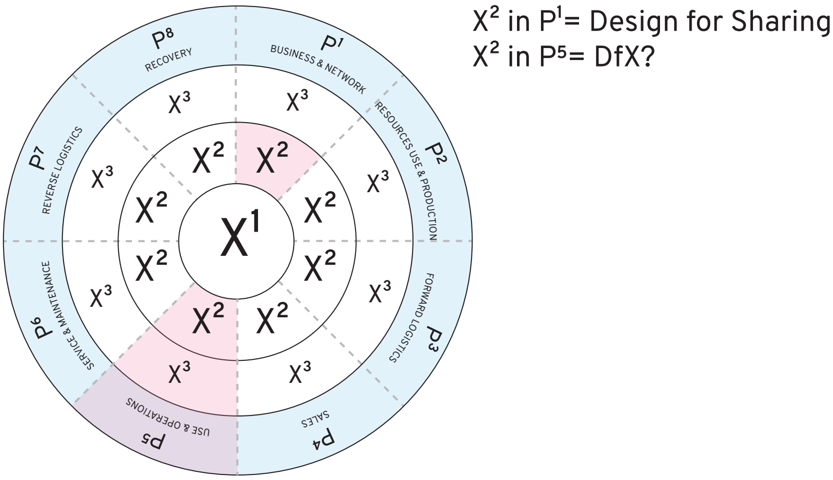


Figure 6.2.A. Focus of the chapter and multi-phases analysis.

Design for Sharing strategy can also be named the access model strategy, as defined in Ch. 1.

potential customers. An important characteristic of this research is the introduction of the aesthetic and symbolic aspects in the CE, as levers to influence behavior change. To uncover key elements of design for sharing, four activities were identified:

- interviews and analysis of the interviews;
- a broad literature review on circular product design;
- a specific literature review on Design for X and comparison with the outputs of interviews;
- synthesis and development of a conceptual framework for the design of bike sharing in P5.

A qualitative semi-structured survey was developed and conducted. This survey is willing to help addressing the question: "How might designers incentivize user acceptance of bike-sharing systems based on the Multi-hierarchical DfX framework?"

To address this question ten interviews were set-up. The respondents were made up of three women and seven men. All the interviews were registered in Italian and the selection of the interviewees was made by considering those users who used at least two out of the three bike-sharing services available in Milan (Table 6.2.A.).

The interview script was based on Homburg, et al., (2015) and Candi,

Table 6.2.A. Interviewee code.

INTERVIEWEE CODE	AGE	GENDER	BIKEMI	MOBIKE	OFO
1	35	M	✓		✓
2	31	M	✓	✓	✓
3	38	M	✓	✓	✓
4	38	M	✓	✓	✓
5	36	F	✓	✓	✓
6	34	F	✓	✓	✓
7	27	M	✓	✓	
8	43	M	✓	✓	✓
9	25	M	✓	✓	
10	37	M	✓	✓	✓

et al. (2017) conceptual framework of functional, aesthetics and symbolism. The interviewees were introduced to the research goals and asked for their motivations, with relation to the service, preferences, as well as similarities and differences between the three BSSs available. Two images for each bike (both sides) on a white background were provided (Tab. 6.2.B). Each interview took approximately 30 minutes. The interviews were recorded and transcribed, then a deep analysis was carried

Table 6.2.B. Characteristics of bike sharing in Milan (May 2018).

	TYPOLOGY	ACCESS	BASIC FEE (May 2018)	No. BICYCLES (October 2017)	AVAILABILITY	TERMS OF PAYMENT
BIKEMI (in Milan from 2008) 	Docking stations	Smart card access	360 days € 36 7 days € 9 Daily € 4.50	4600	Everyday 7.00am to 1.00am	Credit Cards
MOBIKE (in Milan from 2016) 	Free Floating	App	360 days € 150 180 days € 110 90 days € 60 30 days € 25 Pay Pass € 0.50 per ½ hour	8000	24/7	Klarna, credit, prepaid and debit cards
OFO (in Milan from 2016) 	Free Floating	App	30 days € 20 7 days € 5 Pay Pass € 0.50 per ½ hour	4000	24/7	Credit, prepaid and debit cards

out to condense and code the results of the interviews. This process was lengthy, but it was essential in order to capture all the data in line with the Auerbach and Silverstein (2003) methodology.

6.3. Influencing functional factors

User's perception of the product is influenced by the ability of it to fulfil its purpose (Homburg, et al., 2015). However, functional perception can be affected in two different ways: one technical and the other aesthetical (Creusen et al., 2005). This section investigates the technical perception of functionality - even if the functionality of products is first communicated through appearance and then proven during their use. Technical function factors are commonly associated with quality of product and service to move from point A to point B. Bike stability, comfort or pedaling, easy adjustment, intuitiveness of the mobile app, return of bikes and many other factors should be orchestrated from a design point of view to make a pleasant experience.

As shown in Table 6.3.A, selected design framework for the functional sphere is provided. This framework is the result of an intertwined selection between, literature review and the outcome of interviews.

Table 6.3.A. Taxonometry of Design for X approaches for BSS in CE context.

Influencing factor: functional.

INFLUENCING FACTOR	X^2	X^3	X^4
FUNCTIONAL	DESIGN FOR RELIABILITY	Design for Voluntary Behaviour	Design for Customer Cooperation
			Design for Reward
		Design for maintenance	Design for Preventive Maintenance
			Design for Security
	DESIGN FOR FLEXIBILITY AND EFFICIENCY OF USE	Design for Ergonomics	Design for Adjustability
			Design for Comfort
			Design for Lightness
		Design for Usability	Design for Quick Start
			Design for Simplicity
			Design for Security

6.3.1. Design for Reliability

A variety of X^2 design strategies for circular transportation and mobility exist. Among others, Design for Reliability tackles a key role for the maintenance of performance in the transportation systems such as BSS. Stapelberg, (2009) described reliability as "the probability of successful operation or performance of systems and their related equipment, with minimum risk of loss or disaster or of system failure". System failure should be prevented by designers through a detailed analysis of the reasons for which failure occurs. The result of the interviews showed that major service failures are related to the full/empty stations (1; 2; 3; 5; 7; 10) or the bicycle dysfunctions (2; 3; 4; 5; 6; 7; 8). Therefore, when the design strategy is reliability, designers have to intervene in the system by designing more efficient operational relocation of bikes and mechanical configuration of the bike to prevent possible system failures.

In regard to full or empty stations, Aeschbach et al. (2015) proposed the concept of Design for Customer Cooperation. The strategy could potentially apply for both free floating and docking station systems by actively involving customers in the re-balancing mechanism through a computer-assisted system. Mobile apps can be used to reroute the user first choice station with alternative stations that are within 500 meters from the original target (Aeschbach et al. 2015). This design strategy can optimize relocation of bicycles avoiding the use of trucks resulting in an operational and environmental benefit. In order to collaborate, users must receive a sort of recognition from the system that acknowledges their effort and rewards them. Pfrommer et al. (2014) suggests the dynamic pricing approach, which rewards the customer's perceived cost of additionally travelled distance. Other kinds of rewards can be evaluated accordingly with possible partners and sponsors.

One of the most common design focuses for reliable products is Design for Maintenance. Design for maintenance should prevent failures through a superior technical design. From the interviews emerged that users who complained about technical malfunctions of the bicycles referred six times out of seven to Ofo, Bikemi or both (1; 3; 4; 5; 8; 9). The main difference between those two bikes and Mobike is that the latter was better designed to works within a service system (Wu et al. 2017). Bicycles are subject to recurrent problems such as chain drops off or tire punctures. Instead, Mobike's designers, following the rules of Design for Preventive Maintenance, replaced elements subject to frequent dysfunctions with solid tires and chainless transmission. On one hand, this design decision reduces the unpredictability of the mechanical system and increases the users' confidence in using the bicycle. On another hand, it limits some important riding performances such as shock absorbing and gears shifting, making the pedaling hard and tiring for riders (3; 4; 5; 6; 9; 10). It is important for designers to prevent breakdowns by considering and eliminating all the relevant and common causes of dysfunctions, however, the bike experience should remain comfortable and smooth to ensure a high level of ride performance.

Bike-sharing, besides being subjected to meteorological stresses, is often the target of urban vandalism (Fig. 6.3.1.A.). This phenomenon

Figure 6.3.1.A. The vandalization of different bike-sharing systems.

(which affects mainly dock less bikes) forced large bike-sharing companies to withdraw entire systems from many cities across Europe, showing one of the limits of dockless bike-sharing concept. To avoid this problem, Lockton proposed the 'security lens' as a design strategy to effectively treating users to encourage or force a desirable behavior. Design for Security is an important criterion that must be addressed by designers to avoid repair costs, but also the system inefficiency perception by the users (Lockton, 2013). Lockton states that the behavior of people can be intentionally influenced through design, when this happens it is possible to notice more sustainable and respectful behavior (Lockton, 2013).

6.3.2. Design for Flexibility and Efficiency of Use

Designing bikes that are able to adapt to different genders and age groups is an important focus for designers to facilitate the functional use of bicycles and increase the perceived value of the product from customers. Design for Flexibility and Efficiency of use requires that the bike can be simple to adjust for the optimum and comfortable position of its rider. The same design strategy can be extended to the cognitive interaction between the user and the bike to improve the simple use of the service for different typologies of users.

When designing for ergonomic bike-sharing, at first designers shall decide what percentiles to design for. It is quite hard to design for all human dimensions. For instance, many problems have been reported with Mobike's bikes, six out of ten interviewed said that the bicycle was too small as they struggled to ride it (2; 3; 5; 6; 7; 8). While the Chinese company applied ergonomic parameters best suited for their Chinese customer base during the start-up phase, those did not apply quite well for their worldwide expansion outside their home market. This forced the brand to produce several new alternative bicycles for the international market causing a wrong perception of the brand by the users and an additional effort/cost in designing and introducing a new bicycle model. Thus, designers should apply criteria of adjustability on the key elements of the bicycle such as handlebars and saddles to fit the majority number of riders. Also, quick adjustment of seat height should be possible without getting off the bike in order to facilitate the most comfortable position to the different riders.

An inherent design challenge that emerged from most interviews is the heavyweight of the bicycles (4; 5; 7; 8; 10). Those should be robust but light as users, when riding outside bike lanes, are quite often forced to move bicycles between street and sidewalk. According to the interviewees, Bikemi is the heaviest bicycle and also, quite ironically, the only one that needs to be lifted every time to be hooked to their dock station. For instance, the interviewee 7 said: "Sometimes weight is a problem, especially to get on sidewalks" or interviewee 10 said: "Bikemi is very heavy, I suffer from back pain … and lifting the bicycle to hook it up is a problem for me". Other bike-sharing models such as Chicago's BSS (Fig. 6.3.2.A) have developed hooking systems that minimize physical effort to pick up and hook the bicycle. The lightness of the bicycle frame is also a fundamental parameter to allow adoption. In the interviews, two out of three women have criticized the heaviness of Bikemi compared to its competitors. The lightness of the bike is influenced by the designer's choice of materials and structure. Materials should not just be lightweight but also tough and rigid to improve driving performance. Designers should also design simple hooking systems to make it easier for users to return the bicycle.

Figure 6.3.2.A. Divvy bikes, Chicago's bike-share system.

The functionality of the BSS system depends on many factors, one of which is usability. Usability is the connection between the interface and the system and facilitates users in achieving their final goal, guaranteeing its usefulness (Nielsen, 1993). When designers overlook usability, they can cause users negative emotions like frustration. This is especially tangible with unfamiliar products, such as mobile apps. User 3, for instance, said: "Bikemi's app doesn't tell the status of docking stations, neither at the beginning nor during the ride. This bothers me a lot.". In bike-sharing, the app plays a crucial role with the overall user satisfaction of the system, in fact, not surprisingly, when the app fails, the overall experience feels broken and ineffective. Negative emotions caused by inaccurate geolocation, poor bike status updates or bad reservation process are all little pitfalls in the user's experience which affect the overall perception of BSS, as reflected by the respondents (3; 4; 5; 6; 8; 10).

In designing BSS usability, designer must consider two variables factors to design an effective app. The first very important variable is time, users are willing to move quickly (Avineri et al., 2010). It is recommended to avoid unnecessary intermediate steps, postpone the request of optional data and to design simple interfaces, enabling faster on-boarding. The second factor is the constant technological innovation embedded in the bike or docking stations. This has significant implications for designing bikes able to be upgraded quickly. As an example, Transport for London or ATM Milano offers a flexible and fast contactless payment solution by using credit cards, the system will balance the weekly, monthly or annual fare automatically depending on final use rate. The ticket barriers have been updated and adapted to read credit cards without replacing them. This little improvement, without infrastructures renovation, avoid user's mental effort of learning new things while improving the option of payment (Fig. 6.3.2.B).

Figure 6.3.2.B. UH Bikes, Cleveland's bike share system.

6.4. Influencing aesthetic factor

The influence of aesthetics on users to increase purchasing has been well demonstrated by empirical research (Holbrook, et al. 1982; Chitturi, et al., 2008; Homburg, et al. 2015; Candi, et al. 2017). Nevertheless, it is still unclear how to best leverage the design for sharing - specially to persuade users to use the shared product through aesthetical factors. A X^2 design strategy that focuses on aesthetics in the complex PSS scheme should take into account (Ceschin, et al. 2010, B) not only the aesthetics of the product (i.e. materials, surfaces, etc.) but also the aesthetic evolution over time of the product, and the possibility that users' aesthetic perception will change accordingly. The aesthetics and the role of more careful design is a hotspot influence factor in designing for BSS (Roy et al., 2007). Designers must be able to coordinate and harmonize aesthetics and symbolism of the product-service in order to create a "cultural icon" that is able to last, adapt and resist to aesthetical change.

The results of the literature search on the influence of aesthetic factors and interviews have been combined, with the objective to produce a list of key DfX strategies that designers might consider when designing for BSS (Tab. 6.4.A). Clearly, these strategies must be considered together with other circular design strategies that take into consideration not only functional, aesthetic and symbolic factors but also technical and service ones.

Table 6.4.A. Taxonometry of Design for X approaches for BSS in CE context.

Influencing factor: aesthetics.

INFLUENCING FACTOR	X^2	X^3	X^4
AESTHETICS	DESIGN FOR ATTACHMENT AND TRUST	Design for Simplicity	Meaningful Design
			Design for Robustness
			Design for Lightweight
		Design for Timeless Aesthetics	Design for Upgradability
			Design for Ageing Gracefully

6.4.1. Design for product attachment and trust (Aesthetics)

A product capable of stimulating a vast range of personal meanings through its aesthetic qualities is able to stimulate "a more successful process of skill learning related to its functional application, deeper attachment in the sense of continued use in the face of possible alternatives, and long term product commitment" (Cupchik, 1999). Designers can change users' habits through different aesthetic levers such as materials, proportions, color, ornamentation, shape, size, texture, and reflectivity (Noble and Kumar, 2010). In the design of shareable objects, unlike personal objects, designers must consider that there is not a single target but that users are multiple and varied. Furthermore, shareable products are meant to last longer which is why designers should focus on attachment and trust to avoid desire of users to change products according to the trends of the moment (Bakker et al., 2014). In the aesthetic dimension, by focusing on attachment and trust, designers will work through the medium of beauty. By creating messages or emotional connection between products and users, designers can change user perception of the product and creating a persuasive effect of desirability (Noble and Kumar, 2010), affecting their way of consumption.

Looking at the current bike-sharing on the roads of Milan, it is clear that a formal and aesthetic design for sharing exists already. The Bikemi bicycle, for example, was designed with a “bodywork” to protect the sensitive parts of the bicycle, such as brake cables (Fig. 6.4.1.A). The same problem was solved by channeling the cables inside the bicycle’s frame in Mobike, avoiding the use of additional “bodywork”. Although these two bicycles are designed with greater attention than the competitor Ofo, which does not manufacture its own bicycles but adapts them to service uses (Wu et al. 2017), the interviews showed that five out of ten interviewees prefer Ofo to the two opposite bicycles (1; 4; 5; 6; 8). The most motivated reason is the lightness of the frame, but also the color and the fact that, for many, Ofo represents a “traditional” bicycle. The result seems to be in contrast with the sense of functional reliability of the bicycle from users, who, in general, trust Bikemi and Mobike more. Thus, even if an aesthetic project exists, this seems inadequate due to an imbalance in favor of technical factors compared to aesthetic ones (Candi et al., 2017). That said, designers should avoid adding aesthetic superstructures that weigh down the aesthetic line of the bicycle to give users the feeling of using lightweight and agile bicycle, rather they shall be paying attention to the design for robust and the essential aspects, the product shouldn’t be burdened with non-essentials.

Figure 6.4.1.A. Esthetic details of Bikemi.

Design for Robustness is connected with the design for functional and structural trust X^1 in the previous section. Aesthetically, perception of trust can be given at first glance - the first time the user sees the bicycle (Cupchik, 1999). But the same feeling should not diminish over time, but rather be reinforced. Perception of robustness and trust can arise in the user through the use of material and colors to influence functional performance judgments (Hoegg et al., 2011) but also working on thicknesses of the frame, wheels and handlebars.

To encourage trustworthy appearance, attention to detail is essential. For instance, Citroën developed an innovative protection system called AIRBUMP® to protect the C4 Cactus from park damage and the urban rough and tumble (Citroën, 2017). The air-filled capsules ensure the car body always looks optimal and invulnerable (Fig. 6.4.1.B.). The same concept could be reinterpreted for bicycles, working on the surface of the

Figure 6.4.1.B. First Study marked first appearance of Airbump in 2008.

frame through special textures or by adding components to protect them from vandalism or negligent behaviors.

Contrary to current trends that foment the incessant consumption of products through an always new and modern aesthetic vision of products, Design for Sharing should focus on Design for Timeless Aesthetics. A good example to clarify this concept is the famous "Arco Lamp", a product designed by the Castiglioni brothers in 1962, which is still globally recognized as an example of eternal beauty. It is aesthetical qualities, proportions, simplicity, materials and symmetry makes it a timeless product. In the bike-sharing, as emerged from the interviews mentioned above in this paragraph, many users preferred recognizable aesthetics that put them at ease with the object. However, this does not mean they did not appreciate high-tech bicycles, as demonstrated by (9): "Having a hi-tech, advanced bike could incentivize me to use it more." Designers should, therefore, balance a tangible sense of traditionality, simplicity and geometricity with highly functional technology. The integrated technology should be able to evolve with the bicycle, be updated and in the event of malfunction replaceable.

Figure 6.4.1.C. Aesthetics material change in BSS.

Another aspect that must be considered in the Design for Timeless Aesthetics is cosmetic obsolescence. This strategy refers to the user's perception of materials over time (Lilley et al., 2016). Designers should consider ageing of all components' materials, finishing, texture and colors. In products shared by many people and under weather conditions - especially plastic components - may change color, degrade or be vandalized.

Another aspect that the interviews have highlighted is that bright colors increase the discoverability of bikes in the city. Colors can be a very persuasive and attractive tool for users (Muis, 2006). Variation of colors with the use of patterns and good surface finishing of the frame can maintain a more positive feeling of cleanliness (Mital et al., 2014). Designers can test with users' variations in colors and material surfaces to evaluate the acceptance of the bike over time.

6.5. Influencing Symbolic factor

To understand the motivations that push users to sign up, use and become attached to bike-sharing, it is necessary to understand the emotional and symbolic factors influencing BSS. By analyzing different sharing models outside bike-sharing, it seems clear that symbolic and emotional factors are key design strategies. Indeed, it is possible to drive cars like the BMW 2 Series Convertible (DriveNow), experience gastronomic and educational classes (Airbnb), or rent high-end fashion clothes for a few hours (Dress You Can) without spending a fortune to access to luxury products. These examples are by no means always successful models, but compared with bike-sharing, they clearly illustrate the limited offer of it. In many of this cases, the symbolic factor is the strongest reason why the user prefers these products, to experience personal values, to engage actively with others, to try new experiences or simply to use luxurious products (Roy, et al., 2007; Candi et al., 2017). For this reason, greater attention to the symbolic factor in the design of shared systems and products such as the BSS must be provided by designers.

Some design strategies have been defined and described below (Table 6.5.A.). Such framework shows the symbolic design opportunities gather from the literature and interviews in order to provide an initial frame for designers to deal with design for symbolic factors in BSS.

INFLUENCING FACTOR	X^2	X^3	X^4
SYMBOLIC	DESIGN FOR ATTACHMENT AND TRUST	Design for Emotionally Durability	Design for repair relationship
			Design for motivations
			Design for Smart Features
	DESIGN FOR INTERACTIVE EXPERIENCES	Design for Satisfaction	Design for Eco-feedbacks
			Design for Reward
			Design for involvement

Table 6.5.A. Taxonometry of Design for X approaches for BSS in CE context.

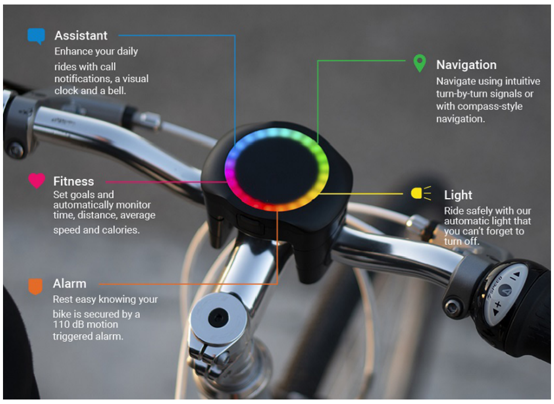
Influencing factor: symbolic.

6.5.1. Design for product attachment and trust (Symbolic)

According to interviews conducted, users are marginally emotionally involved into the overall service experience. As with aesthetics, so with symbolic factors, one possible design strategy is attachment and trust. However, unlike the aesthetic, symbolic approach puts more emphasis on the process rather than the product in order to create empathic and desirable services. When designing for such a strategy, it is important to focus on design for emotions. The concept of emotion in design refers to an individual's alteration of mood in relation to a product or service (Jordan, 2000; Chapman, 2005 and Lilley, 2007). Designers that want to discover potential emotional levers should first consider how habitual and other intuitive behaviors occur to improve the overall customer experience. Looking at the interviews, for example, more than half alleged some kind of issues which, in the long term, might cause detachment. Companies know their weak spots well, a strategy that uses criteria such as Design for Transparency (Verbeek et al., 1998), where they recognize their own mistakes, combined with the design for relationship repair might turn an infuriate user into a forgiving one. This straightforward solution is used in hotels and airline companies when problems occur with rooms or overbookings to better manage customer relationship, ultimately resulting in increased Net Promoter Score (McKinsey & Company). In essence, as highlighted by Spelman (2002), it provides an attempt to repair a "broken relationship" to minimize damage from a delusion.

On the basis of the interviews, it was found that most reasons and drivers for using BSS are economical and practical (2; 4; 6; 7; 9; 10). These motivations are not enough to fully engage and stimulate bike-sharing membership growth. This aspect highlights the need for the designer to digging into the users' subconscious in order to find multiple motivations to prefer the use of bicycle over more polluting means of transportation. For example, interviewee 5 said: " … with the bike sharing, I got back the happiness of riding a bike, stretch my legs, take some fresh air even for short trips. Instead of commuting … inside a subway coach, packed with people in the dark. I rediscovered the pleasure of biking… this reminds me the sense of freedom of when I was a child”. Shaheen, et al. (2010) pointed out several values to encourage and harness intrinsic motivation such as environmentally friendly, promoting a healthy lifestyle, and enjoyable social activity. Designers can use these values to generate strategic communication campaigns that lead to persuade new, irregular or lazy users to prefer bike-sharing (Ceschin, et al. 2010, B).

Figure 6.5.1.A. Smart Halo features.



Another possibility for designers to enhance users' emotional durability is design smart features. As humans, we become naturally attached to technological devices because they make life easier (Chapman, 2005). This principle has been improperly used by many technology companies in a linear economy, often to accelerate the consumption of digital devices to sell more (provoking technological obsolescence). Technology, though, could be applied to create an “upgradable” and “circular” bicycle that simplify, protect, motivate and inform the rider for a better experience. For example, SmartHalo is a tool which connects to a bike's handlebar and helps the rider, through an intuitive light, to guide in the city, as well as being a fitness tracker (Fig. 6.5.1.A.). Users will be safer as they will not need to use their phones, and they can keep healthy and motivated thanks to activity tracking through the bike-sharing company's app, making the service experience pleasant and user-friendly.

6.5.2. Design for interaction

Design for Interaction is one of the most efficient X2 when designing for sustainable BSS (Ceschin, et al. 2010, B). The main purpose of this approach is to fulfil the interactive activities between the user with other users, the provider and the system. Ceschin, et al. (2010, B) claim that designers in the PSS, should contribute substantially to the achievement of satisfaction of the users by creating a comfortable community where users can understand, communicate, cooperate, engage and exchange feelings with one another. Thus, it is important to identify how specific mechanisms can help build engagement. The challenge here is to understand how to create an appealing content to trigger engagement between the different parties involved.

A possible design strategy proposed by Lilley, (2007) is Design for Eco-feedback. This strategy is meant to nudge users in the right direction by informing them about their ecological choices (Lilley, 2007). Today's technology enables massive data harvesting, these data can be filtered and refined from the system to return appealing information. Such information may be used to affect individual riders by monitoring Co2, energy or fuel saved, etc.

A similar design strategy is Design for Rewarding. As shown in the functional factor sphere, this strategy is a powerful design approach to persuade riders in engaging with bike-sharing, but, unlike the above, the mechanics here aim at building a peer-to-peer engagement. For example, in this case, a user X set up a “mission” to reach a Co2 reduction.

Consumption could be calculated by the app in a given timeframe. User X could then invite other users (Y and Z) to join his challenge asking their contribution to reach the target in time. This mechanism, used in many crowdfunding platforms, this could be an idea to stimulate new users to use BSS. The final reward could be a prize that certifying the subtracted quantity of Co2 from X, Y and Z to be shared in social platforms. This "gamification" approach can help designers to produce new stimulus for users.

6.6. Discussion

The chapter discussed above shows that developing a BSS is complex and challenging and whilst many BS systems are in operation, more work is still needed to help realize their potential. In particular around the product design which leads to greater user acceptance. The research has a focus around the work of Homburg, et al., (2015), and this shows how, by adopting functional, aesthetic, and symbolic dimensions, product design can be a key element to analyze, discover and creatively interpret possible solutions to support the circular transition. To help orient designers, the chapter has contributed to product design activity in several ways.

First, the literature was analyzed concerning a more human-centered design approach, which highlighted that the CE literature is often more technical-centered. From a broader perspective, the highly technical evidence on activities such as maintenance, reuse, remanufacturing and recycling in the CE context is essential, however, the aspects of user acceptance is largely missing. In this respect, this chapter engages with societal-human aspects, as the main and usually the most difficult part of the system.

Secondly, this chapter proposed a multidimensional approach to BSS that extends the discussion around design for sharing. This research identified potential directions of BSS in terms of strategies, examples and opportunities to explore and implement bikes, service and the wider system. The same approach could be adapted for other product-services and design strategies.

Thirdly, when designing for sharing, designers should adopt a different mindset. Here, the designer is not designing for selling to a narrow and well-defined target user group, but for a large variety of people across society, who will not own the product. This consideration requires attention to identify products and arousal solutions that will suit the many, not the select few.

6.7. Conclusions

The preliminary question that was set out for this research is "How might designers incentivize user acceptance of bike-sharing systems based on the Multi-hierarchical DfX framework?" Through a review of the literature and the reference of other cross-sectoral case studies, a range of possible design strategies (based on functional, aesthetic and symbolic factors) has been outlined. The results of the interviews in Milan clearly showed significant performance gaps across all three BSSs. Those outputs are not meant to be a comprehensive mapping of design strategies for sharing, but instead, a collection of multiple opportunities that designers can weave and integrate to their projects to incentivize users acceptance in the Use & Operation phase of the Multi-hierarchical

DfX framework (Chapter 5).

In short, this chapter advocates the need for a societal - human consideration when designing for sharing. In existing, linear products, designers have tried to simplify the design process to make it faster and more dynamic. When designing for sharing this approach appears to be insufficient in the circular context, where the designer must consider not only the technical and functional aspects, but also emotional and social factors of users.

Designers have the capacity to create visions that go beyond the status quo in society. But these visions seem limited in the context of design for sharing. In a linear economy, designers have the power to manipulate and change the behavior of customers through shapes, meanings and stories, with the goal of enhancing sales. This approach has led to highly successful (if damaging) globalization, consumption and waste. This chapter outlines how such design power can be harnessed to ensure a low carbon, circular, low waste future, leading to improvements in the way society consumes, behaves, and relates to each other and the world.

Recommendations for further work includes expanding connections with issues around energy, climate, materials, water, food, biodiversity, etc. The selection and analysis of multiple cases, with a statistically representative sample, across different geographic contexts is recommended. Further empirical testing of the change of design in relation to users BSS incentivization is required.

Importantly a number of practicing product designers should be engaged in the future work, along with product design educators to ensure long term embedding.

Chapter 7

CIRCULAR DESIGN CARDS

Synopsis
In the previous chapter it is proposed how to analyze and define DfX strategies in the bike sharing case study to incentivize the use of it. However, it is not always possible to review and explore DfX in such a way. For this reason, this chapter presents the Circular Design Cards, a practice-oriented tool for designers and design educators working with multiple level design approaches in complex contexts. It is described how the circular cards were developed and evaluated during a workshop. The chapter contains an introduction to the cards and describes the structure and content of the individual cards.

7.1. Introduction

Conventionally, design is seen as a completely new craft activity or a project performed by one or a limited design team supported by software or other creative tools. In design teams, it is challenging to have a complete overview of the entire design cycle and to deal appropriately with such an intertwined content and structure of the work (Lutters et al., 2014). This is especially noticeable in the context of CE, where many capabilities that were once separate into silos, now are connected, combined and overlapping more and more (Bakker et al., 2014b; De Los Rios et al., 2017). Keoleian (1994) cites the example of the fire extinguisher for jet airplane cockpits designed by 3M. Although the product was working correctly, it failed to receive a permit from the EPA as it was harmful to fish and other aquatic life. Keoleian (1994) continues by saying that, in only one week, 3M scientists could identify the different toxic chemicals in their first design and found substitutes that were one-fortieth as harmful. After this stage, the product not only was better for the environment but also less expensive to produce. If environmental experts had participated in the design, regulatory actions might have been avoided (Keoleian, 1994). Having a total overview of all the circular design requirements and strategies is complicated, and companies often encounter barriers (Badke-Schaub, et al., 2011). Without proper support, many circular products may fail.

Designers are not yet prepared to meet the transition to a CE (Vezzoli et al., 2008; Preston, 2012) as it is not growing at rates necessary to meet the Global Goals for Sustainable Development in 2030 (e.g., reduce carbon dioxide emissions). Design schools are not providing enough training and exposure to the concept of CE, which remain inadequate. In order to try solving this problem, this chapter presents the Circular Design Cards developed as a physical learning tool to inspire all the designers involved in the product life cycle system. The cards have been developed with two objectives, as an educational and a corporate tool in order to communicate existing real-life challenges and future potentials.

The Circular Design Cards consists of a deck of 30 cards focused on different design strategies to support decision-making for the CE. The cards are not meant to be comprehensive or exhaustive of the myriad of possible design decisions. It is, however, an instrument from which the design team can start developing their design strategies, from a defined set of significant provocations.

The cards can be used to:

- Guide, inspire and create awareness towards sustainability in design processes;
- Frame and bring to life processes and strategies for sustainable thinking;
- Communicate knowledge and values to external stakeholders
- Create a shared understanding of cross-disciplinary teams;
- Reflect on and re-examine existing processes or strategies to identify new opportunities.

7.2. Previous method cards

Commonly, designers use design tools and techniques to search for inspiration to solve problems. Some tools help the design teams to define better an idea (e.g., CAD tools), whereas some others are used to get inspired and facilitate design-decision over the design process (e.g., TRIZ method). Cards can be classified as the latter case. Moller (2014), groups 82 design card decks in six categories: Framework cards (task checklists), Index cards (digests of information or methods), Libraries cards (useful data), Strategy cards (thinking strategies), Grid cards (selection criteria), and Visual inspiration cards (pictorial prompts). Meanwhile, Roy et al., (2019) classify 155 card design tools in 5 types of mechanisms, (1) Creative thinking and problem-solving, (2) systemic design method and procedures, (3) Human-Centered Design, (4) futures thinking, and (5) team-building & collaborative working. The latter seems a more exhaustive classification based on scientific validation – this classification concern with different design methods, from design thinking to biomimicry.

Figure 7.2.A. Circular strategy cards designed by IDEO.

Recently, different circular design cards have been developed by several organizations. For example, IDEO created six circular cards with six strategies, (1) product as a service, (2) product life extension, (3) closed-loop / Take back, (5) Modularity, and (6) Embedding intelligence (Fig. 7.2.A). This deck, for each card, describes the strategy and shows a case study. The Eco Innovators Agency, an Australian design agency, developed a deck of 50 cards divided into three macro groups (1) design strategy, (2) design problems, and (3) design inspiration. Another example of circular cards is from The Agency of Design, a UK based design agency that developed a deck of 30 circular cards. They divide their card into three categories: (1) product innovation, (2) business model, (3), and system-level change. Also, the Design School Kolding in Denmark developed a deck of 25 cards based on six categories (1) Material, (2) Production, (3) Transport and Retail, (4) User and Practice, (5) Recovery and (6) Design and concept.

Roy et al., (2019) argued that card-based tools have some advantages compared to other more pragmatic tools to help designers to engage with new knowledge and to combine overlapping concepts. Unfortunately, most of these cards have been developed by private agencies that did not share their tools at the time this research took place in May 2017. For this reason, it was decided to develop a new deck of cards starting from what was already available at that time.

7.3. Methodology

This study aims to create a tool to educate students and designers to design for the CE and to test the Circular Design Cards with students empirically. The Circular Design Cards are intended as an enabler to better understand the links between different design strategies on multiple levels that might be employed in the ideation phases. Based on this overall objective, a systematic literature review was performed to identify publications offering insights on design strategies for the CE. The search engine used to gathering data was Google Scholar, and the terms used consisted of (a combination of): “Design Strategies”, “Circular Economy”, “Sustainability”, “Design Management”, “Reuse”, “Refurbish”, “Remanufacturing”, “Recycling”. No limitation was provided regarding the non-peer-reviewed studies; this helped to have a better overview of case studies and direct design experiences.

The results were scanned by reading the titles, abstracts, and keywords of the published research. Thirty-two studies were selected based on the relevance with the aim of the research.

Table 7.4.A. Possible design approaches in the CE.

CATEGORY	DESCRIPTION	REFERENCE
System	System is related to the bigger picture. Designers in this category work in the macro area and design multiple flows of designers in complex domains. In this category, the designer can interlink various design approach with the whole.	Pauli, 2010; Midgley, 2011; Baxter et al., 2017; Ordoñezet al., 2013; Tseng et al., 2018; Domenech et al., 2019;
Material	Materials are a key aspect to consider when designing for the CE. The understanding of how materials can enable circularity is fundamental for designers, especially the difference between technical and biological materials. In this category, the designer should define how and where the "Material" flow should be recaptured to start a new flow.	Chen, 2009; Ashby, 2012; Whalen; 2014; Ashby, 2015; Peck et al., 2015; Geldermans, 2016; Lilley et al., 2016; Peck, 2016; Baxter et al., 2017; Hallstedt et al., 2017; Camere et al., 2018
Business	Business are slightly related to materials and design of product. In the CE, through an appropriate business it is easier to keep control on product. In this category, the designer should relate business model with the way products are designed in order to guarantee the reliability and the longest product lifetime possible.	Vasantha et al., 2012; Ceschin 2013; Ceschin 2015; Tukker, 2015; Bocken et al., 2016; Haines-Gadd et al., 2017; Rodriguez et al., 2017; de Pádua Pieroni et al., 2018; Khan et al., 2018
Design	Design is a broader category that encloses specific strategies related to engineering and product design for the entire product lifetime. In this category, the designer should aggregate different design approach to facilitate the reuse, refurbishing, remanufacturing, recycling of the product.	Brezet et al., 1998; et al., 2014; Bakker et al., 2014; Bakker et al., 2014; Bocken et al., 2016; Ceschin et al., 2016; den Hollander et al., 2017

7.4. Findings

After the analysis of the selected papers was completed, the 32 studies were additionally examined to identify a possible basic structure to develop the cards. The papers were divided into four categories that represent the possible approaches a designer should be able to control (Tab. 7.4.A). The structure of the cards reflects the findings of the research and help navigate between cards and subjects during creative sections.

7.5. Design of the cards

A complete overview of all the design strategies is impossible to get

FRONT CARD
Inspiring Case Study

BACK CARD
DfX strategy description

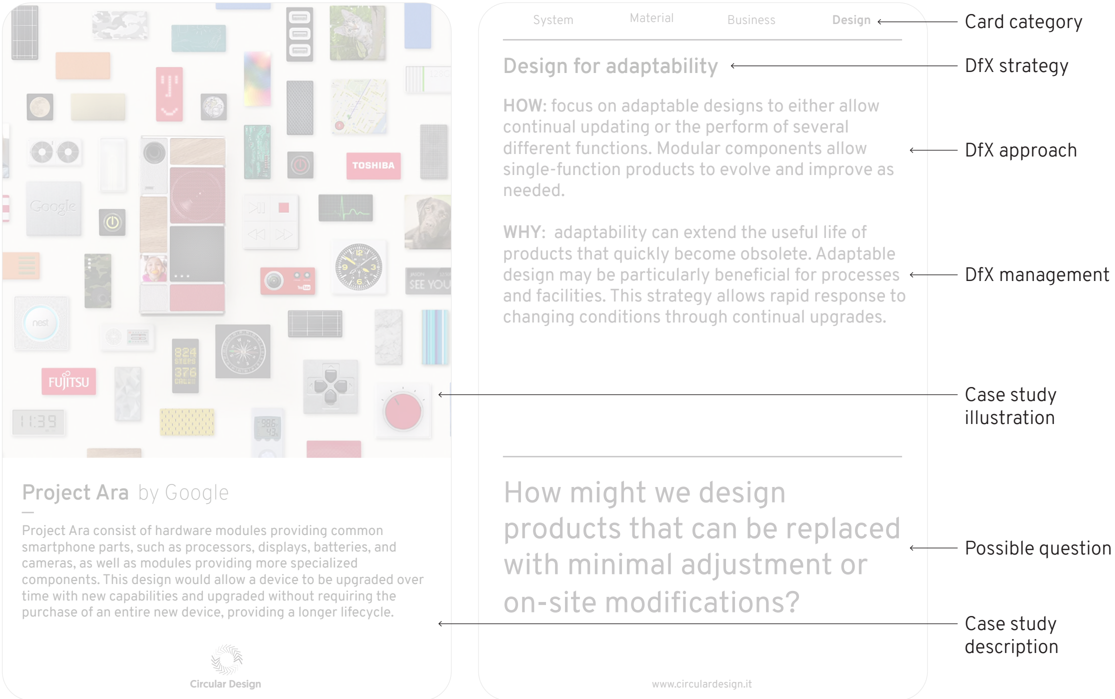


Figure 7.5.A. An example of a card for the approach 'Design for adaptability'.

Figure 7.5.B. Overview of the Circular Design Cards deck.

(Lutters et al., 2014), it was then decided that the cards should touch only some of the many aspects of CE. All the aspects considered were the most comprehensive design approaches described in the literature.

Both sides of the cards were used to include information about a specific design strategy, including descriptions of how to use the design approach, why it is useful, and possible questions that designers can answer when designing for that design strategy. The question was based on the “How Might We” method, developed by IDEO. On the flip side of the card, a big picture with a real-life case example is shown. A card example is shown in Fig. 7.5.A and the overview of the deck in Fig. 7.5.B.

7.6 User experiences with the Circular Design Cards

On Monday the 5th of February 2018, the Circular Design Cards were tested through a one-day workshop with an MBA class at the European Institute of Design in Venice (Fig. 7.6.A.). The class consisted of interdisciplinary students from different backgrounds. Students were divided into two groups of five people each. Based on a design brief, each group developed a concept for a possible sustainable museum for the city of Venice. The participants used the circular cards during the workshop to find out possible solutions by combining different design strategies. None of the participants received an introduction to the cards before their use. After the workshop, a survey helped to enhance the level of understanding and engagement of the cards.

Figure 7.6.A. Various project phases. - Final presentation of the developed project.

7.6.1. Card categories understanding

Respondents were asked to estimate how clear for them was the classification in four categories of the deck (Tab. 7.6.1.A.). The project categories provided flexibility and a proper level of planning for the users. However, as shown in Table 7.6.1.B., not all the respondents understood the overlapping of the different categories; for this reason, the categories section may be changed and improved in order to facilitate overlapping topics connection.

Card category describe the general classification of the areas concerning the single card such as System - Materials - Business - Design. Did you find the classification useful?

Yes, it was clear and useful	8 (80%)
Yes, it was clear but not really useful	2 (20%)
No, it wasn't clear	0 (0%)
I thought it was something else	0 (0%)

Table 7.6.1.A. Understanding the classification of the different categories.

Have you thought to strategically combine the various categories (System - Materials - Business - Design)?

Yes, I thought about that	4 (40%)
I prefered to combine only the same categories	3 (30%)
No, I didn't thought about that	2 (20%)
No, it wasn't clear	1 (10%)

Table 7.6.1.B. Understanding of the various combinatorial categories.

7.6.2. HOW and WHY understanding

In this section, respondents were asked how good the communication of the strategies was related to "how" they could use the strategy and "why" they should use the strategy. Table 7.6.2.A. shows that most of the responses found this section useful, and most of them read all the information (Tab. 7.6.2.B.) carefully.

Did you find the DfX block useful to understand the HOW and WHY you might use the specific strategy?

Yes, it was useful	7 (70%)
Yes, it was clear but not really useful	2 (20%)
No, I didn't understand	1 (10%)
No, it wasn't useful	0 (0%)

Table 7.6.2.A. Understanding the clarity and completeness of the explanation of the strategy .

Table 7.6.2.B. Comparisons between HOW and WHY and the Case Study usefulness.

Did you read the HOW and WHY carefully or did you preferred to concentrate on the case study as a better explanation of the methodology used?

Yes, I found the HOW and WHY really useful	6 (66,7%)
Yes, it was useful but I prefer to read the case study	1 (11,1%)
I preferred to read the case study	2 (22,2%)
Neither of them	0 (0%)

7.6.3. Question understanding

In this section of the survey, participants were asked whether they found interesting and useful the question related to the design strategy. For half of the participants, this section was useful. However, it seems that to some participants, the question did not directly link with their project. This may be a pain point for the development of the tool because it is difficult to stimulate designers in thinking about possible solutions if the question is not strictly related to their project (as shown in Figure. 7.6.3.A).

Table 7.6.3.A. Question usefulness.

Did you find the question related to the DfX strategy useful?

Yes, I found it really useful	5 (50%)
Yes, it was useful not related with my project	2 (20%)
yes, it was useful but too broad	2 (20%)
I didn't find it useful	0 (0%)

7.6.4. Case study understanding

Finally, the last question was about the usefulness of the case study on the flip side of the card. Without any surprise, the case study was the most valuable part of the cards (as shown in Figure. 7.6.4.A).

Table 7.6.4.A. Case study clarity and usefulness.

Did you find the case study clear and useful?

Yes, it was clear and useful	8 (80%)
Yes, it was clear but not related to the DfX strategy	1 (10%)
No, it wasn't clear and useful	1 (10%)
I thought it was something else	0 (0%)

7.7. Conclusions

The Circular Design Cards represent an effort to articulate reliably and effectively design knowledge and skill competencies for circular designers. It provides a mechanism to stimulate the assessment of circular design competences. This study provides preliminary evidence that the tool is reliable and valid for educational purposes by a modest sample of MBA students with little interest and experience in CE.

The deck seems to capture a general level of self-perceived circular competence. With such overlapping complexity, the question arises whether a higher level of detail of this tool is needed. However, it is argued that this minimum level of detail is needed to provide accurate elaboration of the knowledge base and skill competencies that can be useful for those less familiar with circular design practice. Moreover, within circular design courses, cards may help to make distinctions

Table 7.7.A. Overview of all the DfX strategy cards.

Design for **Renewable Energy System**	Design for **Urbanisation**	Design for **Product System Life Extension**	Design for **Operating Lease**
Design for **Pay-per-use**	Design for **On-demand**	Design for **Industrial Symbios**	Design for **Urban Biocycle**
Design for **Collaborative Consumption**	Design for **Dematerialised Services**	Design for **Reverse Business Model**	Design for **Long Life**
Design for **Performanced Based**	Design for **Incompatibility**	Design for **Compatibility**	Design for **Durability**
Design for **Efficiency**	Design for **Adaptability**	Design for **Reliability**	Design for **Maintainability**
Design for **Reuse**	Design for **Dis- and Assembly**	Design for **Energy Conservation**	Design for **Remanufacturing**
Design for **Repairability**	Design for **Technical Nutrients**	Design for **Biological Nutrients**	Design for **Material Cascade**
Design with **growing materials**	Design for **Urban Mining**		

System
Business
Design
Material

among competencies, whereas for use in industrial environments, it needs evaluation and validation. In examining the circular method cards with MBA students, it has been deducted that the complexity of managing strategies from multiple life cycles is a critical aspect of design. Perhaps it can be related to the educational background of students. However, from the emerged data of this study, method cards represent a helpful approach for developing competence and consolidating knowledge for designers. Participants' feedback on the tool was generally positive. Some respondents clearly stated that not all the sections of the card were connected, but others stated that the sections were connected and helpful. At this point, there is not enough concern expressed about the tool's clarity to consider changing it significantly (Fig. 7.7.A.).

Chapter 8

CIRCULAR DESIGN TOOL

Synopsis
The Circular Design Tool is an online platform that helps designers in the management and hierarchization of DfX strategies. Based on the Multi-hierarchical DfX framework, the tool can facilitate and accelerate the understanding of design strategies and the connections between them. The chapter presents an introduction to the tool, describes how it was developed, and the proposed next steps for further improvement.

8.1 Introduction

In a rapidly changing world, primarily due to technology, the industry is becoming increasingly complex. Materials, the variation of manufacturing methods, organizational strategies, the variation of size, shape, or colors for each market, and many other elements make this sector particularly complicated to manage.

This complexity can exponentially increase if the designer is called to consider many loops for a single product and forecast internal and external forces that will impact the product in the future. Therefore, in order to balance design choice between many limitations, constraints, and opportunities, it is essential to understand the systemic perspective for which designers must conceive improvements jointly with stakeholders and other inter-sectorial departments. Within this more extensive view, the design needs to be managed appropriately. This chapter introduces the preliminary study of a Circular Design Tool (CDT) developed during the thesis. The tool is available at www.circulardesign.it.

The CDT has been developed for design teams to support multi-criteria and complex decisions. The tool is designed to be used to cross industrial decision-makers as well as in education to improve the need for multi-criteria decision analysis from the phase “0” of the design process. The tool was developed as an open-source tool available for all, where people can introduce information and connect them across different sectors for the development of circular products. This tool is based on the Multi-hierarchical DfX framework developed in chapter 5.

8.2. Multiple design decisions

In designing for the CE, as it was already made clear in chapter 5, many different design teams have to make different decisions in order to pursue a common circular goal (X^1). In the framework proposed, managers of the design teams at the earliest design process (stage “0”) interact with one another to define a reasonable circular goal for each of the loops the product will have. Different designers should find various solutions for different problems. Even though all the design teams have distinct decisions to take, most of the time, decisions are interconnected between multiple areas. Decisions in this stage of the design process are considered, most of the times, an indication for the next stage.

Additionally, in this phase when designing for multiple loops conflicting design strategies could emerge. For this reason, there is potential the need for a tool that can facilitate the evaluation of possible alternative design strategies and their dependencies on multiple comparative factors. At early design stage, the uncertainty is high, with a simple comparison of multiple sustainable design strategies it is possible to better identify the type of effects, consequences and incidence on cross-sectors, over multiple product life cycles.

8.3. Systemic structure of the tool

Many academics in literature have proposed to organize the design process in different areas in order to keep separate ideas, records, requirements, information, and specific needs of each sector. Knowing how to manage accurately all the possible design disciplines involved in one project for a single person, it is too hard. Sometimes, it is even problematic for teams of designers and experts of a specific sector. However, in a CE, this is a key to designing reliable systems that can get back in the industry to make a new life cycle. For this reason, a systemic architecture where disciplines are connected is needed.

This systemic tool can be based on the product life cycle system model. This model divides the product life cycle into sequential phases in time that can be replicated for multiple loops. The sequence can be useful to understand step by step all the phases that the product pass through (Figure. 8.3.). This solution can provide two advantages, the first advantage is that, by structuring workflow to describe how and when specific DfX can be applied it is easier to fit specific strategies on the specific phase of the product life cycle. Secondly, it is possible to use a unified measure for all the decision-makers involved in the design of the system.

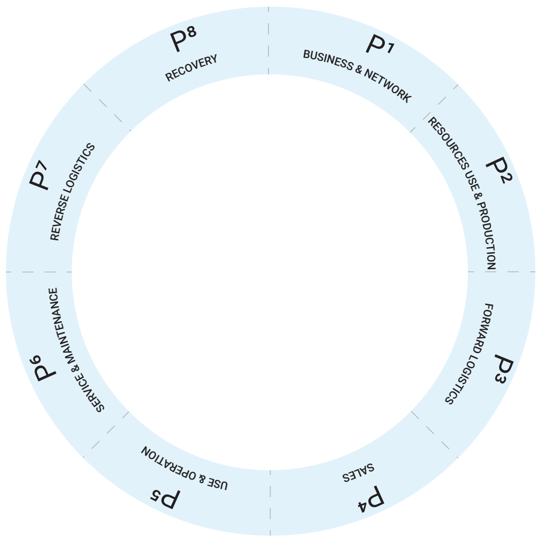


Figure 8.3.A. Circular product life cycle systems.

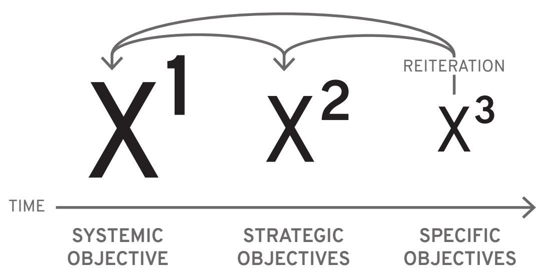


Figure 8.3.B. Strategy hierarchy.

DfX are organized in the hierarchy depending on the degree of circular relevance for each phase of the product life cycle system. As introduced in chapter 5, in the circular economy, only five circular approaches are considered to be circular (X1), Maintenance, Reuse, Refurbish, Remanufacturing, and Recycling. Other strategies are not directly recognized as circular but better definable as sustainable strategies. Starting from the main circular strategies that are also the systemic objective for each loop (L), one or more sustainable design strategies can be described (X2). X2 are multiple and determined in each phase, so it is possible to defined it as the strategic objective of each phase (P). Those strategies are defined in relation to X1, and they will change when X1 changes. Finally there are various sub-related strategy that can be defined as specific strategies (X3) for each phase. This strategies may vary in different circumstances (Fig. 8.3.B.).

CDT is not meant to be a technical tool where designers tasks are accomplished, but instead a tool where designers are free to explore alternative solutions for the design of their circular products or services. The tool can connect different solutions between different phases of the product life cycle system; by doing so, designers can orient their strategic choices. This plethora of multiple perspectives can be recognized as a complex system that should be examined by different domains. A strategic choice approach can be described from three dynamic interrelation - Organization, Process, and Product (Nightingale, 2000). Based on Nightingale (2000), the tool has been developed to optimize and manage cross-functional knowledge coordination. Table 8.3.A. shows the overall view of the multi-dimensional approach of the tool. Each aspect of P focuses on one or more elements of the dynamic correlation - yet none of them can ever be viewed entirely in isolation from the other two.

Table 8.3.A. Organization, Process and Product for each phase of the Product Life Cycle System.

FOCUS	ORGANIZATION	PROCESS	PRODUCT
X^2-X^3 in P^1	✓		
X^2-X^3 in P^2		✓	✓
X^2-X^3 in P^3	✓	✓	
X^2-X^3 in P^4	✓	✓	✓
X^2-X^3 in P^5	✓		✓
X^2-X^3 in P^6	✓	✓	✓
X^2-X^3 in P^7	✓	✓	
X^2-X^3 in P^8		✓	✓

8.4. Development of the tool

The tool aims to help designers to organize the information in a more interactive way compared with the Circular Design Cards. The CDT is implemented as an open-source web service, which manages the different DfX approaches, connects specific design strategies between cross-disciplinary strategies, and stores information about each design strategy on different levels of depth. The tool suggests questions about the specific strategies that designers can use to get inspired and store different case studies for each design strategy. The tool was developed in a simple user interface to facilitate the accessibility to companies and students. Users can explore and read about different design strategies and analyzed which of those strategies can be applied to their projects. The tool is still under development, and the present available tool is an initial prototype (image of prototype Fig. 8.4.A.) However, the final solution should allow the following services:

- Creation of personal projects - companies or single designers can create and save their project on the platform;
- Multiple users. The tool is meant to be a collaborative tool where multiple designers can work and modify the same project. Projects can be public or kept private between defined users;
- Upload design strategies - users can upload in open-source new design strategies; however, they may also need to update on private project-specific design strategies, these strategies will not be shared;
- Scientific based - strategies should be rigorously scientific-based, and an essential reference should be available at the end of each strategy;
- Save mode. Designers can save their projects online, and all the information will be kept with their user account.
- Links between and across phases. Links between and across different phases should be differentiated based on the relationship and importance of strategies.
- Strategies organization. The tool can organize strategies and links based on different factors and assign personal tags to facil-

itate the understanding of relationships between strategies and links. These features could help designers simplify the understanding of the work magnitude.

Figure 8.4.A. Current viewing ot the prototype.

First basic visualization of the tool is available below, Fig. 8.4.B.

Figure 8.4.B. Final visualization of the tool (this image is for illustration purpose only).

8.5. Conclusions

This chapter has attempted to provide an overview of the CDT for supporting designers while exploring new possibilities for systemic design approaches. Many examples suggest that design exploration for new design strategies can be beneficial for designers; the main challenge may be in how to access the information needed to use circular strategies effectively and favorably, other than through difficult-to-access databases. Hence an alternative, introductory interactive-based, and open-source tool have been introduced.

The essential aspect of this tool is the introduction of links between phases. Indeed, no designer can fully understand the complexity of decision-making during the design process. By suggesting links between different DfX strategies and by simplifying the visualization of such connections, it is more manageable for designers to remember and quickly understand the correlation of strategies.

Chapter 9

RECAPITULATION OF THE RESEARCH AND EVALUATION WORKSHOPS

Synopsis
This chapter summarizes the findings and tools of the research and introduces a new workshop method for lean circular design management in product design. Observations from the comparison of two workshops with lean principles led at the University of Venice, helped the research to further development and definition of the Circular Design Workshop. This final workshop may help designers to manage circular design strategies better.

9.1. Introduction

Despite its potential Lean Product Development (LPD) or 'Lean Design' has received little attention in the CE compared to research and application of LPD in other sectors. Mainly, the focus of this process seems to be centered on the PSS (Romero et al., 2017), hence only on the first stage of the product life cycle design (Business & Network). This chapter attempts to generalize the integration of multiple design perspectives with a lean design methodology to facilitate the improvement of decision-making for the CE. More specifically, this chapter focuses on how to accelerate the achievement of multiple product life cycles and economic benefits by using a lean design approach.

The LPD is a methodology developed by Takahiro Fujimoto, W. Bruce Chew, and Kim B. Clark in 1987 in their study Product Development in the World Auto Industry. The study was the result of an analysis of 22 international car projects between America, Europe, and Japan to investigate engineering hours and lead time (Clark et al., 1987). The comparison of the different design approaches led to the discovery that Japanese car companies and their engineers were able to optimize the design process with greater variety, higher quality, and lower cost compared to competitors (Netland et al. 2016). This was only possible, according to Clark et al. (1987), thanks to the overlapping design process, reduced complexity, and increased collaboration between multifunctional teams. After Product Development in the World Auto Industry publication, the "Lean Thinking" become a massive field of research and experimentation (Rossi et al., 2016b).

In LPD, five lean principles guide product development:

1. define value for the customer;
2. identify the value stream;
3. create flow by eliminating waste;
4. establish pull;
5. seek perfection.

Worldwide, many private and public sectors have applied the same principles (Comm et al., 2015; Blazer, 2010; Blazer et al., 2016), not only to make the design process more efficient but also to motivate the individuals involved. Bretschneider et al., (2011) described eleven motivational factors of the lean design approach: fun, intellectually stimulating, altruist, reciprocity, recognition, self-marketing, identification with the organizing firm, product improvement, need, learning and contacts to peers. The same motivational factors can be used in creative environments to increase interest and fast learning in the circular design, also because designing for the CE means being able to handle different knowledge of widely different topics (Moreno et al., 2016). Thus, recognizing the complexity and urgency for better solutions for the CE in companies, as well as, in training designers in all kind of education (not just schools), this chapter will present a theoretical foundation to develop a lean workshop to tackle critical design problems and come up with viable solutions within five days.

9.2. Participant Selection

The participants of the research were students from the University

Iuav of Venice. All the students involved are currently studying product design or communication design, and they are from different grades except for first-year students. The design student populations were chosen based on two factors. The first is related to the difficulties experienced by the author of this research at organizing workshops with companies. Students were also preferable as their minds are generally less biased compared to more expert designers.

9.3. Methodology

A qualitative approach analysis has been used in this chapter. According to Auerbach et al., (2003), "The qualitative approach to research design leads to studies that are quite different from those designed using the more traditional approach. The traditional approach, often referred to as quantitative research, leads to hypothesis-testing research, whereas the qualitative approach leads to hypothesis-generating research". The specific qualitative approach used was the phenomenological research. The main objective of the approach is to describe the nature of the particular phenomenon (Creswell, 2013). In general, two broad questions are answered by research: What have you experienced in terms of the phenomenon? And, what contexts or situations have typically influenced your experiences of the phenomenon? (Creswell, 2013). The phenomenon research was used because the main focus of this chapter was to gather data regarding the understanding of participants about the phenomena of multiple perspectives in the CE to create a new, more structured framework to accelerate the transition to CE for future and present designers.

Workshops are used among different designers and decision-makers to find creative solutions, explore new concepts, and testing new design ideas. Through the use of conversations and specific exercises, a team of people who hold different perspectives can generate novel and valuable insights (Kumar, 2012). During the workshop, many different points of view are shared, and the interaction and mutual understanding between different parts can lead to higher-level insights that speed up the identification of systemic problems and their resolution. This study used the Google Design Sprint (GDS) as a good starting point from which to explore how participants in a workshop can develop a circular product that takes into consideration all the multiple design perspectives needed to achieve as truly CE.

GDS is an LPD approach developed by Google Venture and applied internally from Google product teams and many of its stakeholders. Knapp et al. (2016) described how the workshop had been developed based on the viability of the new business, mobile apps, to improve products with millions of users, to define marketing strategies, and many other challenges. Many tasks are organized along five days; for each day, the design team has a goal to accomplish: Understand, Diverge, Decide, Prototype, and Validate.

Day 1 - Understand: Participants evaluate the problem they are trying to solve, the personas they are designing for, and the form factor they are going to use.

Day 2 - Diverge: Participants are encouraged to let go of all their presumptions and engage in different activities to generate as many ideas as they can, regardless of how feasible or far-fetched they are.

Day 3 - Decide: Through different activities, participants decide which ideas to pursue further.

Day 4 - Prototype: Participants rapidly sketch, design, and prototype their ideas, concentrating on specific pain points identified previously. The aim is to validate the ideas that came out during the workshop.

Day 5 - Validate: Participants put their product in front of users and encouraging them to touch and test the product giving possible feedback.

It has been assumed, based on the structure of the workshop just described, that the GDS is one of the most incisive workshops which includes multiple design perspectives and helps to lead the focus of designers from multiple design problems to a coincided challenge. The final objective of the research is to identify a possible "lean" approach in the form of a workshop, to accelerate and facilitate the transition to the CE for designers with multiple design perspectives.

9.3.1. The research procedure followed for the final Circular Design Workshop

In order to expose designers to the CE and create a collaborative environment, a special workshop has been created and named Circular Design Workshop. In principles, the Multi-hierarchical DfX framework represents the way designers can manage design strategies, whereas the Circular Design Workshop together with the tools the way they accelerate the CE. For this reason, this chapter summarizes and connects previous chapters with the creation of the Circular Design Workshop. The workshop can be summarized in five phases, shown in Tab. 9.3.1.A.

Phase 1: Research planning and exploration of key dimensions of design for CE

Accordingly to the Ellen Macarthur Foundation, (2012), designers should able to control four main key elements when designing for the CE:

- Design out waste: In a CE, waste is intentionally designed out. Biological materials are non-toxic and returned to the soil while technical materials are designed to be recovered, minimizing the energy input required and maximizing the retention of value;
- Build resilience through diversity: Diversity is valued as a means of building resilience, balancing efficiency and adaptability;
- Shift to renewable energy sources: The energy needed to fuel the circular economy should be generated using renewable sources, thus decreasing resource dependence and increase systems resilience;
- Think in systems: In a CE, systems-thinking is applied broadly, considering the system dynamics between businesses, people, or plants, how they are linked, and respond to each other.

Table 9.3.1.A. Circular Design Workshop development process.

Stage	Activities	Date	Phase
SYNTHESIS OF RESEARCH	• Literature review • Planning of research methodology • Synthesize of the research throug a presentation and design strategies cards • Analysis and selection of a LPD method - Design Sprint	May 2018	**PHASE 1** Research planning and exploration of key dimensions of design for CE
WORKSHOP 1	• Refinement of Research Workshop 1 output • Further literature review • Presentation of the research PSS, obsolescence management and circular design strategy literatures • Presentation and use of case studies throug the circular cards	June 2018	**PHASE 2** Workshop 1 with integration of Circular Cards
ITERATION AND SYNTHESIS OF THE RESEARCH	• Extension of the literature review based on the interation of workshop 1 for refinment of workshop 2 • Re-synthesize of the research throug a presentation and the Multi-hierarchical DfX framework. • Modification of the Design Sprint based on research and presentation	May 2019	**PHASE 3** Iteration and extension of the research
WORKSHOP 2	• Application of the framework in the participant • Analysis and observation of participants' behavior • Data collection and analysis after the workshop • Presentation and use of case studies throug the circular design tool	September 2019	**PHASE 4** Workshop 2 with integration of Multi-hierarchical DfX framework
FINAL CONCLUSIONS	• Final analysis • Areas of opportunities	November 2019	**PHASE 5** Final iteration

Based on these points and after an extensive literature review, four other sub-elements were defined to link different circular case studies: systems, materials, business, and design (Table 7.4.A.). The first categorization of the research was used to create an initial presentation to fixing all the essential information during the research. A second categorization was used to define the multiple design perspective that the designer should consider during the design of a product. Because this chapter aimed to understand how to integrate with agility multiple design perspectives to develop circular products, an additional literature review on workshops and other agile methods was performed. The final decision fell for the GDS workshop method. The GDS was considered the most appropriate approach designers can use to tackle the "circular" complexity and create alternative solutions.

Phase 2: Workshop 1 with integration of Circular Design Cards

During the first workshop, the GDS method was followed accurately, as described by Knapp et al. (2016). GDS was run in order to verify the participants' understanding of critical elements of the CE, and how they could solve significant and systemic problems in a limited time. Four main elements have been introduced to the participants through a presentation (Appendix A): design out waste, build resilience through diversity, shift to renewable energy sources, think in systems (Ellen Macarthur Foundation, 2012). Moreover, the other four sub-elements: system, materials, business, and design, have been introduced in the form of cards to the participants. For each card, a case study was described in detailed. The case studies description tried to integrate various PSS approaches (bringing mixed case studies for different business model strategies), materials usage (with case studies related to technological materials, and biological materials), and design strategies (introducing specific design strategy that can prolong the life cycle or increase the quality for multiple cycles of the product) (Chapter 7). The cards consist of a physical deck of 32 cards/strategies (Fig. 9.3.1.A.) and cover the micro-level, meso-level, and macro-level. Participants could use the cards throughout the entire workshop.

Figure 9.3.1.A. Circular design strategies cards during the Workshop 1.

Twenty-eight participants took part in the workshop and were divided into five groups. For each group, it has been assigned a different project, and five days to complete it, they had to rely on their knowledge and capabilities based only on the presentation on the first day and the Circular Design Cards tool. During the workshop, a facilitator helped the groups to keep the schedule and explain each step of the GDP. The facilitator was allowed to help the participants only if required from the group or individuals. The project and the outputs of the workshop 1 are presented in Appendix B. During the workshop, observation and systematically watching of the participants' behaviors and their way of thinking was monitored and annotated in a research journal (Bailey, 2007).

Phase 3: Iteration and extension of the research

In phase 3, the observations were analyzed together with the feedback of the participants (Appendix B). During the workshop, the different groups were observed to understand how well each task of the workshop worked. The output of the workshop for each task was recorded in the observations. Last, a series of questions have been prepared to evaluate each project and the workshop structure systematically. These were the following questions:

1. Has the product been looked at under multiple design perspectives? How?
2. Did the participants consider multiple product life cycles?
3. Were the participants able to integrate different strategies?
4. Did the participants understand the different design strategies required for each product life cycle?

Answers to these questions were collected for each product designed by groups (see Appendix B). Based on the analysis mentioned above, further analysis of the literature was performed.

In general, it has been observed that participants were, most of the time, focused on the first life cycle of the product, assuming that the consecutive product life cycles were identical to the first one. This may seem not self-evident from the final products presented during the last day of the workshop, or their self-evaluation in the survey, however, data gathered on the spot clearly illustrate this gap. The next paragraph will present a more detailed elaboration on this subject, especially confronting the first workshop with the second. From this first consideration, a new set of studies has been planned and completed. In order to tackle the main gap and other minor gaps uncovered during the workshop, a new framework that could help designers achieve a better circular design has been formulated, the Multi-hierarchical DfX framework (Chapter 5). Based on this new framework, a new tool has been developed and named Circular Design Tool (Chapter 8). Accordingly, with the new sets of instruments, the presentation (Appendix D) and some of the tasks of the GDS workshop have been modified to accommodate the Multi-hierarchical DfX framework (Appendix E) better.

While in the next section, phases are explained in greater detail, the main changes to the workshop were in the structure so to highlight the time dimensions and the application of different design strategies for each time horizon. For this reason, the structure of it followed three points, and for each point, different sub-elements were divided into problems and solutions:

- Product-resource Efficiency
  - Problems
    - Increasing of materials consumption
    - Increasing resources demand
    - Consumption, surplus and recycling rate
  - Solutions
- Resource efficiency

- Product-service System
  - Problems - Planned Obsolescence
    - Aesthetics obsolescence
    - Social obsolescence
    - Technological obsolescence
    - Economic obsolescence
  - Solutions - PSS
    - Product-oriented service
    - Use-oriented service
- Result-oriented service

- Circular Product Design
  - Problem
    - Linear economy
  - Solutions
    - Maintain
    - Reuse
    - Refurbish/remanufacturing
    - Recycle

For each point above, a case study was outlined so to give a more comprehensive overview of the CE to students. A new important topic has been introduced in the presentation, such as product obsolescence, considered a cardinal point of the circular design to understand why and when a product becomes obsolete. This can help the designer to manage the maintenance better and recovery process, such assessments are essential to define from the early stages of design (den Hollander, 2018).

Phase 4: Workshop 2 with integration of Multi-hierarchical DfX framework

In phase 4 of the research, a modified version of the GDS workshop was run (Fig. 9.3.1.B.). In the second workshop, 27 students participated. Like the first workshop, the participants of the research were students from the University Iuav of Venice, from different grades except for first-year students. All the students were at that time studying product design or communication design.

As anticipated, to facilitate the systemic understanding of the CE and how to manage the different design approaches, it was decided to change some of the tasks presented in the GDS workshop. The following

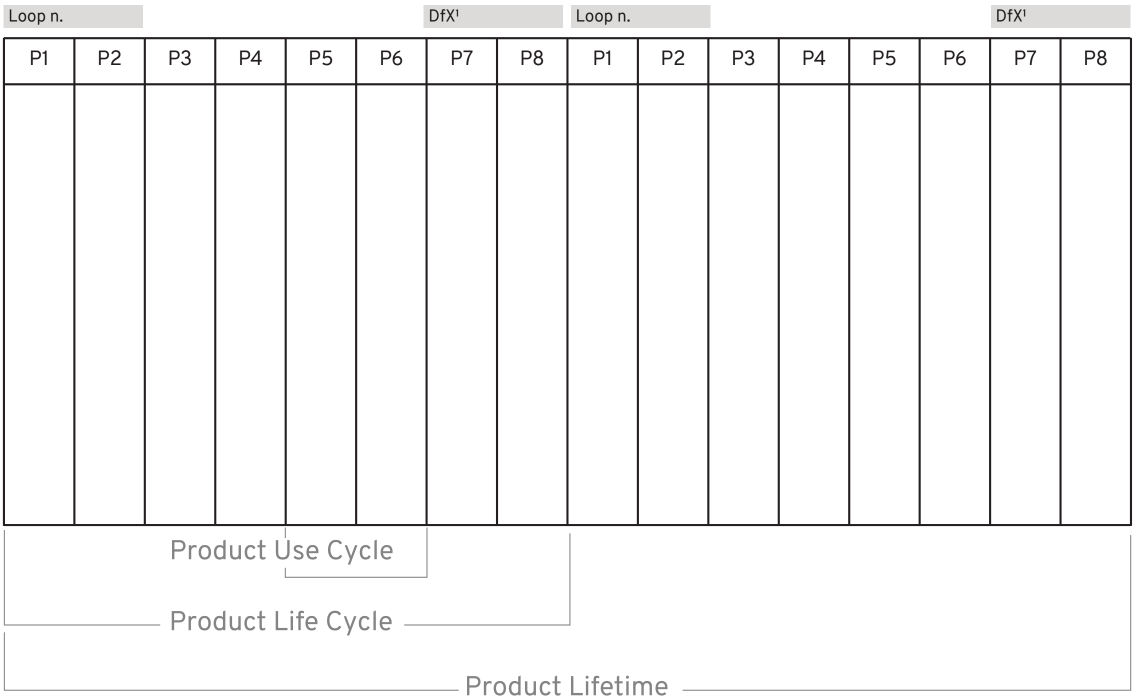
Figure 9.3.1.A. Participants working during the Workshop 2.

are the most significant changes:

Day 1

- It was introduced the Whole System Design exercise (Menter, 2011). This is a method used in the Autodesk Sustainability Workshop to define the broader overview of the user and stakeholder needs through the illustrations of all key phases of the current life cycle of the product.
- Consequently, the participants should map the current social and behavioral phenomena to understand what make a product obsolete.
- Consequently, the participants should decide how many product use cycles they want to achieve, concerning the product typology.

Figure 9.4.B. Product Journey Map.



Then, it was introduced a product journey map, where the participants could better discuss the product lifetime, having a step-by-step timeline. Based on the multi-hierarchical DfX framework, the journey map is composed of eight straight lines that represent each phase of the life cycle system, which includes one product use cycle (den Hollander et al., 2017). At the top of the product journey map, the participants should write the loop number with the main strategy (DfX1) for each product life cycle in order to have the total overview of the product lifetime (Figure 9.4.C.).

Day 2

- In the CE, especially for some products, the product lifetime may be up to fifty or even more years. For the design team, it is essential to understand how external factors will influence the product to anticipate possible bias of the future. For this reason, it was introduced the horizon-scanning methodology (see Chapter 5)

A different protocol of the first workshop was observed during the second one, also it has been introduced a new tool in this workshop, the Circular Design Tool (Chapter 8).

During the workshop, notes were taken by the researcher; then, students were asked to fill out a survey and an analysis with almost the same questions of the first workshop.

Phase 5: workshops and tools evaluation

Both the workshops were evaluated and analyzed equally based on the same questions listed in phase 3. Based on this analysis, an additional literature review has led to a better comprehensive understanding and final results and conclusions.

9.4. Final analysis

This chapter illustrates the analysis and data gathering over three years of work synthetically. Through time, overlapping data had to be collated from different activities (i.e., observation, expert feedback, workshop participant feedback), analyzed, reflections/insights were noted down, and synthesized. Based on these reflections/insights, two tools, a modified lean workshop from GDS and a collaborative framework, were released. All the outputs were tested and improved until the end of the doctoral period (November 2019).

Workshops are mechanisms of creation and essential instruments for all the designers who should solve problems creatively, in order to make a better and more informed decision. This chapter aimed to understand how multi-design decisions might be integrated into an agile and fast process to develop circular products. The result from the first workshop shows that with the GDS and a pilot presentation, participants were able to design the concept of exciting concepts. However, three points were generally missing: most of the time, students were concentrated on the first life cycle of the product, assuming that the consecutive product life cycles would be identical to the first one. Consequently, they were not able to create cross-system, cross-loop, and multi-phase perspectives over multiple product life cycles. Last, they could not plan the product with multiple users' perspectives for each of the product life-cycle. Whereas, participants of the second workshop, thanks to the changes made in the GDS workshop, could better understand and make more informed decisions. Even so, the observations during the workshops demonstrated that students engaged more often with the Circular Design Cards instead of the Circular Design Tool. This can be justified because the cards are a physical tool that is simple to use during a collaborative workshop.

Overall, it can be affirmed that the GDS was a good base on which to test and verify direct feedback from the users through the use of prototypes. In general, students were excited and happy about trying this workshop. Also, they were able to see the value of it with their eyes through the prototypes. Nevertheless, they were also concerned with the limited time available for each task, probably because they are not used to work with such high frequency. The lean process has shown some advantages and disadvantages. For instance, it was good to have a real and testable prototype after only 5 days of work. To conclude the final analysis, some areas of opportunities are listed in Tab. 9.4.A.

KEY ASPECT	DESCRIPTION OF THE AREA OF OPPORTUNITIES FOR A "CIRCULAR" WORKSHOP
Informed decision	Designer should be able to distinguish between product lifetime and product time cycle when designing.
Informed decision	Designers should be able to have always the "big picture" under control when designing for multiple life cycles.
Informed decision	Designers should not tend to generalize according to their time when they are defining pain points by having a systemic perspective.
Informed decision	Designer should know why and when a product can get obsolete to forecast the obsolescence and try to get back the product before it and up in the land field.
Vision	Designers should be able to define for each product life cycle the right customer, and this may change over different time horizons.
Vision	Designers should know what and how innovative technologies will influence their product for each product life cycle.
Systemic decision, collaboration between multiple design perspectives	Designers should know the difference between systems, peers and loop in order to apply cross-system, cross-loop and multi-phase perspectives over multiple product life cycles.

Table 9.4.A. Areas of opportunities that researchers can use for the development of more circular focused workshops for the future.

9.5. Conclusions

This chapter reported the results of the qualitative research, which was undertaken to test and improve the GDS workshop. Based on the results of the research, an evaluation of the workshop for the design of circular products was carried out to assess whether participants could effectively understand CE and how to design for it and whether multiple design perspectives are effectively shared. The final results of this work have revealed that the GDS is a good starting point, but with some modifications of some initial tasks, designers could better understand how to design for multiple life cycles. However, this cannot be considered a final workshop framework because even in the second workshop, participants had trouble understanding some parts of it. Nevertheless, it can be considered a good starting point to iterate and seek a better and more suitable workshop framework for designers.

Chapter 10

FINAL CONCLUSIONS

Synopsis
Findings of all previous chapters are summarized and combined, organized by research questions. In this chapter results are discussed and presented in summary form to offer a general overview of the thesis. Limitations of the study are discussed, and directions for future research are suggested.

10.1 Managing design strategies for the transition to CE

The CE represents a viable alternative to the traditional linear economy to preserve valuable resources in the system, by decoupling economic growth and development from the consumption of finite resources. In the CE, resources are seen as financial capital that needs to be protected and managed to generate multiple cash flows. As it was already showed, by designing better products to meet the requirements of multiple product life cycles, businesses can extend the product lifetime as well as profitability. The transition to a CE, not only involves the redesign of products, but also industrial processes, behaviors, legislations, society, and all the stakeholders involved within systems. However, the design of products plays a pivotal role in the transition to a CE because it can directly affect the characteristics of the physical product as well as the structure of the value chain (De Los Rios et al., 2016).

The thesis explored and defined how multiple design perspectives might be used in a systematic way to take into consideration the bigger picture and how to design across two main systems, the PSS system level and the product-level. The thesis took as its starting point the differences between linear and circular to offer a comparative perspective of the current and general modus operandi of economy, and the opportunities available for the entire system in the transition to CE. This broad view helped the author to understand and develop a scientific theory in order to open the dialogue to the dynamics of complex problems, solutions, and change for the better. Then, the thesis has been developed and discussed in different chapters to answer the following questions:

- What would be a comprehensive design framework that supports multiple design perspectives throughout the design process for effective circular products, thus accelerating the circular economy? (Chapter 5)

In order to defend and demonstrate the main research question, this thesis systematically addresses the following sub-research questions:

- How could a multitude of heterogeneous decision-makers (designers) and their strategies be organized for a collaborative design approach in the context of CE? (Chapter 3 and 4)

- How can design strategies be systematized and organized more efficiently to help designers to cope with cross-system, cross-loop, and multi-phase perspectives over multiple product life cycles? (Chapter 7 and 8)

- How might multiple design perspectives be integrated into an agile and fast process to develop circular products? (Chapter 6 and 9)

This chapter begins with the presentation of the main conclusion of the study in answer to the main research question. Section 10.2 then presents the findings that have led to and support this main conclusion. Section 10.3 presents the empirical research findings of this thesis. Section 10.4 discusses the scientific contribution to the field of design sciences. Section 10.5 presents the limitations of this thesis, whereas section 10.6 suggests possible future research. Finally, section 10.7 provides the closing remarks for this chapter and the thesis.

10.2. Main conclusions

To answer the main research question - "What would be a comprehensive design framework that supports multiple design perspectives throughout the design process for effective circular products, thus accelerating the circular economy?" - This thesis argues that, in order to support the development of an effective circular product, a multiple design perspective approach should be accepted and embraced to manage interconnected problems better and dynamically control possible solutions, and at the same time, to balance the multiple requirements for multiple product life cycles. In order to enable many designers to manage this complexity, this thesis presented a new circular design framework named Multi-Hierarchical Framework that can help designers to:

- Define Multiple Circular Goals (X^1). This should help decision-makers to define a mutual goal for each product life cycle. Starting from the definition of each circular goal for each loop (L) can help decision-makers to structure the strategic approach of the company.
    - Define the circular value. X1 represents the main strategy the company uses to define its circular approach; here the company defines the circular value for each L.

- Define phase-specific goal/s (X^2). It should be possible for design teams to define a phase-specific design goal/s to fulfill all the defined multiple circular goals. Each specific sector takes care of a specific part or process of the product, for each sector, other sub-sectors may be present (X^3). X^2 may change over different product life cycles. The identification of X^2s and X^3s may be directly or indirectly related. Defining this relationship may help the company to define opportunities as well as conflicting design solutions.
    - Prioritizing objectives. By understanding connections between different goals, it is possible to prioritize objectives, hence investments at specific levels.

- Definition of the product horizon (L). It should be possible for the company to understand how many life cycles the product will last. Based on the product horizon identification, the company may define specific users, markets, stakeholders, geographic contexts, and time contexts for each loop.
    - Define multiple customer segments (P^5). This should help to define different customer segments for each loop (L). Here, designers should define how the product can be useful, desirable, and usable for each L defined.
    - Define stakeholders (P^1). It should help to visualize where and when a product should move from a phase to another phase of the product life cycle system. In doing so, decision-makers can define the best stakeholders with whom

to collaborate for each L. This decision depends on the customer segment, market, geographic context, and time context.

- Define sales channels (P^4). It should help to define different channels through which the product can be sold for each loop (L). Here, designers should define what the product touchpoints are and how the customer segment should be reached for each L defined.
- Define relationships (P^1 - P^6). It should help to define how the product can be maintained and how the service can be delivered. This phase is also connected with P^1, where business designers should define the best partners with whom to collaborate.
  - Define resource use and production (P^2). It should help to define how the resources can be maximized to last as much as possible within the technical cycle. Also, it should help to achieve the inertia principle (Stahle, 2010).
  - Define forward and inverse logistic (P^3 - P^7). It should help to define the key activities to moves materials, components, and products during the different design loops.
- Define recovery (P^8). It should help the company to understand how the product can be recovered. Here the challenge is to define whether the loop shall be open or closed.
  - Define networks. If the loop is open, it should define whom the stakeholders to collaborate with to recapture the value first created. How this value flows? What is the company revenue out of this stream? When does the recovery take place?
  - Define networks. If the loop is closed, it should define who the stakeholders who will collaborate to give back the value are. How will the company control the value for each L? When will the recovery take place?

- Mapping. It should help to map design strategies between cross-sectoral approaches over many loops (Ls). This can help the company to point out which combination of options can be used to reach multiple X1s.

10.2.1. The Multi-Hierarchical Framework

The Multi-Hierarchical Framework introduced in this thesis allows a multitude of designers to collaboratively define the path of the product life cycle, phase-by-phase, and cycle-by-cycle. A better and more controlled design approach not only could enhance the circularity of the product but could also evaluate the business feasibility from the early stage of the design process. The potential of the Multi-Hierarchical Framework lies in the fact that all the main decision-makers should agree to defined and design for the same circular objective (X^1). This new and functional modus operandi drives individuals that are usually in different silos to identify decision opportunities and create alternatives together.

The Multi-Hierarchical Framework was developed based on established key concepts such as the Product Life Cycle System, Design for X, Product-Service Systems, inertia principles, managing planned obsolescence, and many others. Thereby, the framework can facilitate the integration of all these concepts that usually are related to specific disciplines, and can generate discussions for the identification of any problem and solution from an early stage of design. The framework was designed to aggregate strategies in both the concepts, the circular and sustainable approaches. In fact, in literature often the concept of sustainability is divided from the concept of circularity. In this thesis, instead they are considered to be part of a unicum visions, where the two concepts enhance each other (Geissdoerfer et al., 2017).

10.2.2. How the Multi-Hierarchical Framework can accelerate the CE

As Govindan et al., (2018) highlighted, many internal and external barriers are preventing a fluid transition to the CE. For example, it is difficult for companies to manage product quality throughout the life cycle of the product, design challenges to reuse and recovery, take the right decisions in the supply chain to implement the CE most efficiently, lack of CE skills by employees in SC, poor leadership and management towards CE in the supply chain (Govindan et al., 2018). Effectively managing the CE requires thinking at a system level, the Multi-Hierarchical Framework can help, as it was demonstrated with the bike-sharing case study, to frame with different levels of detail the approach a company can decide to take. The design and redesign of products that can fit in the CE are a vital and perhaps the most critical activity to accelerate the transition to CE, to accomplish this activity in the best way, it is essential to organize and structure ideas about technology, organization, process, and product, as proposed in chapter 6, 7 and 8. Furthermore, planning processes where different designers can discuss strategic issues through different time horizons should be promoted in academia as well as in the industrial sectors now more than ever, as also suggested by McDonough et al., (2010), Bakker et al., (2014), den Hollander (2018). In this scenario, the Multi-Hierarchical Framework can help to adapt and combine established strategies, or making a myriad of spontaneous adjustments to the different challenges of the CE, ultimately, accelerating it.

10.3. Finding leading to the main conclusions

The main conclusions were derived from the analysis of the sub/research questions, which are described below.

10.3.1. Sub-research question one

The sub-question: “ How could a multitude of heterogeneous decision-makers (designers) and their strategies be organized for a collaborative design approach in the context of CE?” was answered in chapters 3 and 4.

In chapter 3, two issues of a general nature concerning the questions “what the designer looks at?” and “how the designer looks at it?” in the context of CE were tackled. Based on a literature review, four systems-level were introduced and explained, Socio-technical system level, Spatio-social level, Product-service system level, and Product level. Only the Product-service system level and Product level were then studied in detail through the use of the product life cycle system concept. All the designers and their activities at each phase of the product life cycle system were outlined.

Chapter 4 presented a general overview of design strategies and how designers can use them to enhance circular actions between different material flows. Based on a literature review, the main objective of this chapter was to understand and define a common language between many different design categories and disciplines. It has been decided to use the term Design for X, a general term used already in many engineering and business disciplines.

In order to summarize the findings of these chapters to answer the sub-research question one, the following conclusion can be outlined:

- A multitude of heterogeneous decision-makers (designers) may be organized based on the system level they influence. However, as showed throughout the thesis, designers cannot be grouped into rigid perimeters due to multiple factors such as career level, expertise, sector, etc. Furthermore, the thesis highlights that it is possible to organize designers on the base of the product life cycle system, where within each phase, one or more designers can collaborate as long as an overall goal is set. Even in this classification, it is not possible to define a hard border between disciplines where designers shall move within.
- DfX is a common categorization of design strategies that can be used for different design disciplines. This categorization is largely used in many disciplines, such as engineering, business, and product design. Based on the literature, this general and simple definition of DfX can be easily adaptable to a large variety of disciplines.

10.3.2. Sub-research question two

The sub-question two answers the question: “How design strategies can be systematized and organized more efficiently to help designers to cope with cross-system, cross-loop, and multi-phase perspectives over multiple product life cycles?” This question has been answered in chapters 7 and 8.

Two different tools that have been developed during the thesis. Both the tools are based on design strategies and are an attempt to organize multi-phase and cross-phase strategies. The main difference between the two tools is that one is a physical deck of strategy cards, and the other is an online tool.

In order to summarize the findings of these chapters to answer sub-research question two, the following conclusion can be outlined:

- To help designers to cope with cross-system, cross-loop, and multi-phase design strategies could be useful to visualize connections and the relative relevance of the connection between design strategies.
- The organization of information and understanding of the impact of design strategies on other disciplines/phases is vital. In the two workshops described in chapter 8, the approach by participants to the tools has been different. Participants in the first workshop,

where the cards were used, have used the tool much more compared with the online tool. Perhaps, it might be because the online tool is too complicated with much overarching information that may require too much time to grasp. So, the strategy can be organized in different ways for different situations.

- The online tool, because it is flexible and interactive, gives much more information and shows connections and relations between strategies. This tool can be useful for a designer to discover opportunities and better understand cross-system, cross-loop, and multi-phase connections between design strategies.
- Design strategies can be organized in different categories. For each design perspective, the categorization can highlight different connections and information. This can only be implemented in a digital format because of its interactive nature.

10.3.3. Sub-research question three

The sub-research three answers to the question: "How multiple design perspectives might be integrated into an agile and fast process to developed circular products?" This question has been answered in chapters 6 and 9.

In chapter 6, an analysis of different design strategies used for three different bike-sharing systems in the city of Milan has been made. In this chapter, a deep focus on Phase 5 (Use & Operation) of the Multi-Hierarchical Framework has been presented to show how through the analysis of varied design spheres such as the aesthetics, symbolic and functional, the user can better accept the use of bike-sharing. This chapter shows how, through a human-centered design approach, strategies can be defined and managed.

Chapter 9 introduces to the empirical research of the thesis with the analysis of two workshops held at the University Iuav of Venice. Both the workshops have been organized based on the Sprint methodology. However, in the first workshop, the structure of it has remained unchanged, but the circular design cards have been introduced to help students to deal with multiple systems and strategies. Meanwhile, in the second workshop, the structure of the workshop has been modified accordingly to the Multi-Hierarchical Framework.

In order to summarize the findings of these chapters to answer sub-research question three, the following conclusion can be outlined:

- In chapter 6, an in-depth analysis of different design strategies has shown that, even if the focus was on phase P5, strategies are all interconnected. Companies and students can try to define and write down their design strategies to keep track of their understanding. The Multi-Hierarchical DfX Framework is a good starting point. The description of a strategy can define a specific phase where it was used, but can also be connected with other strategies in other phases or even with different strategies on different loops. This exercise can facilitate and increase the efficiency of designing for CE.
- The circular workshop proposed in Appendix C (circular design workshop) produced excellent results, where students were able to mix different design strategies and achieved good results from the various exercises proposed. However, for companies, this can

be considered only the first step of the design process in order to develop a final product. For this reason, chapter 9 can be considered as a guideline to understand needs and requirements in a CE environment.

- The multi-hierarchical DfX concept is an interactive and dynamic idea that can be used for a different "lean approach". In this research, it was adapted from the Sprint methodology, but this is just one possible solution that seemed to work considerably well with students. The multi-hierarchical DfX concept is based on three hierarchies, strategy hierarchy, product life cycle hierarchy, and time hierarchy. These three hierarchies together can be disassembled and reassembled in different forms for any possible solution. However, it is recommended to work with the three parts together.
- The point of contact between chapter 6 and chapter 9 was the interviews. Understand the point of view of customers and organize strategies accordingly can make the difference in accelerating the CE.

Different loops have different users/experts that should be listened to, in a lean process, all users and experts should be interviewed to understand better if the strategies applied worked well for them.

10.4. Scientific contribution to the field of Design Sciences

Different contributions can be identified in this thesis:

- First, a framework describing and explaining how a multi-perspective design approach can take place for a faster transition to a CE was developed. The Multi-Hierarchical DfX Framework reduces the complexity of circular economy and fosters collaborations between a multitude of designers. The framework facilitates a comprehensive view of all the phases of the product life cycle and helps designers seeing the "bigger picture" in design. Moreover, the framework involves designers that usually are considered unnecessary in the critical decisions for the company.
- Second, the framework highlights the importance of loops, hence the time horizons of product in each product life cycle. For designers who are used to a linear economy, understand the time and how to apply different strategies for different time dimensions is challenging.
- Third, the research contributed to clarifying how designers can influence each other and how important it is to understand these influences when designing for anthropic systems. Four systems were defined and described, Socio-technical system level, Spatio-social level, Product-service system level, and Product level. Designers should understand that when they are designing, they very likely designing at least within two systems. So, understanding how systems work and how to manage decisions within the systems is vital.
- Fourth, the research proposed the use the DfX as a general codification of design strategies. It is essential for designers that work in different systems to understand one another; for this reason, this research proposed to expand and amplify the DfX approach

in order to tackle the challenge of circular design better.
- Fifth, two tools have been developed and used in different workshops. The developed tools can facilitate the understanding of the complexity and help designers in uncertain situations. Tools are essential in the hands of designers because they help understand and be creative. In the circular economy, creativity is more important than ever to overcome economic and environmental problems.
- Last, the research developed a workshop based on a previous agile method. This workshop is a first, but an essential step ahead to understand how to manage complexity in classrooms as well in companies. The outlined elements of the workshop, identified within this research, are key components that can be used for shorter design workshops.

10.5. Limitations of the research

In this thesis, four main research limitations can be identified.

Validation of the tools with industrial sectors.

This research presented three main innovative instruments to deal with the circular design, circular cards, circular design tool, and the circular workshop. All the tools have been tested and analyzed in events where most of the participants were students. Therefore, the first limitation concerns the narrow validation of the developed design tools. Some attempts to collaborate with companies have been made but were unsuccessful, two meetings have been organized with Lavazza in Turin (IT), and one meeting was held with Electrolux in Pordenone (IT), in order to set up possible tests. However, it was eventually chosen to work with students only.

Involved participants during the workshop.

All the tools were developed for a collaborative and cooperative design process where multiple design perspectives were involved. Despite this, the research analysis collected data only from “experts” from three of the multiple perspectives needed, product designers, industrial engineers, and graphic designers. This approach may limit the results of this research, in the sense that every perspective could argue during the workshops dissimilar design focus; however, this did not happen because, in most cases, participants were mainly focused on human interaction and less on other disciplines outside their comfort zone.

The systemic theoretical approach.

In order to achieve a true CE, not only products should come back in the system, but the energy and material consumption should be significantly decreased as well. This can only be achieved through a collaborative approach where all the designers involved cooperate. However, to keep control and understand the systemic connections and dependencies is challenging. This research overcomes many disciplines’ borders to provide an answer to the main question and cover most design perspectives together. However, this is an ambitious objective for one person with only one perspective.

Circular Cards Tool.

The Circular Cards, although being invaluable in the learning process, were developed much earlier than the Multi-Hierarchical DfX Framework; for this reason, this tool is inconsistent with the rest of the research. With a limited amount of time (3 years), it was not easy for the author to further update the cards to comply with the new findings and test them again.

10.6. Suggestions for Future Research

Based on the result of the empirical research, the discussion and the review of the research and the limitations identified, below is a list of recommendations for future research:

1. It would be valuable in future research to test the tools created in this thesis, not only with students but also expand the range of action with different companies and their stakeholders to better understand the feasibility and the improvement of the tools with an industry perspective. Moreover, the tool can also be tested with organizations other than companies;
2. The Circular Cards Tool is a valuable tool that can be used during circular workshops to support designers in their decisions. However the tool was developed before the circular workshop, it would be valuable to iterate the Circular Cards Tool and test them again in the Circular Workshop;
3. Even though the Circular Design Tool has been developed properly, the tool was not validated accurately. Further research would be needed to measure the effectiveness of the tool for designers at simplifying the complexity of the CE to designers and students. However, the significant research on strategies for circular design seem to confirm this hypothesis;
4. This thesis has emphasized the multi-design perspectives; however, it focused on PSS and Product-level systems only. It is worth extending the same approach to the other two systems, the Socio-technical system level, and the Spatio-social level, to have a complete overview of all the systems and how they influence each other. This might show marginal changes also on the way designers in the PSS and Product-level make decisions;
5. The research should be driven by different design perspectives to be truly called “multi-design perspectives”. A suggestion for future research is to establish a design research group that can analyze how different designers approach the design of products and systems and how they can collaborate harmoniously together.

GLOSSARY OF KEY TERMS

The following terms are intended for clarification purposes only. Accepted definitions were used when available. In this thesis, the following terms are used accordingly.

Cascading of nutrients: Refers to the reintegration of biological or technological nutrients in an open-loop reverse supply chain system. Pauli (2010) stresses the importance of this approach to dramatically reduce the ecological footprint of industries, and at the same time, enhance local economies through the collection, transformation in new nutrient and use for new cycles.

Component: Refers to a constituent part of a broader defined system; an element of a larger whole object that could be a part and/or a product.

Design for X (DfX): DfX in this is generically considered a design strategy, where the X state for a variable which can have one of many possible values.

Design process: many designers and associations have defined the design process by structuring it in many different ways (for example the double diamond design process developed by the British Design Council in 2005). These frameworks are used by designers to structure their path to the final product. In this thesis, design process does not implicate a specific approach, and indicate when not specifically pointed out the phase "0" of the process. This is the most unclear and ambiguous phase for the company and designers, where they need to make many assumptions in order to develop the product or service.

Durability: is 'the ability of a product to perform its required function over a lengthy period under normal conditions of use without excessive expenditure on maintenance or repair'.

End-of-life (EOL): Refers to the point in the product or object's service life at which the product or object is no longer able to function or perform as required, and for which there are no other options for the product but to be recycled or disposed into the environment.

End-of-use (EOU): Refers to the point in the product or object's service life at which the product may not be needed by the current owner/user, or able to function or perform as required, and for which there are other options available to keep the product and/or its components within the market, via value-retention processes (VRPs). .

End-of-waste (EOW): Refers to conditions under which certain specified waste shall cease to be waste (per Directive 2008/98/EC), specifically: when it has undergone a recovery, including recycling; the substance or object is commonly used for specific purposes; a market or demand exists for such a substance or object; the substance or object fulfills the technical requirements for the specific purposes and meets the existing legislation and standard applicable to products; and the use of the substance or object will not lead to overall adverse environmental or human health impacts. (Directive 2008/98/EC)

Expected service life: Refers to the manufacturer's expectations about the time-period for which a product can be used, usually specified as a median, and reflecting the time that the product can be expected to be serviceable and/or supported by its manufacturer.

Forward-logistics: Refers to the traditional flow of products from the point of production through to the consumer and reflects a traditional supply chain management perspective focused on product delivery.

Life cycle assessment (LCA): As defined by the International Standards Organization (ISO), refers to a technique for the assessment of environmental aspects and potential impacts associated with a product by compiling an inventory of relevant inputs and outputs of a product system, evaluating the potential environmental impacts associated with those inputs and outputs, and interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study. (ISO 14040/44, 2006).

New material: Refers to the total 'new' (not reused via value-retention processes (VRPs)) material that is required as inputs to complete each OEM New and Value-Retention Process. New material can include a mixture of virgin (primary) and recycled (secondary) content, given that most of the materials available for purchase in the global economy consist of some mixture thereof. The assumed ratio of virgin and recycled content used in modeling is based on the global average for each material type, in accordance with the Inventory of Carbon and Emissions (ICE) (Hammond and Jones 2011).

Original equipment manufacturer (OEM): Refers to the manufacturer of the original parts or equipment, including the items manufactured, assembled and installed during construction of a new product. The OEM may or may not be responsible for marketing and/or selling of the product.

Part: Refers to a piece or segment of an object; may also be a component of a product. For the purposes of this research, part is used to acknowledge that the case study product may be a component of a larger defined product (e.g. vehicle parts, which are components of a vehicle).

Product: Refers to an article, object or substance that is manufactured or refined for sale, that is the final output of a process.

Product lifetime: Refers to the period that starts at the moment a product completes original manufacture and ends when the product is beyond any reuse or recovery at the product-level. (den Hollander, et al., 2017)

Product use cycle: Refers to the duration of the period that starts at the moment a product is released for use after manufacture or recovery, and ends at the moment a product becomes obsolete (den Hollander, et al., 2017).

Recycling: Refers to recycling operations that usually involves the reprocessing of waste into products, materials or substances, though not necessarily for the original purpose, and does not cover operations that recover energy from waste.

Recovery: Refers to any operation with the primary aim of reversing obsolescence (den Hollander, et al., 2017).

Refurbishment: Refers to the modification of an object that is a waste or a product that takes place within maintenance or intermediate maintenance operations to increase or restore performance and/ or functionality or to meet applicable technical standards or regulatory requirements, with the result of making a fully functional product to be used for a purpose that is at least the one that was originally intended. The restoration of functionality, but not value, enables a partial new service life for the product.

Remanufacturing: Refers to a standardized industrial process that takes place within industrial or factory settings, in which cores are restored to original as-new condition and performance, or better. The remanufacturing process is in line with specific technical specifications, including engineering, quality, and testing standards, and typically yields fully warranted products. Firms that provide remanufacturing services to restore used goods to original working condition are considered producers of remanufactured goods.

Repair: Refers to the fixing of a specified fault in an object that is a waste or a product and/or replacing defective components, in order to make the waste or product a fully functional product to be used for its originally intended purpose.

Reuse: Refers to the multiple use of a product, object or substance that is not waste, for the same purpose for which it was conceived, without the necessity of repair or refurbishment.

Reverse-logistics: Refers to activities engaged to recapture the value of products, parts, and materials once they have reached end-of-use or end-of-life. All VRPs may be considered to be part of a reverse-logistics system, and in addition activities including collection, transportation, and secondary markets provide essential mechanisms for facilitating reverse-logistics.

Secondary market: Also referred to as the aftermarket, is a market for used goods or assets, or an alternative use for an existing product or asset where the customer base is a second, or derivative (related) market. Items on the secondary market may or may not be manufactured by the OEM.

Servicing or Product Service System (PSS): refers to the value is provided by a combination of products and services in which the satisfaction of customer needs is achieved either by selling the function of the product rather than the product itself, or by increasing the service component of a product offer. For the purposes of this research, servicing or PSS is sometimes generally restrict to product service.

Service life: Refers to a product's total lifetime during which it can be used economically or the time during which it is used by one owner, from the point of sale to the point of diversion for reuse via VRPs, or to the point of disposal (Cooper 1994). This is differentiated from Expected Service Life as it refers to the actual service life and is not necessarily associated with manufacturer expectations or commitments.

Stakeholder: Refers to a single or multiple persons, companies or organizations that are involved in the project or system. Stakeholders can refer also to the user/s or companies who maintain the value in the circular system.

Technical nutrients: Refers to non-toxic, highly stable materials that have no negative effects on the natural environment, that are designed to be recovered and reused within production activities, and can be used in continuous cycles without losing integrity or quality.

Upcycling: A process that can be repeated in perpetuity of returning materials back to a pliable, usable form without degradation to their latent value—moving resources back up the supply chain (McDonough et al., 2010).

Upgrade: Refers to the act of raising a product to a higher standard with the objective to improve performance, efficiency, and/or functionality by adding or replacing components, including electronic and/or software. Upgrades performed as one of several process steps of comprehensive refurbishment or remanufacturing are not distinguished.

Value-retention processes (VRPs): While recycling is also an integral part of circular economy, for the purposes of this study the expression Value-Retention Processes (VRPs) only refers to activities, typically production-type activities, that enable the completion of, and/or potentially extend a product's service life beyond traditional expected service life. These processes include arranging direct reuse, repair, refurbishment, comprehensive refurbishment, and remanufacturing. These processes help to retain value in the system via enhanced material efficiency, reduced environmental impacts, and may potentially offer economic opportunities associated with primary material production and traditional linear manufacturing.

Volatility: Real prices of individual resources vary greatly in terms of their volatility. On average, resource price volatility has increased in the last 10 years, however, similarly high (or even higher) price volatility has occurred in the past for some resources;

Waste: Refers to any substance or object which the holder discards or intends or is required to discard (Directive 2008/98/EC).

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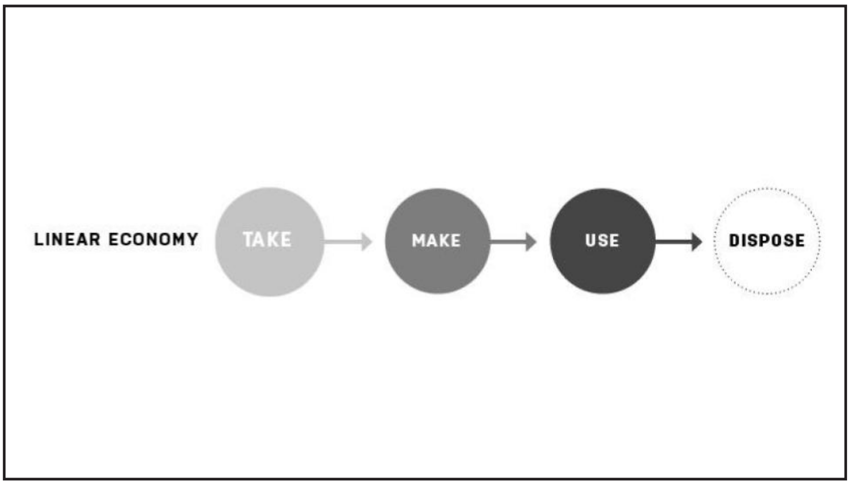
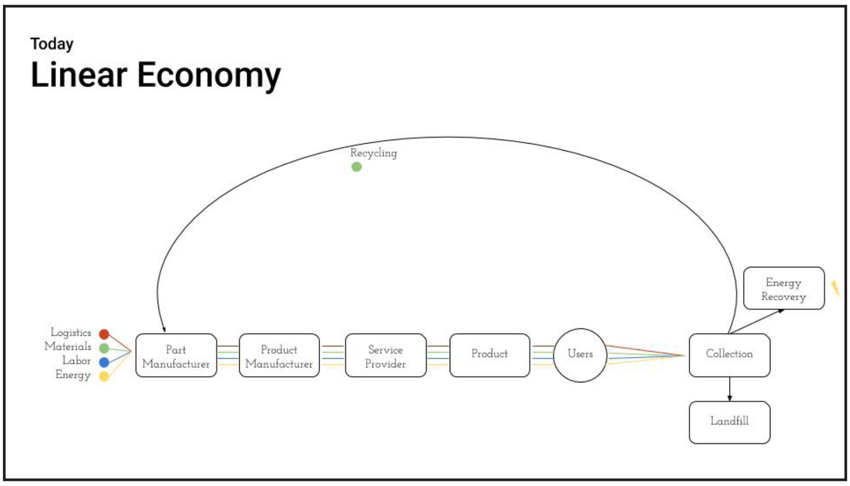
APPENDIX A

Slide 1. The following presentation was shown at the first workshop.

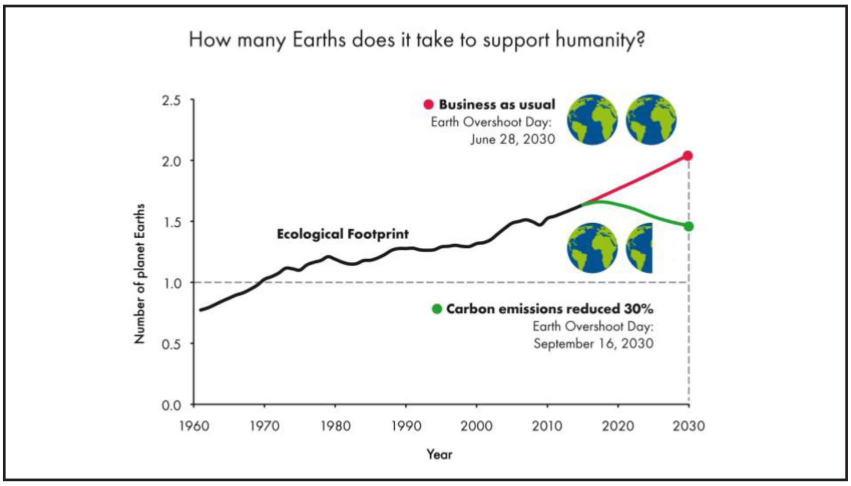
Slide 2. During the workshop, the participants were asked, on which economic model is our current economy based?

Slide 3. The last century of industrial change has been a clear development of a linear economy - a one way flow of goods and materials from extraction, manufacture, use and disposal.

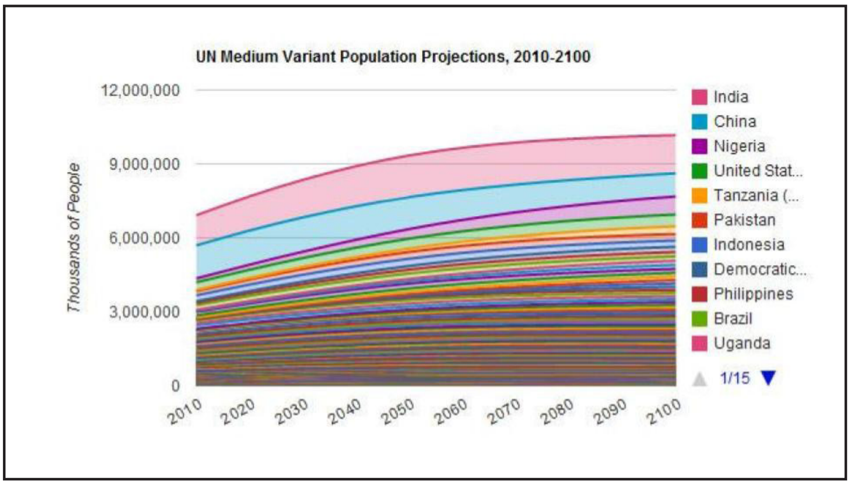




Slide 4. Visualization of the linear economy on the basis of maintained values along the product life cycle.

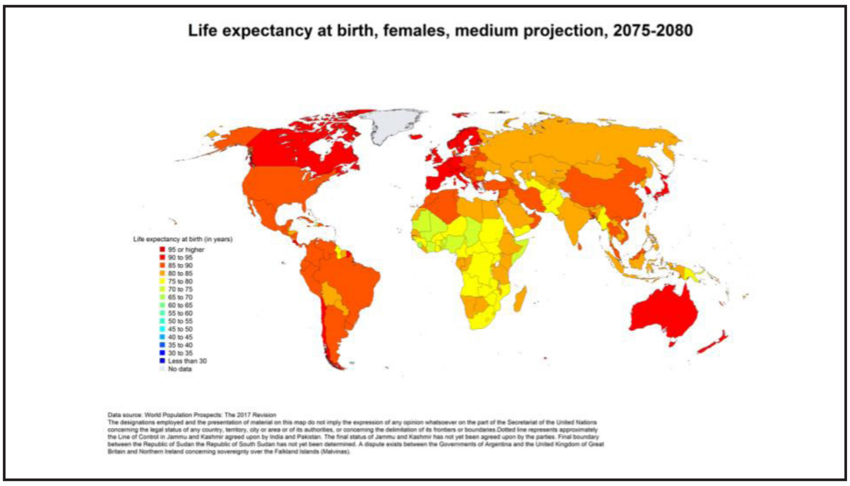


Slide 5. Representation of two possible scenarios, one if we continue to use resources as we currently do, the other if we decrease the use of natural resources.

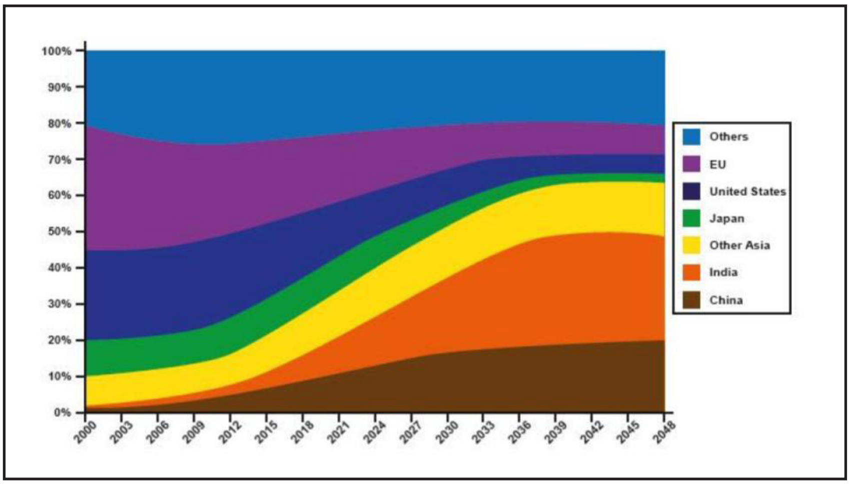


Slide 6. Representation of the current world population of 7.3 million inhabitants and projection of the attainment of the inhabitants in 2030 (8.5 million) and 2100 (11.2 million).

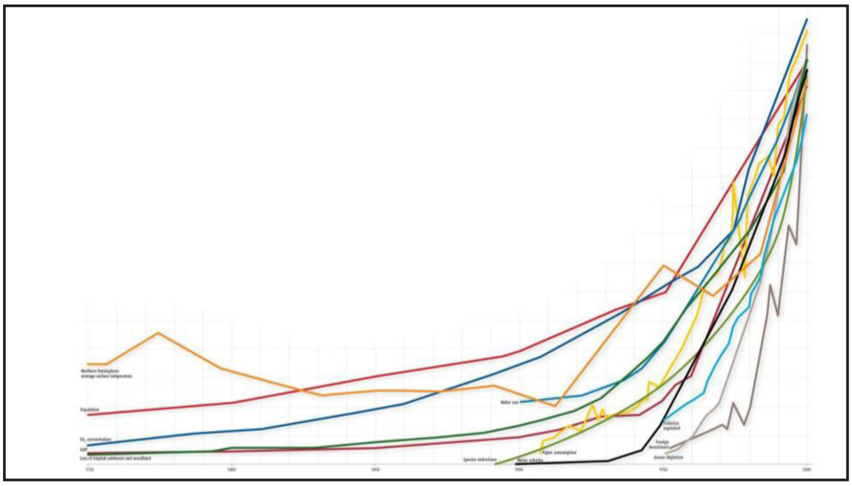
Slide 7. The world population will reach 9.9 billion by 2050, up 2.3 billion or 29 percent from an estimated 7.6 billion people now, according to projections by Population Reference Bureau (PRB) included in the 2018 World Population Data Sheet.

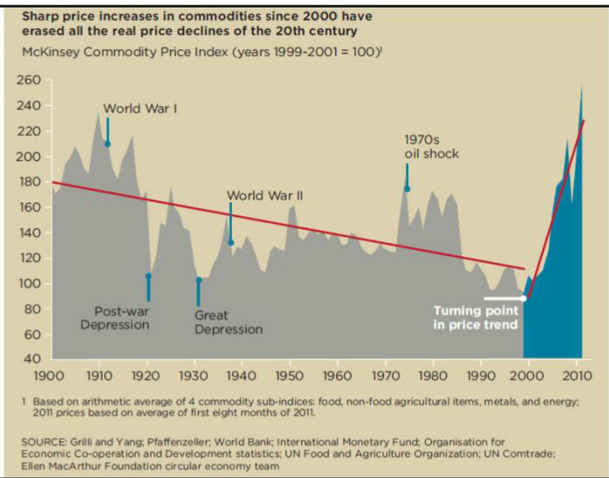


Slide 8. The size of the global middle class increased from 1.8 billion in 2009 to about 3.5 billion people in 2017 – more than half of the world population and is expected to grow to some 4 billion by 2021 and reach 5.3 billion by 2030. Some 88% of the additional middle class population will be Asians

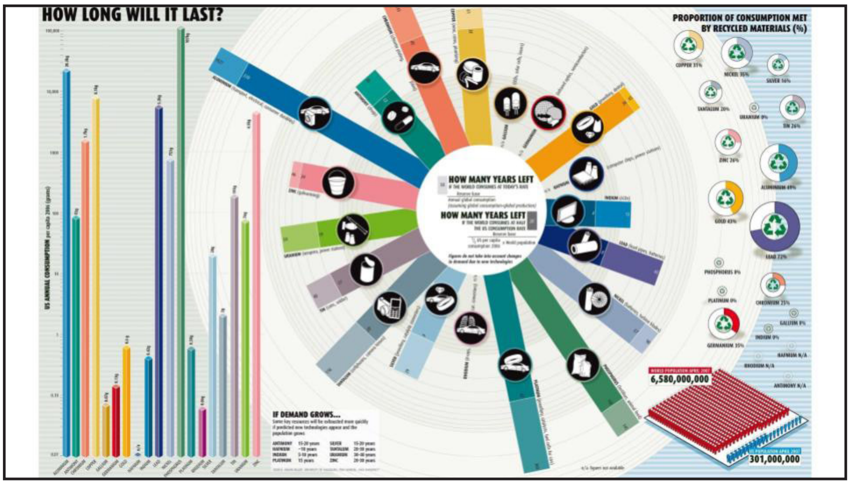


Slide 9. Given current trends of growth, our extraction of natural resources could increase to 100 billion tonnes by 2030. People in rich countries consume up to 10 times more natural resources than those in the poorest countries.





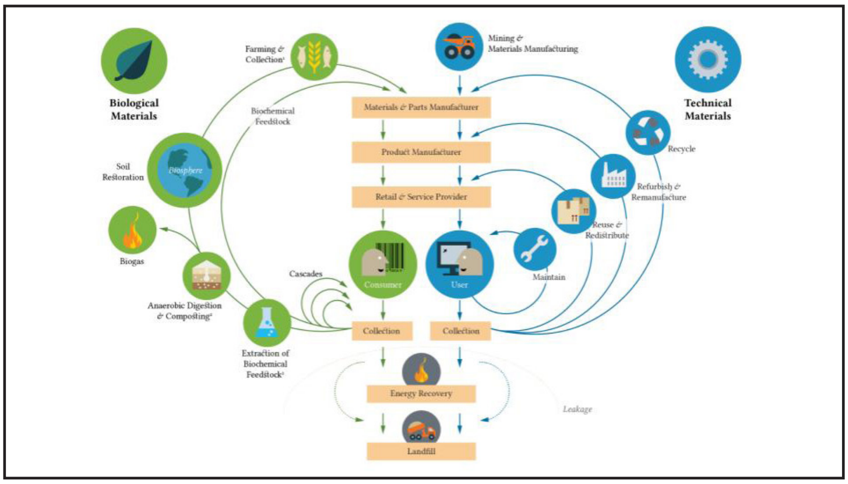
Slide 10. The finite nature of many mineral and energy resources has increased fears of resource scarcity and aggravated volatility of commodity prices. Many renewable resources have also come under growing pressure as demand for food, land, soil and water has increased substantially.



Slide 11. How Long will the earth's resources last? Our planet is running out of room and resources.

Slide 12. The production of goods and services requires energy as an input, which is called a factor of production. Energy sources vary in their effectiveness as a factor of production, depending on their energy characteristics.

Slide 13. The circular economy - a concept which ensures that products are designed with their eventual reuse, upcycling or biodegradation in mind - emerged as the most prominent trend that is driving the innovation of sustainable solutions worldwide.

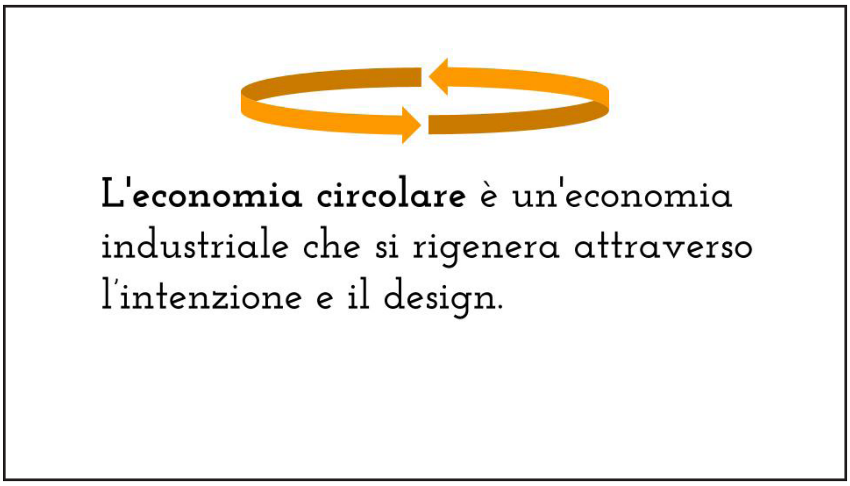


Slide 14. The Brundtland Commission officially dissolved in December 1987 after releasing Our Common Future, also known as the Brundtland Report, in October 1987. This phrase is often used to define what sustainability is.

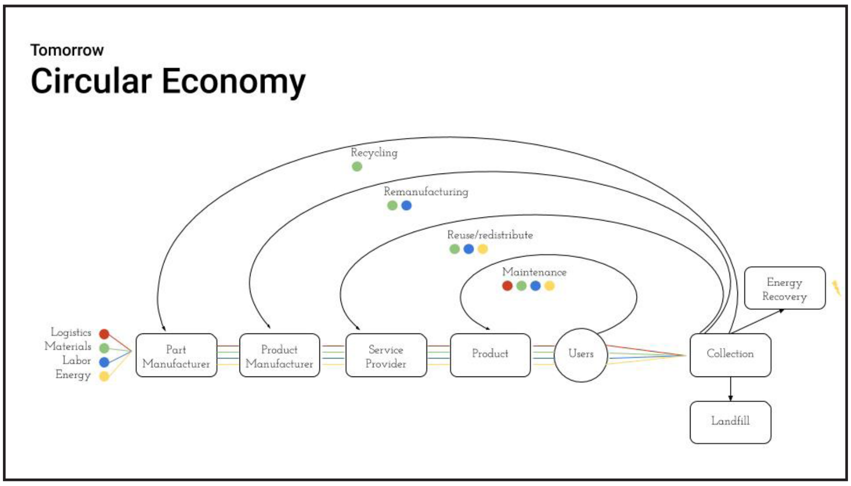
Lo sviluppo sostenibile è uno sviluppo che soddisfa i bisogni del presente senza compromettere la capacità delle generazioni future di soddisfare i propri bisogni.

Da: Our Common Future, 1987

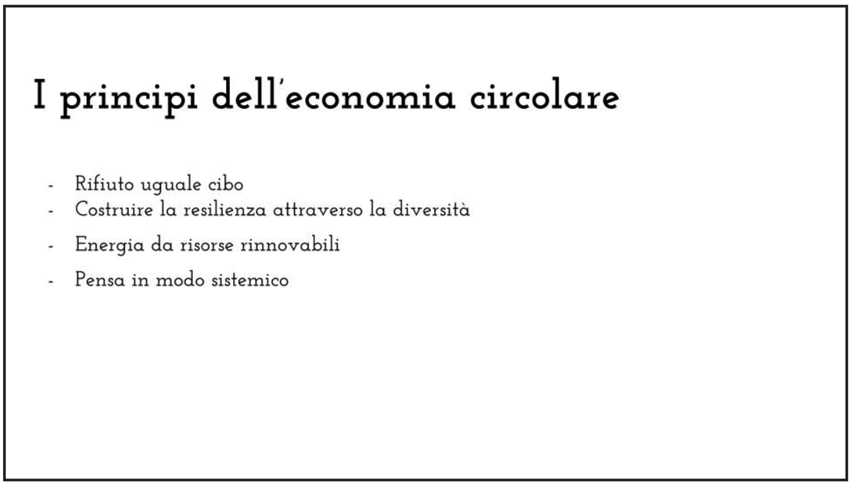
Slide 15. ‘Re-Thinking Progress’ explores how through a change in perspective we can re-design the way our economy works - designing products that can be ‘made to be made again’ and powering the system with renewable energy. - VIDEO -



Slide 16. Circular economy definition provided by the Ellen MacArthur Foundation.



Slide 17. Introduction of the values that are maintained or lost within the circular economy. The image was developed during doctoral research and discussed in Chapter 4.

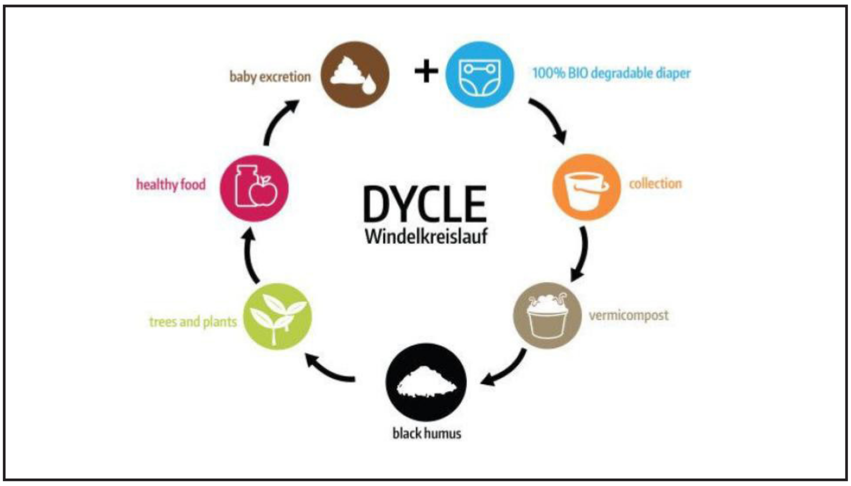


Slide 18. A circular economy seeks to rebuild capital, whether this is financial, manufactured, human, social or natural. This ensures enhanced flows of goods and services.

Slide 19. Eliminate the concept of waste. “Waste equals food.” Design products and materials with life cycles that are safe for human health and the environment and that can be reused perpetually through biological and technical metabolisms.

Rifiuti uguale cibo

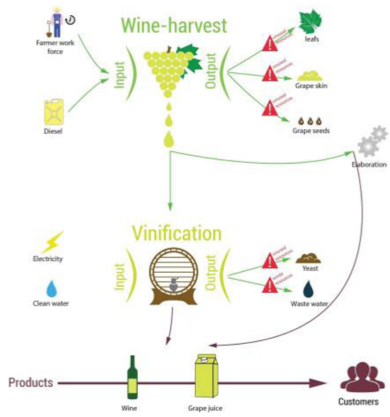
Slide 20. DYCLE is a fundamentally new way of how baby diapers are to be produced, used and recycled, or rather upcycled, when they are no longer a waste but a nutrient for plants, transformed into fertile soil.



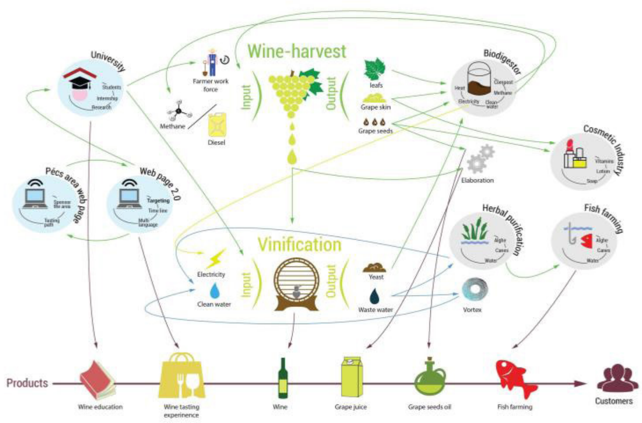
Slide 21. DYCLE video project.

Costruire la resilienza attraverso la diversità

Slide 22. Transitioning to a circular economy represents a systemic shift that builds long-term resilience, generates business and economic opportunities, and provides environmental and societal benefits.

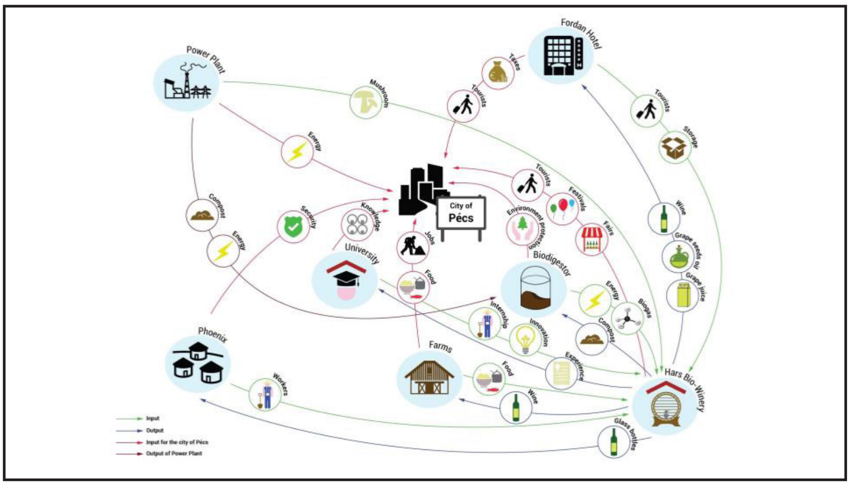


Slide 23. Building resilience through diversity ‘means analyzing material flows to understand where waste can be transformed into a new resource. Case study prsented - Hàrs Family Bio-celler.



Slide 24. Hàrs Family Bio-celler project.

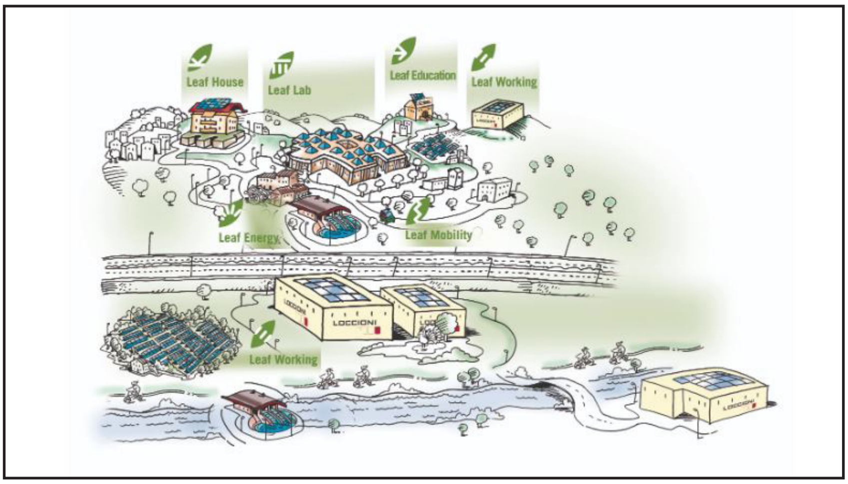
Slide 25. Hàrs Family Bio-celler project.



Slide 26. Power with renewable energy. “Use current solar income.” Maximize the use of renewable energy.

Utilizzare l'energia da risorse rinnovabili

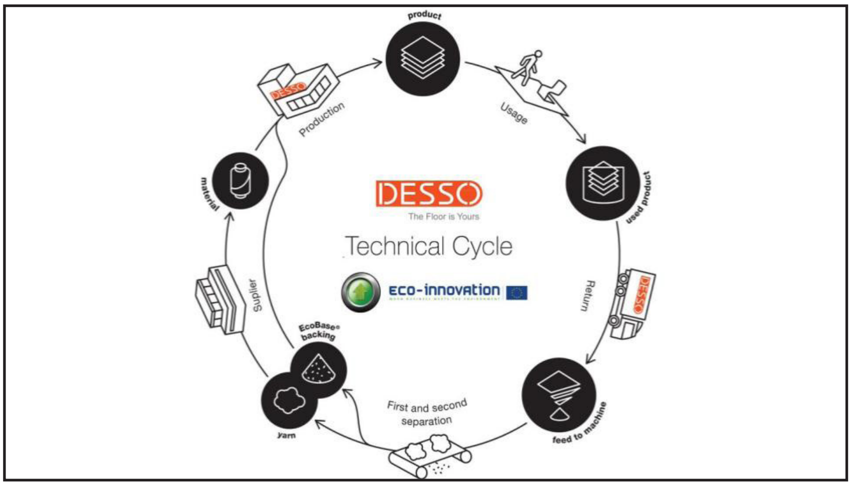
Slide 27. The “Leaf Community”, aiming to create the first ecologically sustainable integrated community in Italy.



Pensa in modo sistemico

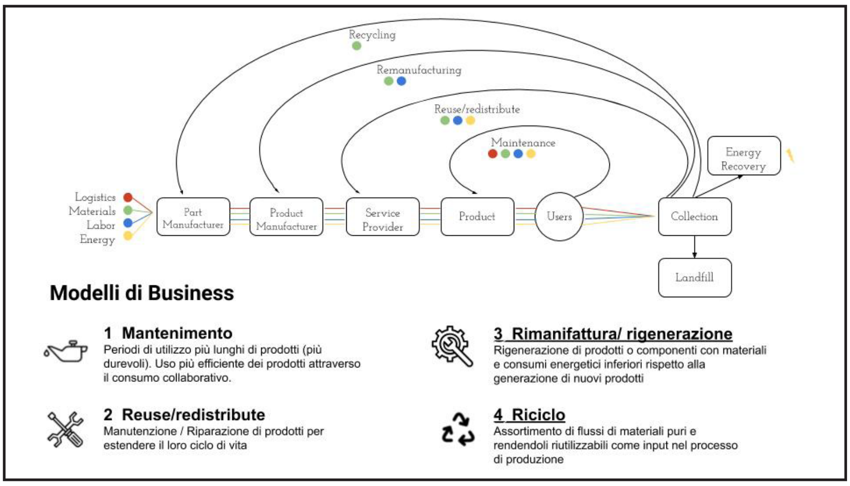
Slide 28. Using the resources available in cascading systems, the waste of one product becomes the input to create a new cash flow'.

Slide 29. ECOVER is a eco-friendly and zero-carbon-emission factory. However, the company relized later that through its approach they were jeopardizing the Indonesian forest and the orangutan habitat because of palm oil used to make products.



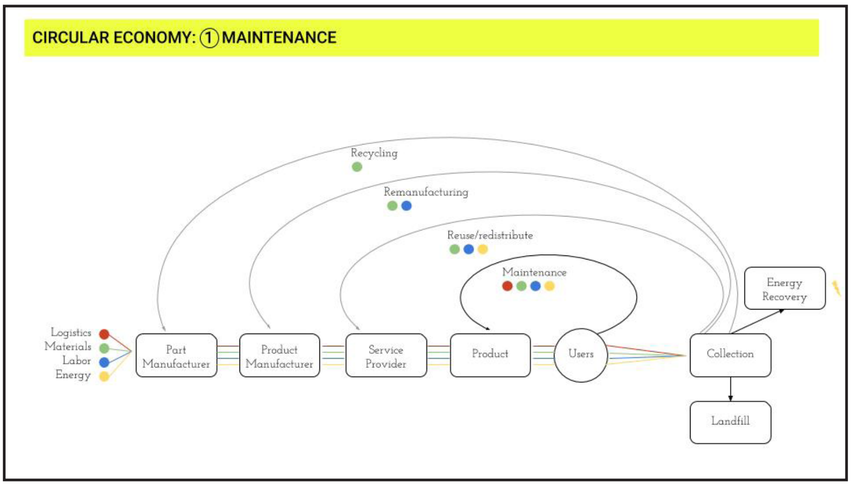
Slide 30. Desso has developed an innovative separation technique, called Refinity®, which makes it possible to separate the yarn from the backing of carpets, producing two material streams which can each be recycled.

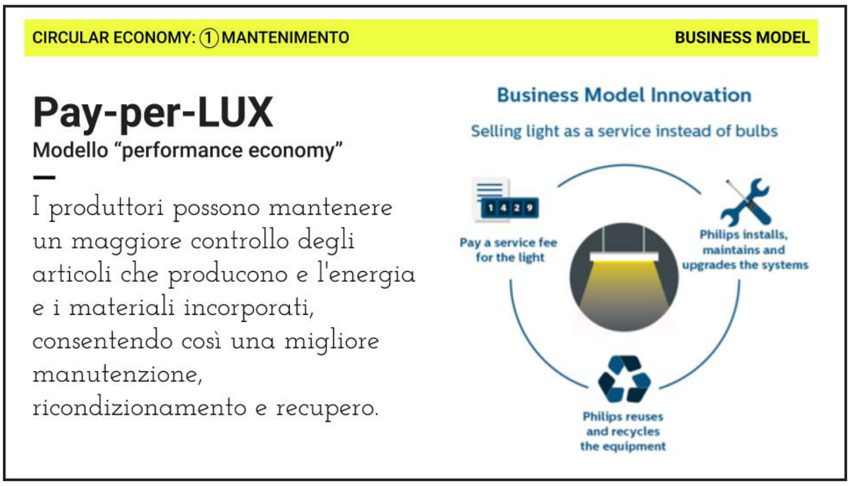
Slide 31. A summary of the values maintained in the circular economy is presented, together with the applicable strategies for implementing a circular economy.



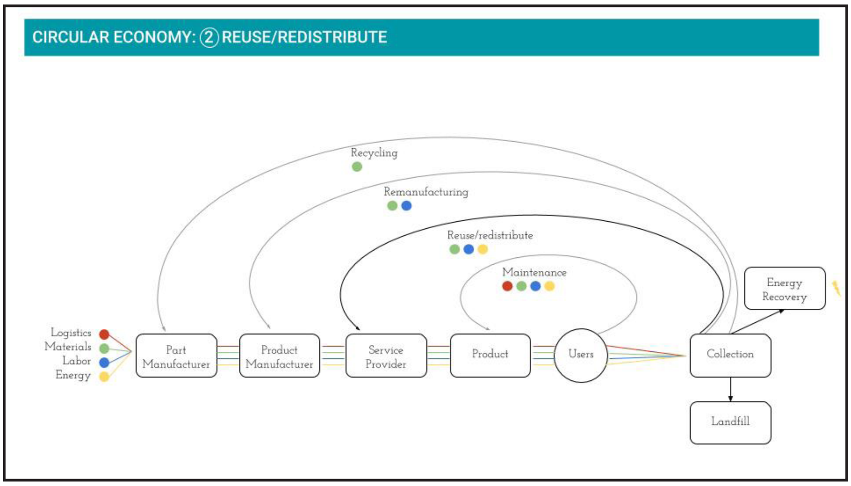
Slide 32. Move to a "service-and-flow" business model - Providing value as a continuous flow of services rather than the traditional sale-of-goods model aligns the interests of providers and customers in a way that rewards resource productivity.

Slide 33. Focus on the maintenance approach.



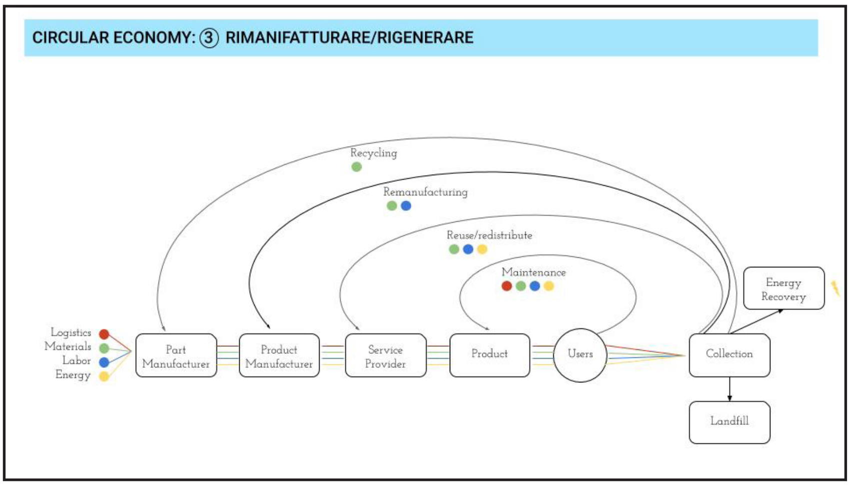


Slide 34. Selling light as a service that fit the requirements of the space, at a manageable price. Philips retain control over the items they produce, enabling better maintenance, reconditioning and recovery.



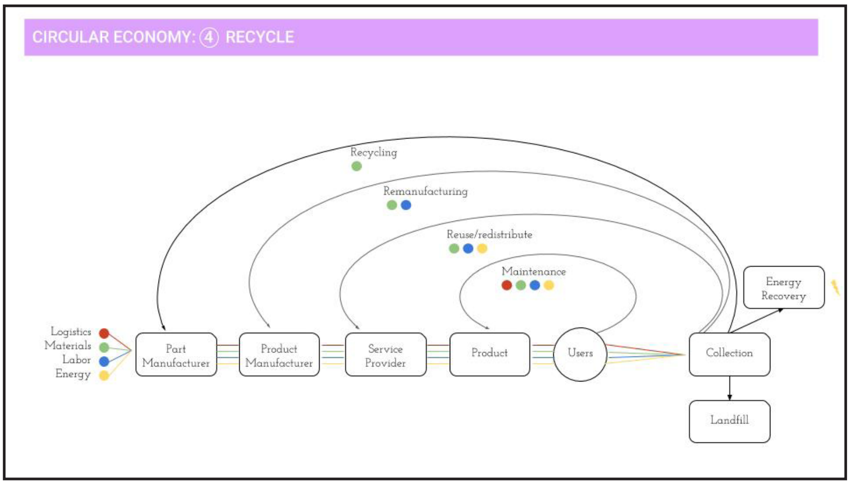
Slide 35. Focus on the Reuse/ Redistribute approach.

Slide 36. In the circular economy, users will rent their bikes. Once finished with, they return it to be rented to another rider.



Slide 37. Focus on the remanufacturing/refurbishment approach.

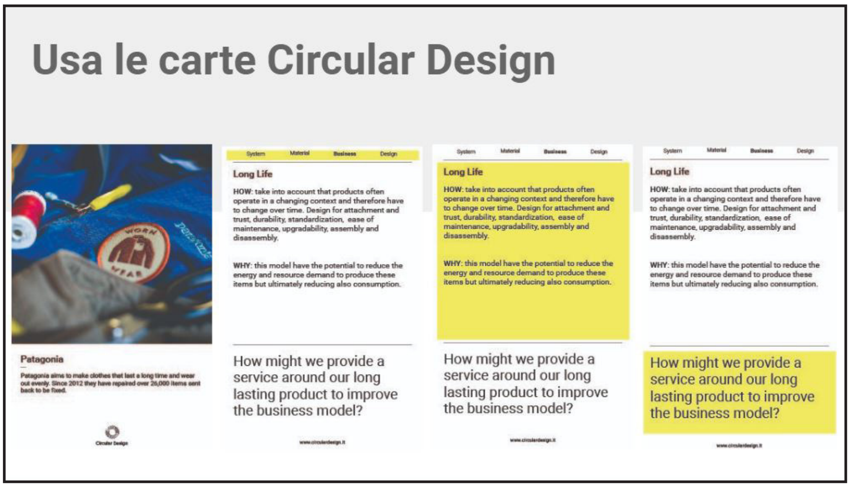
Slide 38. Phonebloks is an idea for a modular mobile phone. A phone that is easy to repair, easy to upgrade and so, easy to remanufacture. And it will help reduce electronic waste.



Slide 39. Focus on the recycling approach.

Slide 40. The crudle to crudle book is entirely made from plastic resins and inorganic fibres which makes it extremely durable and in most places upcyclable by conventional methods. It can be made and remade into the same or a different product.

Slide 41. Sprints are time-boxed periods of one week to one month, during which a product owner, scrum master, and scrum team work to complete a specific product addition. In the workshop number 1 the Sprint was performed without any modification.



Slide 42. Circular Design Cards were introduced and participants were told how to use them within the workshop. In Chapter 8 it is possible to understand how the cards were designed.

APPENDIX B

Workshop 1 - Proteins for all

Challenge - The median estimate for future growth sees the world population reaching 9.8 billion in 2050. The Proteins for all project was about trying to figure out ways to make move consumers from the consumption of classic animal proteins to more sustainable proteins feeding. Efforts from students were concentrated on a new break bar to integrate proteins during all day long. Students then decided to focus on packaging attractiveness to convince users to prefer their product through stimulating packaging. From customer interviews, it was found that users prefer a fun mascot, a transparent pack with bright and colorful nutrition information on it.

Figure B.1. Protein for all team group working on their project and interviewing a potential user.

Table B.1. Protein for all evaluation.

CRITERION	EVALUATION
1) Has the product been resolved under multiple design perspectives? How?	No, the group did not have a multiple design perspective. They focus primarily on ho appealing users.
2) Did the participants consider multiple product life cycles?	No, the group did not consider how the packaging could be reused or recycled. They focused predominantly on the energy bar.
3) Were the participants able to integrate different strategies?	No, they focus mainly on the aesthetics of the packaging.
4) Did the participants understand that different design strategies are required for each product life cycle?	No, they didn't.

Workshop 1 - Rewind

It is expected that the middle class in the next 31 years will dramatically increase, consequently resources such as composed materials and energy will increase too. Rewind aim is to avoid such a problem introducing a new modular fan for domestic use. Rewind offers a modular fan service that allows the users to rent funs for determined times of the years. The modular structure was thought from the students to facilitate the transportation of the fan for the reverse logistics. The fan also has a flexible head that may be positioned in endless positions. During the wintertime, the product comes back to the company and it will be clean and eventually fix in order to be reused it again.

Figure B2. Rewind group working on their project and interviewing a potential user.

Table B.2. Rewind evaluation.

CRITERION	EVALUATION
1) Has the product been resolved under multiple design perspectives? How?	Yes, the group successfully analyzed the multiple design perspectives by creating a fan that could be disassembled by users and send it back to the company. Users could rent the fan thanks to a service system that could allow them to use it only during the summer, without having the ownership of the product.
2) Did the participants consider multiple product life cycles?	Yes, the group consider how the product could be reused for multiple times.
3) Were the participants able to integrate different strategies?	Yes, they focus primarily on the business model and how it could influence the design of the product, especially for the transportation of it.
4) Did the participants understand that different design strategies are required for each product life cycle?	Yes, they did.

Workshop 1 - Reborn

Reborn address the problem of fast consumption of toys for children. Nowadays toys are becoming more and more fast-products that should be adapted to the different children growing phases. In the long term and with the growth of middle-class by 2050 it will result in loss of precious materials and energy. Reborn is a modular toy made out of wood that grows with your kids. It is still sold as a classic product, but once the child does not longer want the toy, parents can exchange it with a new one for a better price. The old product then will be refurbished from the company, will be then taken back from the company in the market.

Figure B.3. Reborn group working on their project and prototype creation.

Table B.3. Reborn evaluation.

CRITERION	EVALUATION
1) Has the product been resolved under multiple design perspectives? How?	No, the group focused mainly on users and much less on the other perspectives.
2) Did the participants consider multiple product life cycles?	Yes, the group consider how the product could be reused for multiple times.
3) Were the participants able to integrate different strategies?	Yes, the group used different design strategies, but most of them were related to the users.
4) Did the participants understand that different design strategies are required for each product life cycle?	No, they didn't.

Workshop 1 - Typo

Typo is a modular furniture system for offices. Too often many office furniture is discarded because the constantly changing needs employees and enterprises are becoming day by day more flux and unstable. In 2050 there will be more people working from home than from offices. Typo aims to avoid waste creation by rethinking a new furniture system in a more simple, dynamic and upgradable way. Students studied a special join to create a dynamic system that can be sold as a service. The materials of it are robust and 100% recyclable in order to keep the value of them for many loops, from reusing to recycle.

Figure B.4. Typo team group working on their project and presenting it to professors.

Table B.4. Typo evaluation.

CRITERION	EVALUATION
1) Has the product been resolved under multiple design perspectives? How?	Yes, the group focused on the business model and how to sell the product as a service. They then design a simple product that was easy to ship and store.
2) Did the participants consider multiple product life cycles?	No, they did not consider multiple products life cycles.
3) Were the participants able to integrate different strategies?	Yes, the group used different design strategies, but most of them were related to the users.
4) Did the participants understand that different design strategies are required for each product life cycle?	No, they didn't.

Workshop 1 - Reshoes

In 2050 a healthy lifestyle will be much needed in order to avoid overconsumption from developed and developing countries. Drawing on prevention not only avoids additional environmental and financial costs but also involves the adoption of circular product able to be reintegrated in the industrial system, thus becoming a great circulatory system. Reshoes aims to incentive people in training and keeping fit by offering a modular and customizable shoe. In fact, through a dedicated application user can decide any details of the shoe, from the colors to the shapes. The user will establish a developing a deep attachment to it in this way, keeping it for a much longer time than the normal run shoes.

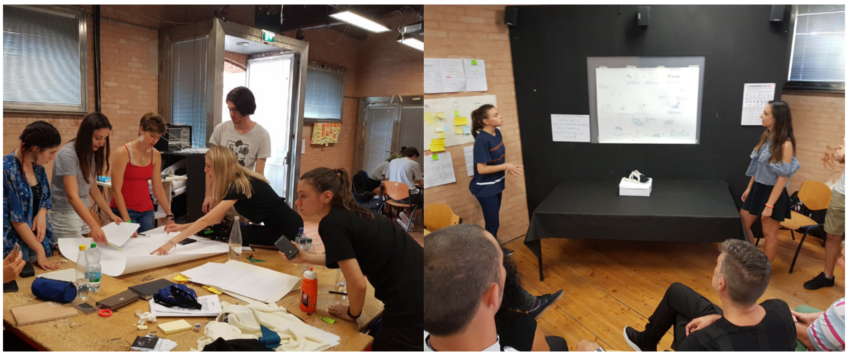


Figure B.5. Reshoes team group working on their project and presenting it to professors.

Table B.5. Reshoes evaluation.

CRITERION	EVALUATION
1) Has the product been resolved under multiple design perspectives? How?	No, the group focused mainly on the design of the shoes.
2) Did the participants consider multiple product life cycles?	Yes, the group focused on how the shoes could be upgraded and reused by the same user, and once the shoes reach the end of life the sole could be composted on the soil, whereas the rest of the shoes reused for a new pair of shoes.
3) Were the participants able to integrate different strategies?	No, the group used different design strategies, but most of them were related only to the users.
4) Did the participants understand that different design strategies are required for each product life cycle?	No, they didn't.

Survey workshop 1

Table B.6. Questions on understanding the circular economy.

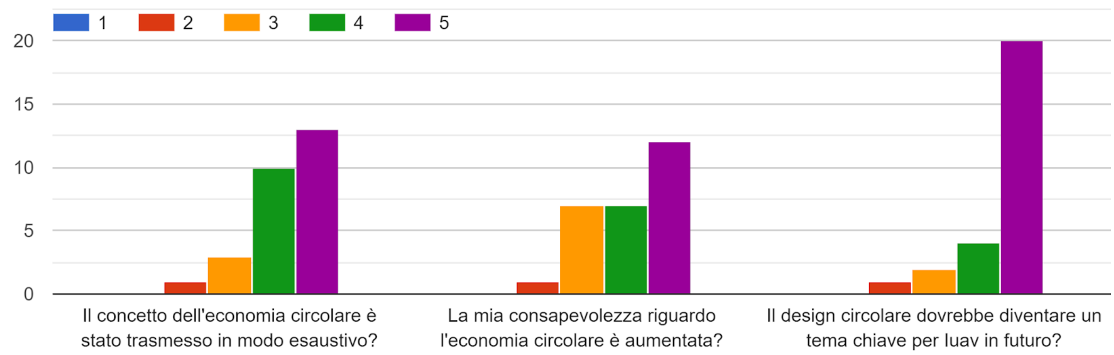


Table B.7. Questions about group collaboration.

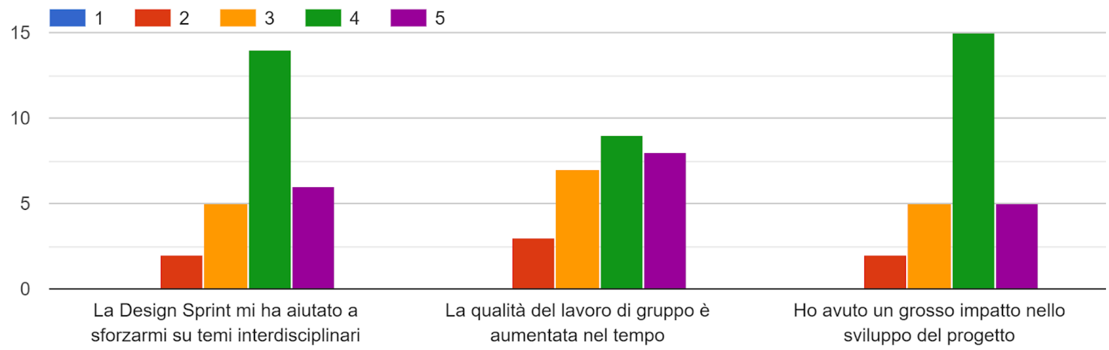


Table B.8. Questions about the results obtained during the workshop.

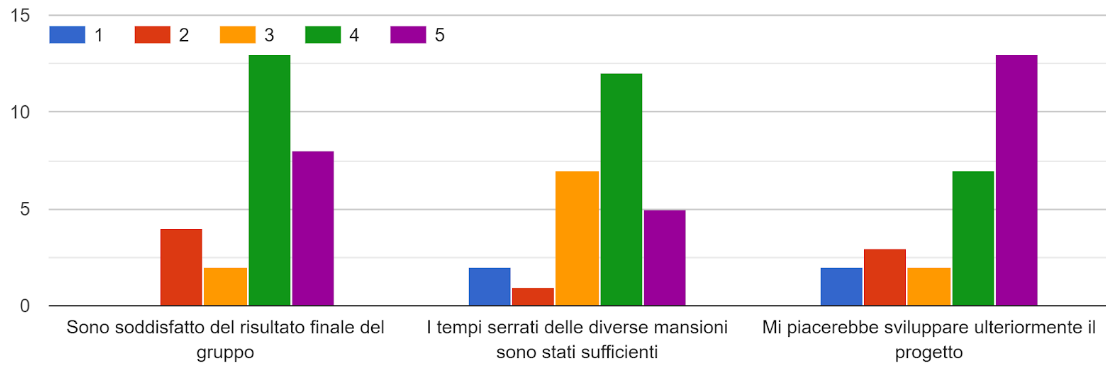


Table B.9. Questions about the benefits obtained from the workshop.

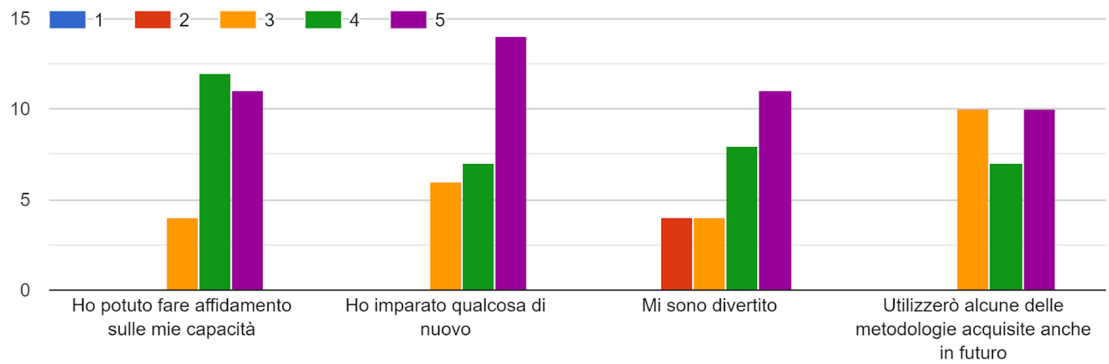


Table B.10. Did the sprint design approach meet your expectations?

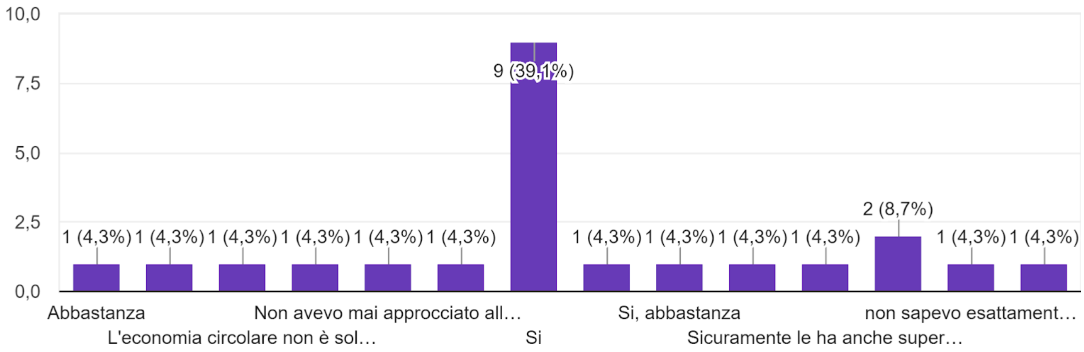


Table B.11. Student feedback on the course.

WHAT WORKED AND WHAT DIDN'T DURING THE WORKSHOP?
Tutto ha funzionato
A mio avviso ha funzionato molto bene la modalità di lavoro attraverso post-it che è stato un metodo molto efficace per visualizzare i dati. Non hanno funzionato i tempi troppo serrati perché hanno portato talvolta a risultati parziali del lavoro e non hanno permesso uno sviluppo completo del progetto. Con tempi così serrati è anche più facile che i componenti del gruppo più forti impongano le proprie idee.
Forse il fatto che il tema fosse già deciso da una parte ha aiutato, dall'altra ha reso difficile il tutto perché non ne sapevamo troppo.
Non c'è niente che non abbia funzionato in realtà, personalmente ho avuto un po' di difficoltà quando c'è stata la parte individuale, poi però vedendo i risultati che ne sono emersi ne ho compreso l'utilità.
Hanno funzionato le tempistiche un po' meno la distribuzione del tel tempo nelle carie fasi: avrei dedicato un po' più tempo al progetto e meno alla parte di studio degli appunto Il lavoro di gruppo e la metodologia serrata in tempi precisi.
L'organizzazione del corso è stata ottima.
Il lavoro di tutti i partecipanti del gruppo ha fatto sì che il progetto non fosse sviluppato ulteriormente, nonostante la soddisfazione del progetto finito.
Hanno funzionato la divisione delle fasi di lavoro, anche se all'inizio erano molto rigide e precise. Il gruppo ha lavorato bene insieme purtroppo essendo tutti designer, quindi specializzati sullo stesso tema, mancava la conoscenza per quanto riguarda gli altri campi di intervento del progetto (economico, organizzativo, ecc.). In generale comunque l'esperienza è stata positiva perché ci siamo sforzati di ragionare in modo complessivo attorno al progetto, senza limitarci all'ideazione di un prodotto.
Le consegne giornaliere ed il calendario non erano ben chiare. Sono state utili le interviste e la possibilità di rivedere con la calma necessaria il lavoro fatto dall'inizio del progetto.
Ha funzionato in quanto nel breve arco di una settimana siamo arrivati a concepire un prodotto interessante per una scena di mercato futura, dove bisognerà offrire più funzioni nel minor spazio e tempo possibile. Ciò che non ha funzionato a dovere è che per applicare correttamente la metodologia SPRINT, serve avere degli esperti del settore all'interno del gruppo, altrimenti è impossibile nel poco tempo a disposizione, essere a conoscenza di tutte le problematiche relative al progetto, e così facendo si rischia di progettare un prodotto non idoneo all'apparato produttivo dell'azienda.
Il gruppo ha sicuramente funzionato, è mancato secondo me un programma dettagliato

da seguire.

Ha funzionato tutto bene tranne il gruppo. Tranne una-due persone, erano tutti demotivati e disinteressati a compiere un buon lavoro; non per il corso in sè, che è stato affrontato in maniera interessante, ma perchè c'erano persone che venivano evidentemente solo per i crediti, e pesavano sul lavoro di squadra, con idee che andavano completamente fuori tema, e affrontate senza serietà. Inoltre, finita la settimana di sprint anche quando bisognava fare tutto il resoconto finale, nessuno ha collaborato e il lavoro è stato portato avanti solo da due persone; forse sarebbe stato utile creare il resoconto finale direttamente l'ultimo giorno prima di andare a casa tutti insieme finchè si era in aula. Mi è dispiaciuto affrontare questo workshop, per me davvero molto importante, con un gruppo così demotivato; invece guardando gli altri gruppi ho visto molta più determinazione, voglia di fare, di sperimentare, di osare e di mettersi in gioco con delle idee originali. Forse era il tema difficile poco studiato a scuola che ci è capitato, e sarebbe utile in futuro dare due o tre temi a disposizione per i gruppi tra cui scegliere, senza che essi siano vincolati ad una sola scelta di progetto da portare avanti. Forse in futuro sarebbe utile proporre delle tematiche per formare i gruppi, e in base agli interessi di ognuno formare un gruppo affiatato. Oppure il mancato impegno era dato dalla mancanza di una valutazione, e forse aiuterebbe dire fin da subito che passano dei docenti importanti dello Iuav, a vedere i progetti realizzati e che questo comunque, non inciderà sul voto ma influirà nel giudizio generale dell'impegno della persona; così le persone saranno più motivate a fare del proprio meglio.

Ha funzionato sicuramente il metodo utilizzato, l'approccio del docente la collaborazione degli studenti, la disponibilità dei laboratori.

Ha funzionato il lavoro in gruppo, anche se individualmente c'erano diverse opinioni, alla fine si è giunti ad un risultato condiviso.

Andavano spiegati meglio i passaggi della sprint, cioè dire esattamente per ogni step a tutti gli studenti (non ai singoli gruppi) cosa si dovesse fare nello specifico: avere la scadenza a tempo va molto bene e si è rivelata una strategia proficua, ma molto spesso ci siamo trovati a non capire esattamente che cosa dovessimo fare e di conseguenza sprecare tempo utile. Le intenzioni della nostra start-up erano chiare (e stimolanti), ma dal momento che si trattava di creare un sistema e non un vero e proprio prodotto fisico ci lasciava sempre un po'disorientati, specie su cosa avremmo dovuto consegnare alla fine (il risultato è stato un singolo possibile progetto di gioco da esporre, ma il vero Reborn era più il sito che il prodotto singolo in sé).

Ha funzionato molto l'utilizzo di post-it durante il confronto.

Ha funzionato il lavoro in gruppo, mentre alcune consegne non erano chiarissime.

Table B.12. Student suggestions for workshop improvement.

WHAT COULD BE DONE BETTER?
Scelta dei progetti.
Forse chiudere un occhio sulla parte di business a favore della parte di economia circolare: ho trovato che il mio gruppo abbia trascurato la circolarità del prodotto a favore del business.
La parte di progettazione potrebbe durare un po' di più, magari un giorno intero al posto di mezza gioranata, in questo modo si riuscirebbe a definire meglio ogni dettaglio di progetto per arrivare ad avere un prodotto veramente definitivo.
Più approfondimento sui temi trattati.
A volte era complicato capire le consegne, ritrovandoci a svolgere degli esercizi senza comprenderne a pieno le modalità e lo scopo.
Spiegare in modo chiaro le consegne giornaliere.
Bisognerebbe avere a disposizione degli esperti, almeno uno per gruppo, specializzati nel caso studio che verrà assegnato.
Sicuramente garantire punto per punto il processo da svolgere nel metodo sprint chiar-

endo fin dal principio che cosa si dovrà andare a svolgere passo per passo.

Il corso secondo me andava già bene così: gli argomenti sono stati esposti in maniera chiara e completa. Inoltre sono venuto a conoscenza di molti aspetti interessanti della progettazione. Forse sarebbe utile avere della documentazione sull'economia circolare e sul metodo sprint con vari esempi da guardare se si volesse utilizzare questo ottimo metodo in futuro. In conlusione sono felice di aver partecipato e ho imparato molto.

Nulla è già tutto perfetto.

La lezione sull'economia circolare andrebbe migliorata, alcuni esercizi del processo sembravano forzati e controproducenti.

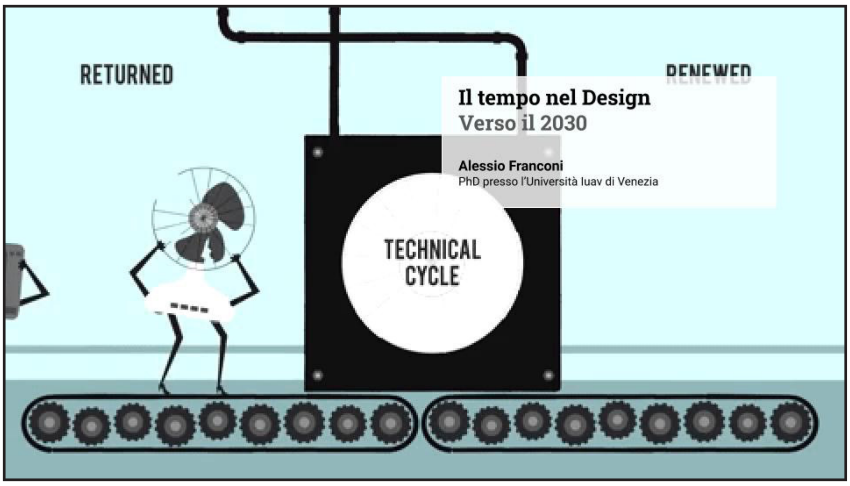
Come già detto, spendere più tempo nel spiegare passo per passo i passaggi della Sprint in modo che ognuno sappia di preciso cosa deve fare.

È stato a mio parere tutto esaustivo, sono stata molto soddisfatta del risultato finale.

Ridurre ore del laboratorio o assegnare più crediti rispetto alla quantità di lavoro portato avanti in classe e a casa.

APPENDIX C

Slide 1. The following presentation was shown at the first workshop.

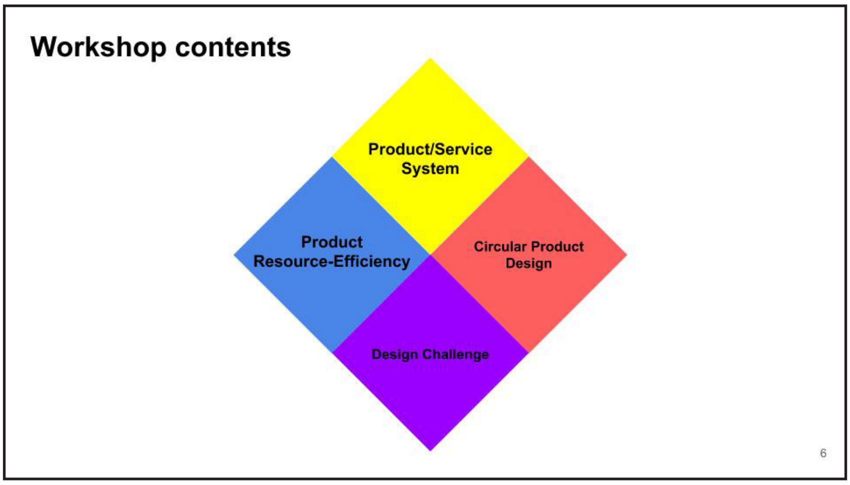


Slide 2. Participants were asked to answer the question: What is your idea of sustainable development? And why does design play a fundamental role?

Slide 3. The Brundtland Commission officially dissolved in December 1987 after releasing Our Common Future, also known as the Brundtland Report, in October 1987. This phrase is often used to define what sustainability is.

Slide 4. In the first place it has been explained how too often the design is seen through only an aesthetic lens.

Slide 5. In the following, it has been explained that design can have a thousand facets and that it is a complicated and multidisciplinary discipline.

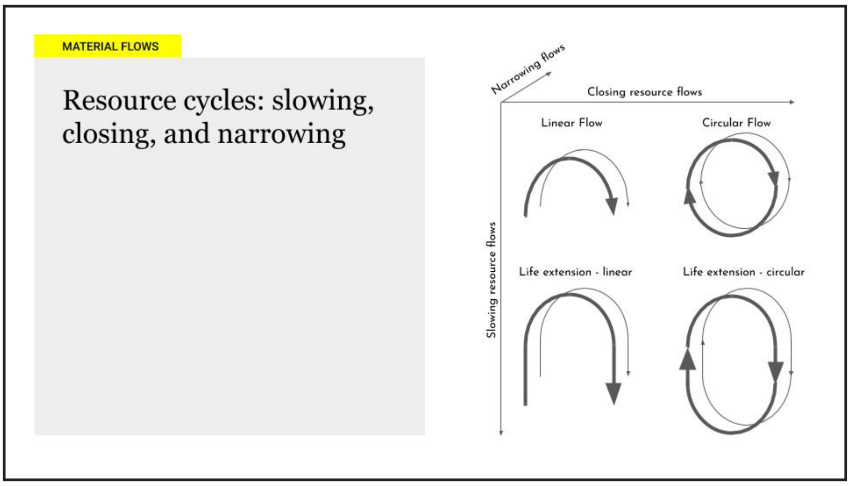


Slide 6. Based on the feedback from workshop 1, the themes of workshop 2 were organized into four areas.

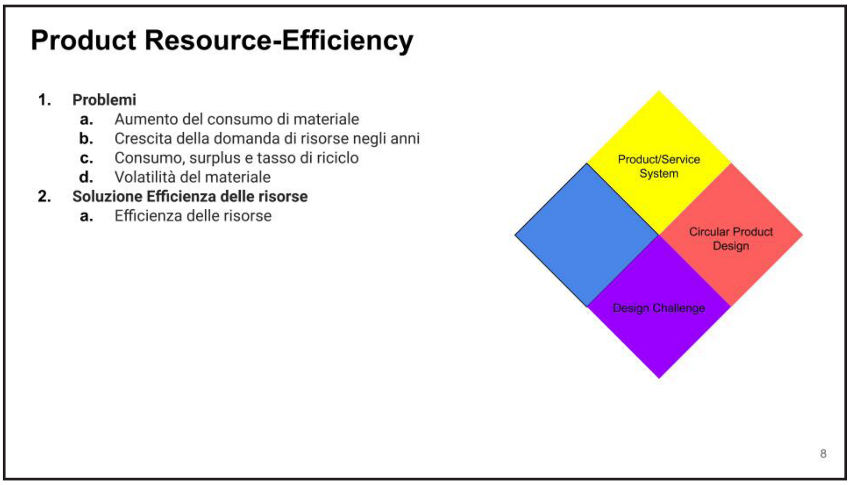
- Product Resource-efficiency
- Product-service System
- Circular Product Design
- Design Challenge

Slide 7. The different types of material flows possible in the circular economy have been introduced. Resource cycles have been presented in chapter 4, and are:

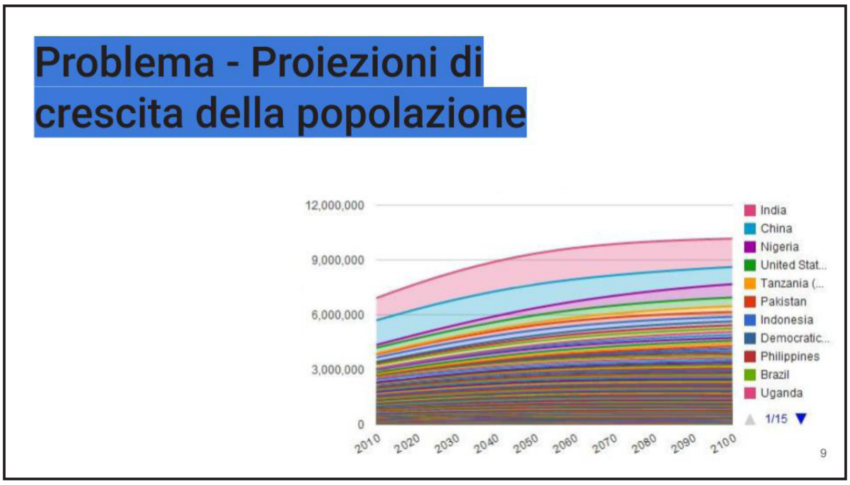
- Slowing flow
- Closing flow
- Narrowing flow

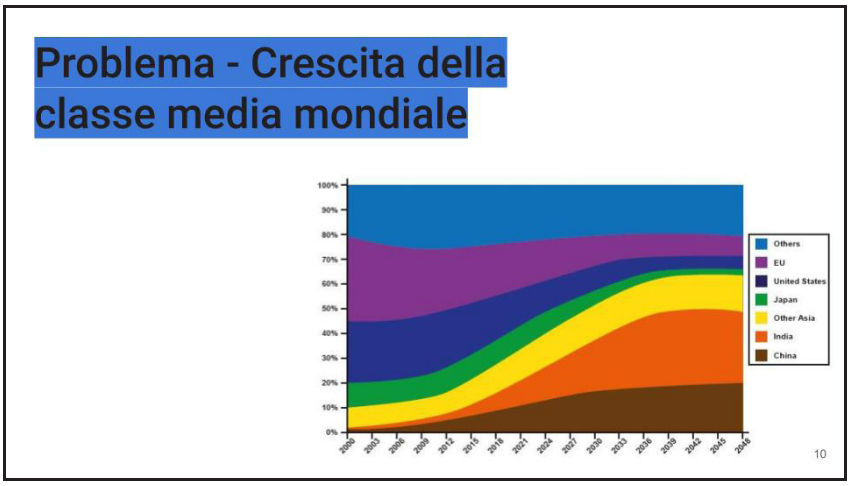


Slide 8. Product Resource Efficiency focus.

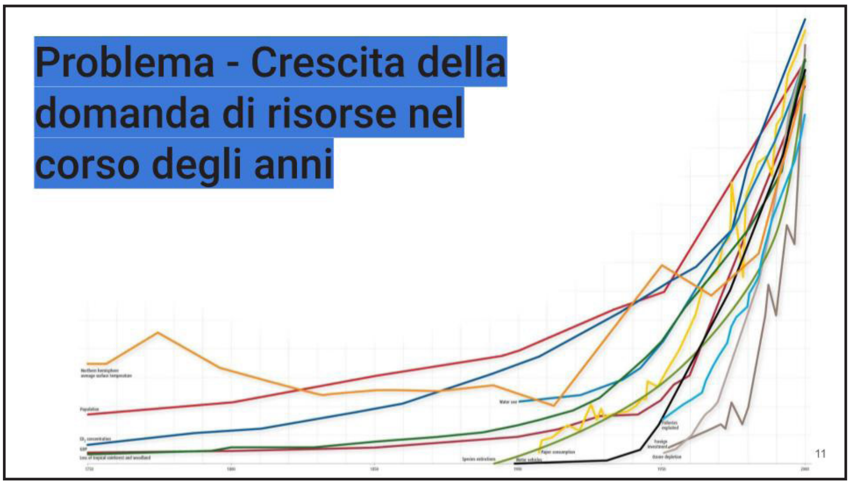


Slide 9. Representation of the current world population of 7.3 million inhabitants and projection of the attainment of the inhabitants in 2030 (8.5 million) and 2100 (11.2 million).





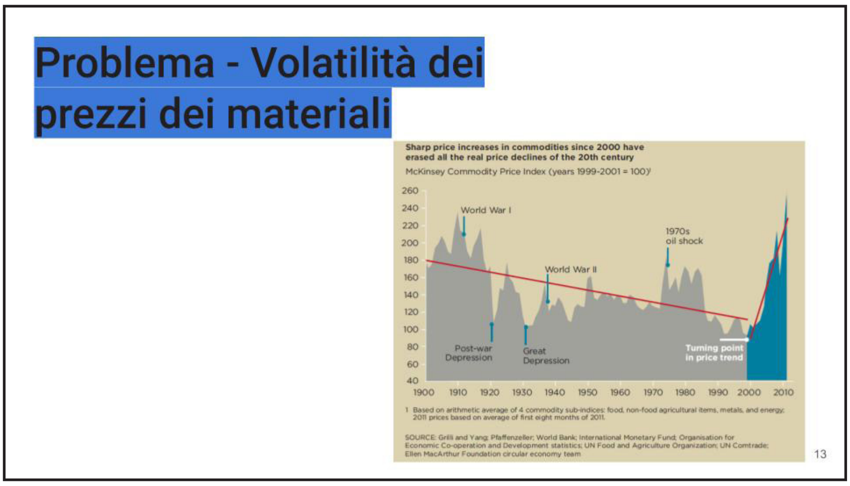
Slide 10. The size of the global middle class increased from 1.8 billion in 2009 to about 3.5 billion people in 2017 — more than half of the world population and is expected to grow to some 4 billion by 2021 and reach 5.3 billion by 2030. Some 88% of the additional middle class population will be Asians



Slide 11. Given current trends of growth, our extraction of natural resources could increase to 100 billion tonnes by 2030. People in rich countries consume up to 10 times more natural resources than those in the poorest countries.

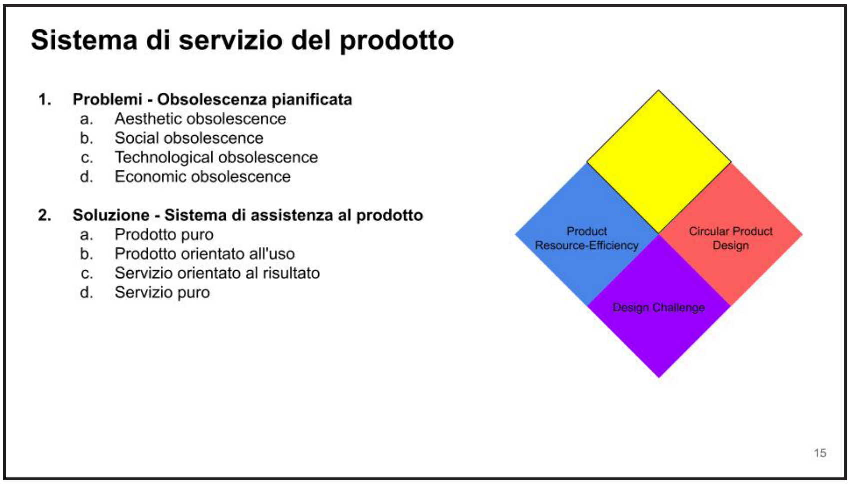
Slide 12. How Long will the earth's resources last? Our planet is running out of room and resources.

Slide 13. Many mineral and energy resources has increased fears of resource scarcity and aggravated volatility of commodity prices. Many renewable resources have also come under growing pressure as demand for food, land, soil and water has increased substantially.

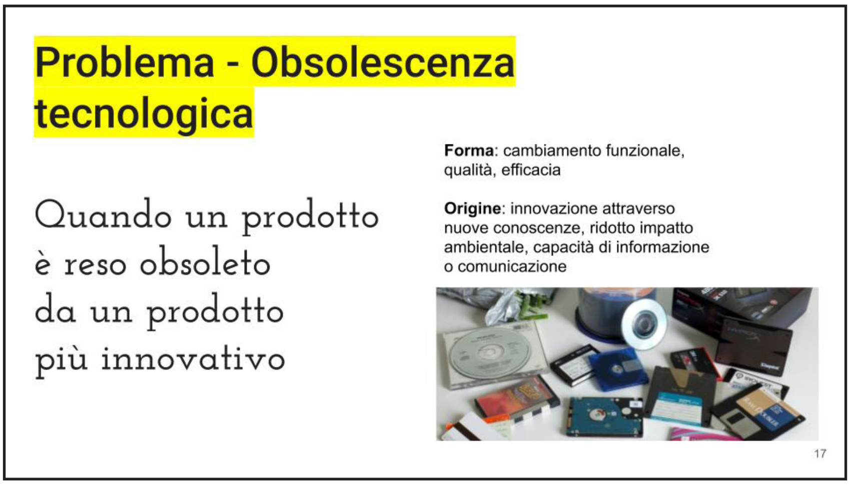


Slide 14. The design of consumption and production systems are central to resource efficiency outcomes; from the choice of resource inputs, to the exchange of waste material becoming feedstock for another, to recovery of materials at the end of their life.

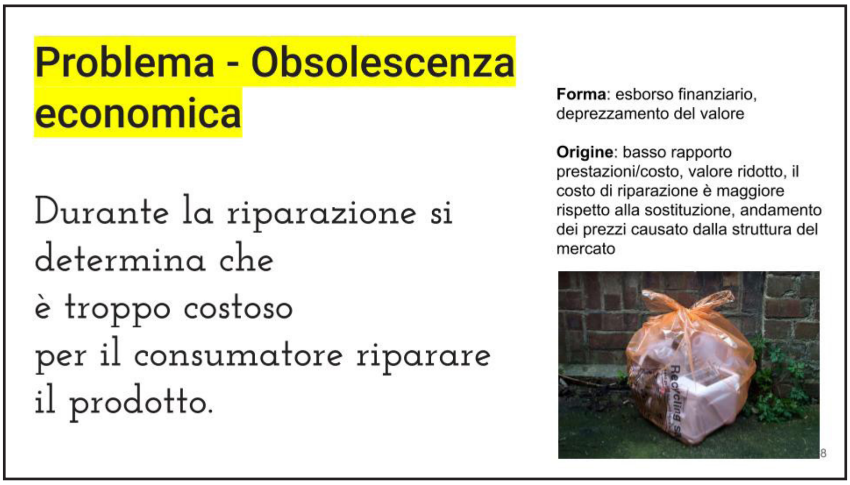
Slide 15. Product-service System focus.



Slide 16. Aesthetic Obsolescence happen when a product or asset is no longer desirable to the owners because it has gone out of the popular fashion, its style is considered to be obsolete.

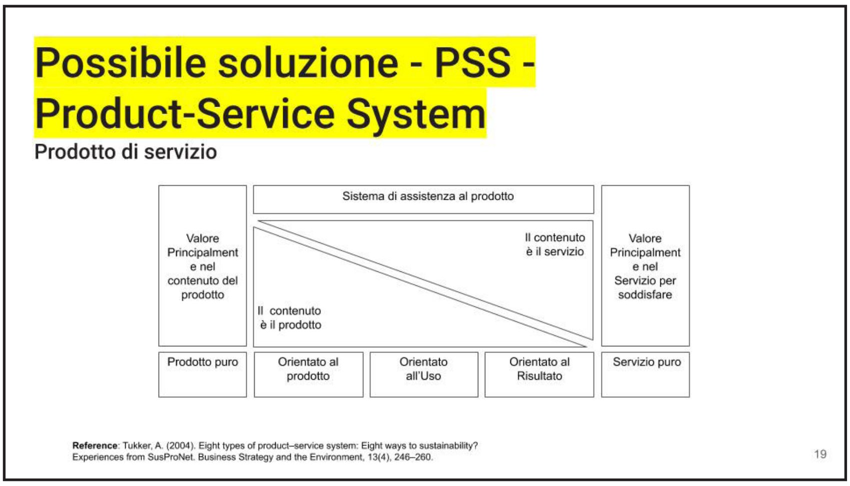


Slide 17. Technological obsolescence occur when an asset or the components of an asset become irreplacable due to changes in technology over time.



Slide 18. Economic obsolescence is the replacement or retirement of an asset because objectives and/or functionality can now be achieved in a more cost efficient way.

Slide 19. Product-service systems (PSS) are business models that provide for cohesive delivery of products and services. PSS models are emerging as a means to enable collaborative consumption of both products and services, with the aim of pro-environmental outcomes.



Slide 20. Pure product means the product where the ownership of the product passes from the retailer to the customer. Once the product has been sold, the retailer has no obligation to maintain the product.

Slide 21. In this case, the provider not only sells a product, but also offers services that are needed during the use phase of the product. This can imply, for example, a maintenance contract, or a take-back agreement when the product reaches its end of life (Tukker, 2004).

Slide 22. In relation to the product sold, the provider gives advice on its most efficient use. This can include, for example, advice on the organizational structure of the team using the product, or optimizing the logistics in a factory where the product is used as a production unit. (Tukker, 2004)

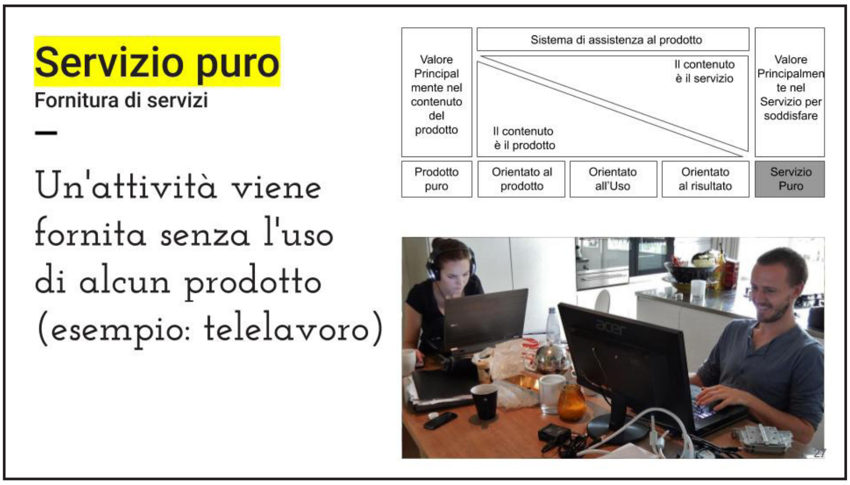
Slide 23. In this case the product does not shift in ownership. The provider has ownership, and is also often responsible for maintenance, repair and control. The lessee pays a regular fee for the use of the product. (Tukker, 2004)

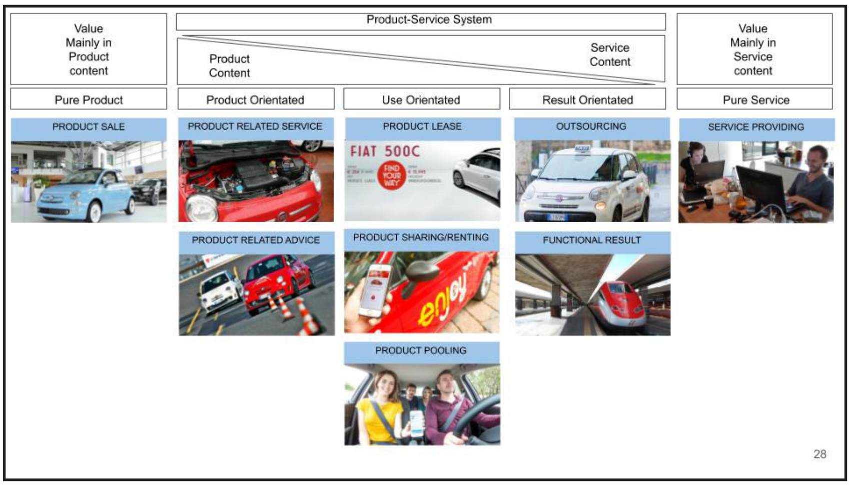
Slide 24. The product is owned by a provider, who is also responsible for maintenance, repair and control. The user pays for the use of the product. The main difference to product leasing is, however, that the user does not have unlimited and individual access. (Tukker, 2004)

Slide 25. Here a part of an activity of a company is outsourced to a third party. Since most of the outsourcing contracts include performance indicators to control the quality of the outsourced service, they are grouped in this paper under resultoriented services (Tukker, 2004).

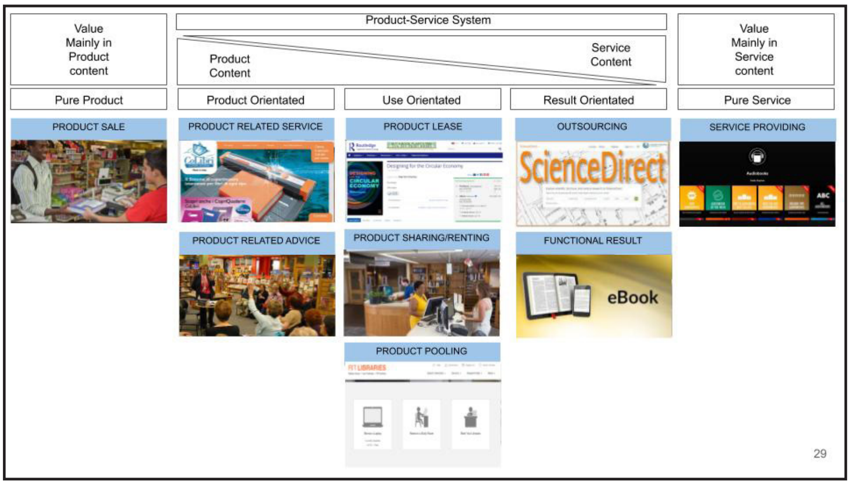
Slide 26. In this case the user no longer buys the product, only the output of the product according to the level of use. Well known examples in this category include the payper-print formulas now adopted by most copier producers (Tukker, 2004).

Slide 27. In the latter case, the supplier provides a service but not the product.

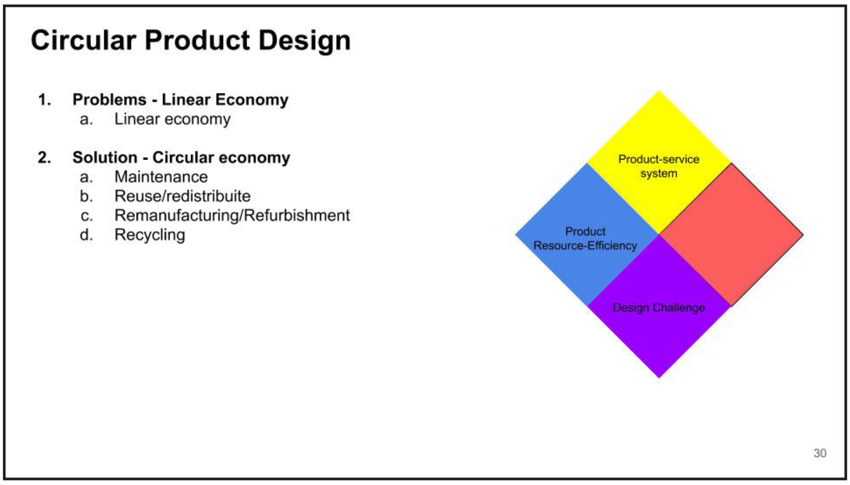




Slide 28. Case study of a car in a Product-Service System.

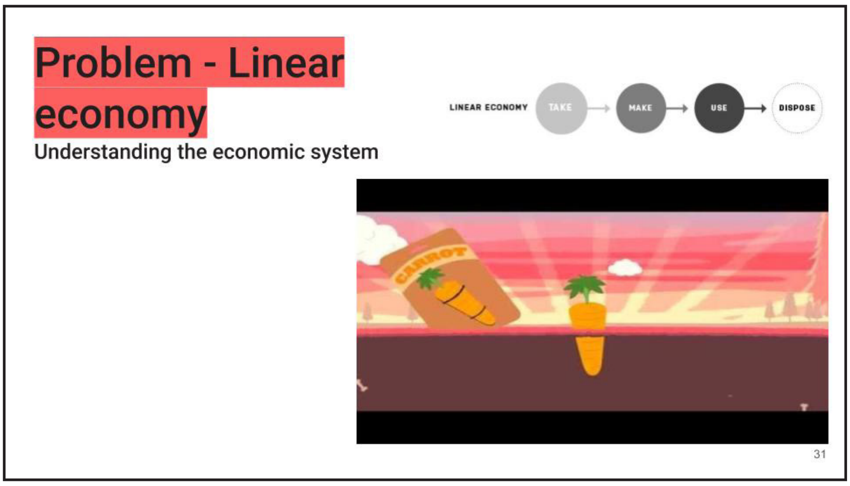


Slide 29. Case study of a book in a Product-service System.

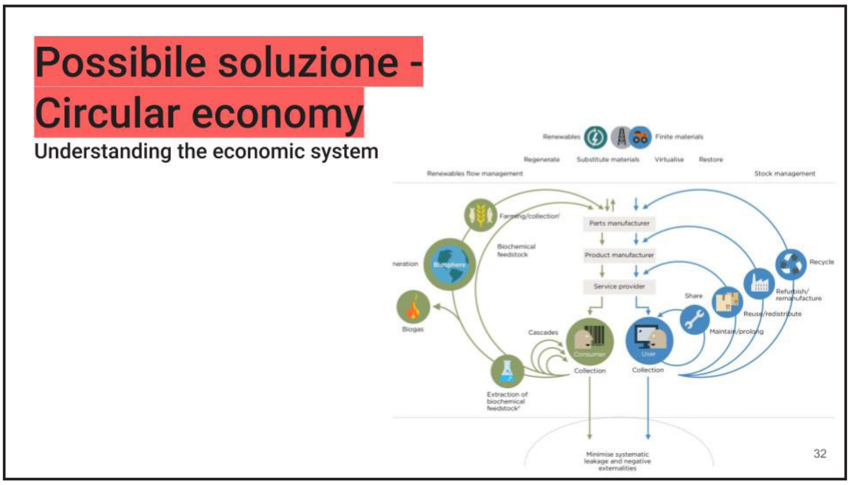


Slide 30. Circular Product Design focus.

Slide 31. The last century of industrial change has been a clear development of a linear economy - a one way flow of goods and materials from extraction, manufacture, use and disposal.



Slide 32. The circular economy - a concept which ensures that products are designed with their eventual reuse, upcycling or biodegradation in mind - emerged as the most prominent trend that is driving the innovation of sustainable solutions worldwide.



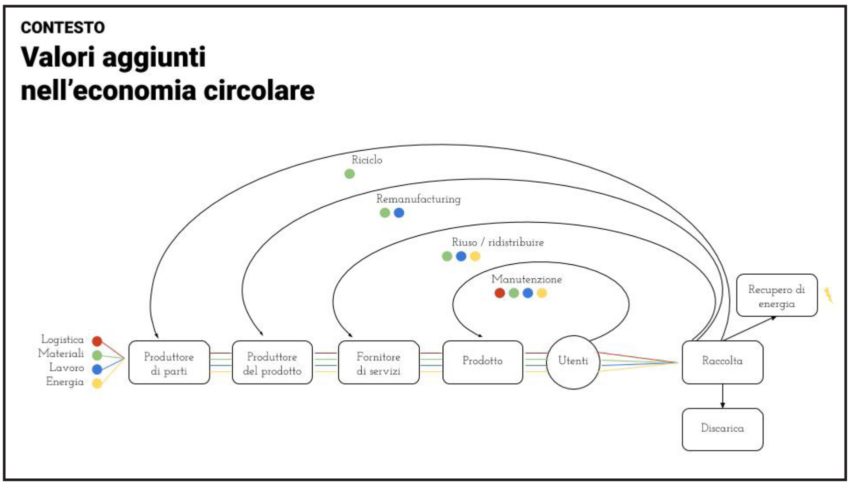
Slide 33. Maintenance is the most efficient way to retain or restore equipment to its desired level of performance. Proper maintenance has the added responsibility of protecting the equipment from further damage, personal safety and pollution prevention (Ajukumar 2007).

Slide 34. Direct Secondary Re-usage or resale extends the product life by second hand use. Therefore, fewer products, which serve for the same purpose, have to be produced.

Slide 35. Remanufacturing is the industrial process whereby used products referred to as ‘cores’ are restored. It is a process of recapturing the value added to the material when a product was first manufactured.

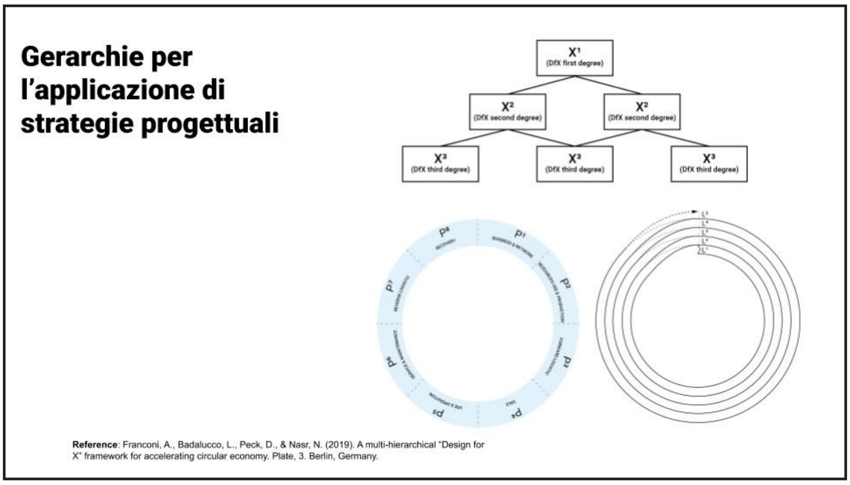
Slide 36. Recycling is the process of using materials at the end of their life for new products. The process avoids waste going to landfill, reduces energy usage and the impact on the environment. Recycling is commonly done in the metals, paper, glass, plastics and textiles (Bor, 1994).

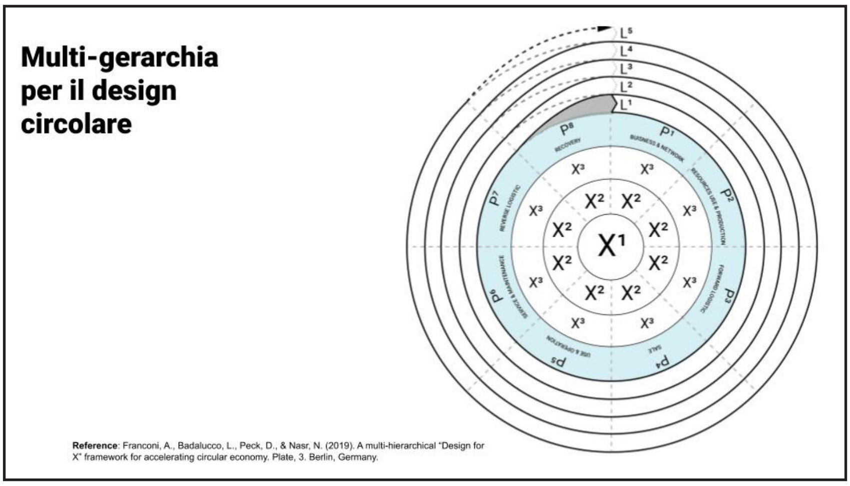
Slide 37. Introduction of the values that are maintained or lost within the circular economy. The image was developed during doctoral research and discussed in Chapter 4.



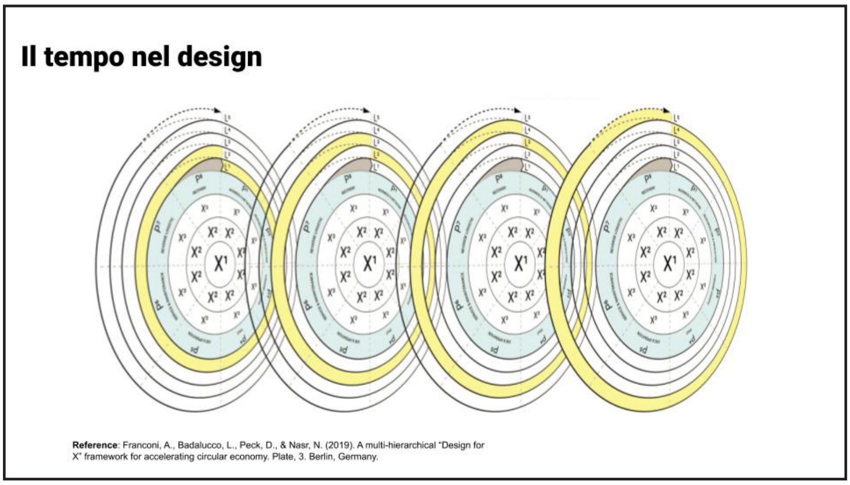
Slide 38. Complexity management is a business methodology that deals with the analysis and optimization of complexity in enterprises. Effects of complexity pertain to all business processes along the value chain and hence complexity management requires a holistic approach.

Slide 39. Introduction to the workshop participants of the possible ways in which design strategies can be applied to various criteria.





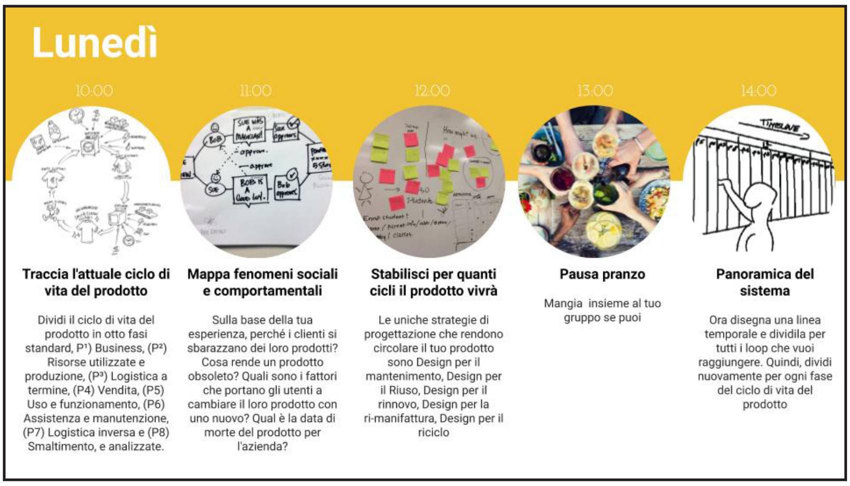
Slide 40. Introduction of the multi hierarchical framework for the prioritization of design strategies to the participants of the workshop. The framework is presented and discussed on this thesis in chapter 5.



Slide 41. Introduction to the workshop participants of the vision of multiple life cycles and how careful planning for the management of resource design can increase the product life cycle.

Slide 42. Sprints are time-boxed periods of one week to one month, during which a product owner, scrum master, and scrum team work to complete a specific product addition. In the workshop number 2 the Sprint was performed with various modifications.

Slide 43. Detailed presentation of the workshop and all the tasks of the participants. For a more detailed view of each task, please refer to Appendix D



Slide 44. Detailed presentation of the workshop and all the tasks of the participants. For a more detailed view of each task, please refer to Appendix D

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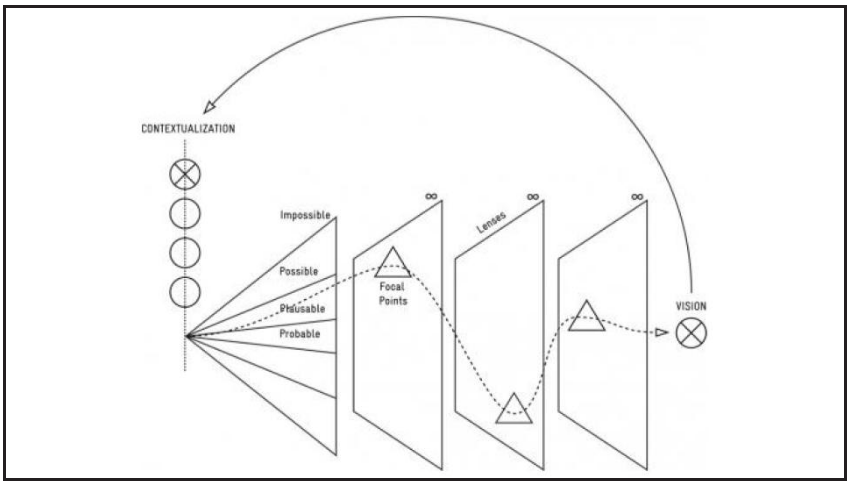


Slide 46. Extrapolation Factory Process Diagram - Future Cone.

Slide 47. Detailed presentation of the workshop and all the tasks of the participants. For a more detailed view of each task, please refer to Appendix D

APPENDIX D

Documents presented on the first day of the workshop 2:

DESIGN FOR DIFFERENT PRODUCT LIFETIMES

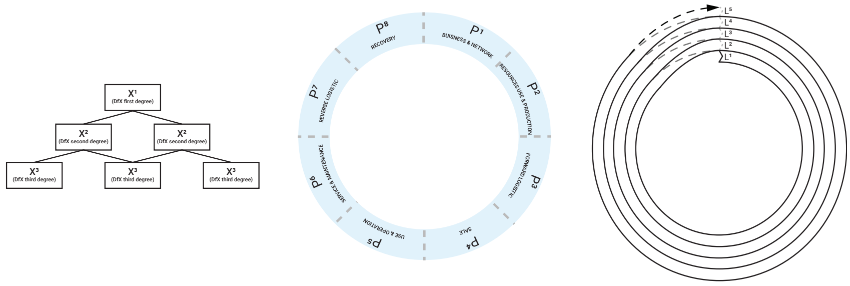


Figure D.1. Possible hierarchies.

X= Design strategy

Hierarchy of degree of importance of a design strategy

P= Phase of product lifecycle

Hierarchy of sequential phases of the product lifecycle

L= Lifecycle or loop of the product

Hierarchical sequence of the lifecycle of the product.

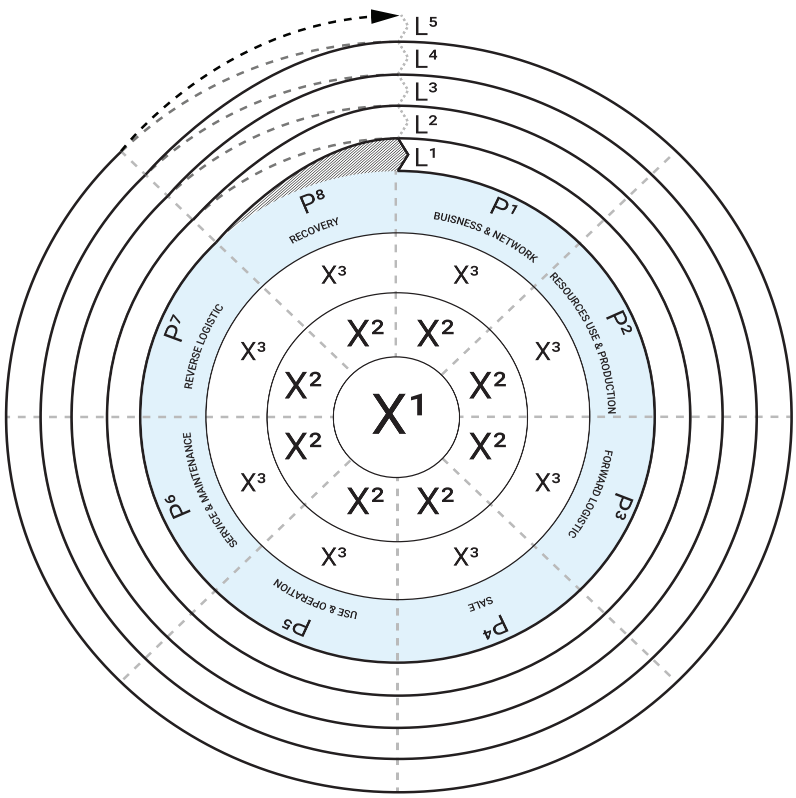
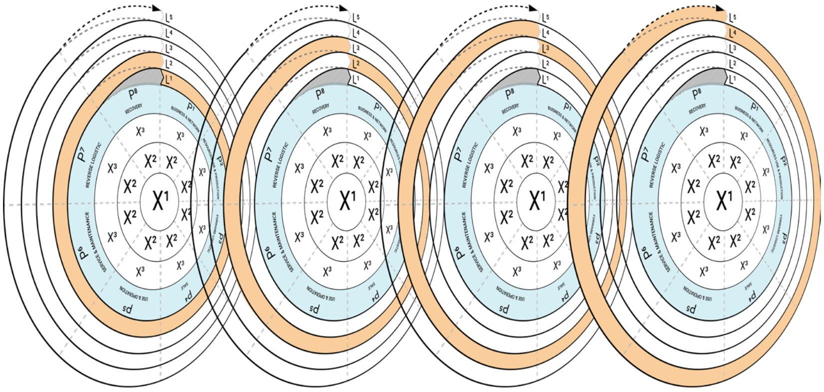


Figure D.2. Multi-hierarchical DfX framework for designing circular products.



The concept of time on different loops of the same product. For each loop X^1 can change, and consequently the associated strategies will also change (X^2 and X^3).

X^1 - Main circular strategy

The X^1 strategy represents the only and the first strategy that the company needs to define when designing for the circular economy. It identifies the general circular business approach for each Loop (L). Therefore it will define all the other design strategies (X^2 and X^3) for each phase of the design process of the same Loop. Designers can substitute X^1 with one of the following design strategies:

1. Design for Maintainance;
2. Design for Reuse;
3. Design for Refurbish;
4. Design for Remanufactured;
4. Design for Recycle.

P1 - Business & Network

The P^1 represents the Phase (P) in which the business model is determined. In this phase is defined how the company/ies and the stakeholders should create, deliver and capture value in each loop (L).

X^2 in P^1

The X^2 in P^1 strategy represents the main strategy or strategies business designers can use in order to make X^1 possible.

X^3 in P^1

The X^3 in P^1 strategy represents the strategy or strategies business designers can use in order to make X^2 possible.

P^2 - Resources use & Production

The P^2 represents the Phase (P) in which the resources use and production is determined. In this phase is defined how the company/ies and the stakeholders should create, deliver and capture value in each loop (L).

X^2 in P^2

The X^2 in P^2 strategy represents the main strategy or strategies industrial engineers can use in order to make X^1 possible.

X^3 in P^2

The X^3 in P^2 strategy represents the strategy or strategies industrial engineers can use in order to make X^2 possible.

P^3 - Forward Logistics

The P^3 represents the Phase (P) in which the forward logistics is determined (from raw materials to end-user). In this phase is defined how the company/ies or stakeholders organize the infrastructural movement of the value in each loop (L).

X^2 in P^3

The X^2 in P^3 strategy represents the main strategy or strategies logistics engineers can use in order to make X^1 possible.

X^3 in P^3

The X^3 in P^3 strategy represents the strategy or strategies logistics engineers can use in order to make X^2 possible.

P^4 - Sale

The P^4 represents the Phase (P) where it is determined how to sell the value. In this phase is defined how the company/ies or stakeholders sale the value to the final-user for each loop (L).

X^2 in P^4

The X^2 in P^4 strategy represents the main strategy or strategies marketing designers can use in order to make X^1 possible.

X^3 in P^4

The X^3 in P^4 strategy represents the strategy or strategies marketing designers can use in order to make X^2 possible.

P^5 - Use & Operation

The P5 represents the Phase (P) where it is determined how users will use the value. In this phase is defined how the company/ies or stakeholders design the value for the different final-users for each loop (L).

X^2 in P^5

The X^2 in P^5 strategy represents the main strategy or strategies industrial designers can use in order to make X^1 possible.

X^3 in P^5

The X^3 in P5 strategy represents the strategy or strategies industrial designers can use in order to make X^2 possible.

P^6 - Service & Maintainance

The P^6 represents the Phase (P) in which the value is maintained through related services. In this phase is defined how the company/ies and the stakeholders should provide the maintenance of the value in each loop (L).

X^2 in P^6

The X^2 in P^6 strategy represents the main strategy or strategies service designers can use in order to make X^1 possible.

X^3 in P^6

The X^3 in P^6 strategy represents the strategy or strategies service designers can use in order to make X^2 possible.

P^7 - Reverse Logistics

The P^7 represents the Phase (P) in which the reverse logistics is determined (from end-user to recovery or to a new user). In this phase is defined how the company/ies or stakeholders coordinate the infrastructural return of the value in each loop (L).

X^2 in P^7

The X^2 in P^7 strategy represents the main strategy or strategies reverse

logistics engineers can use in order to make X^1 possible.
X^3 in P^7
The X^3 in P^7 strategy represents the strategy or strategies reverse logistics engineers can use in order to make X^2 possible.

P^8 - Recovery
The P^8 represents the Phase (P) in which the recovery of the value comes about. In this phase is defined how the company/ies or stakeholders coordinate the recovery of each part of the product each loop (L).
X^2 in P^8
The X^2 in P^8 strategy represents the main strategy or strategies recovery designers can use in order to make X^1 possible.
X^3 in P^8
The X^3 in P^8 strategy represents the strategy or strategies recovery designers can use in order to make X^2 possible.

L^1 - First product lifecycle
In L^1 the product is new and usually, this is the most easy design process to design. However, from the good management of this loop depends the succesfully of the next loops (L^2, L^3, etc).

L^2 - Second product lifecycle
In L^2 the product is in its second lifecycle. From this loop on out, the product may have been reused, refurbished, remanufactured, or recycled. All the loops after the first are more difficult to manage because the company should take into consideration different factors for each of the different loops, such as recovery, market, target, etc.

CIRCULAR DESIGN WORKSHOP
DAY ONE

10:00
Defining the current design process. Try to visualize on a whiteboard all the current individual *phases* (P) which your product come across throughout its entire life cycle [You can use as a reference phases: (P^1) Business & Network, (P^2) Resources Used & Production, (P^3) Forward Logistics, (P^4) Sale, (P^5) Use & Operation, (P^6) Service & Maintenance, (P^7) Reverse Logistics and (P^8) Dispose]. See Figure 1.

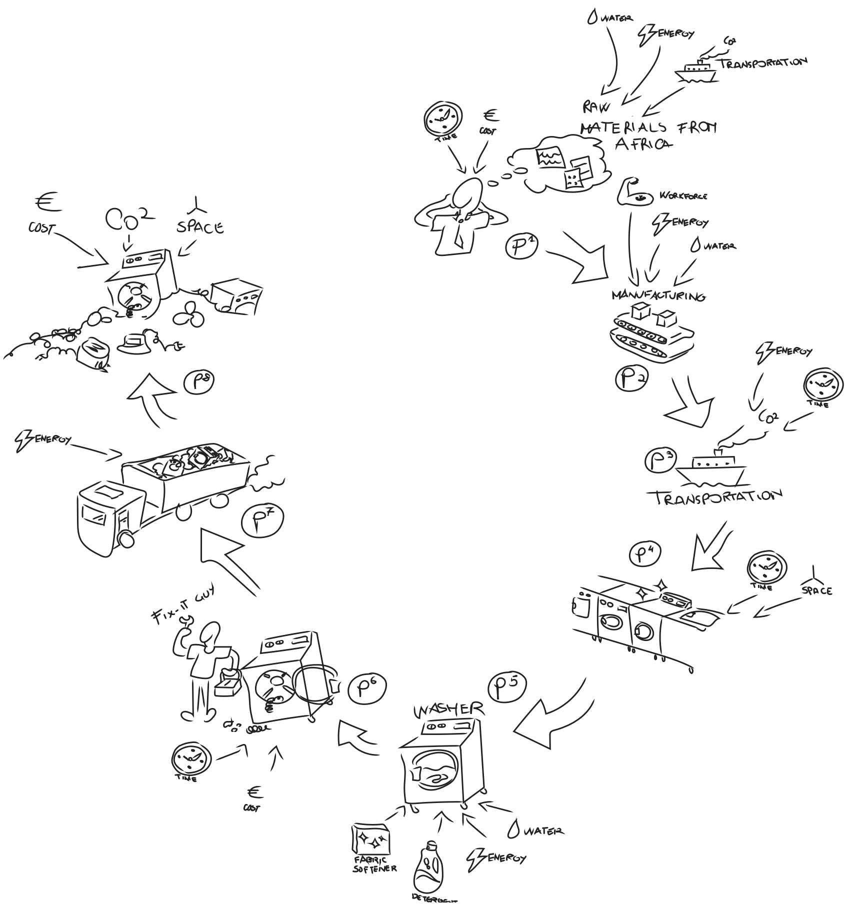
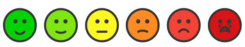
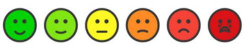


Figure 1. Example of a life-cycle visualization of a washing machine.



11:00
Map social and behavioral phenomena. Gather on your expirience why customers got rid of their products. What make a product obsolate? Which are the factors that lead users to change their product for a new one? Which is the death-dating of the product for the company?



12:00
Set a multi circular design-life goal. Depending on the product you are designing, determinate on how many loops the product should get back into the system (Fig. 2). Think big, think positive. Ask: Which is the most desirable vision of the world in 50 years we would like

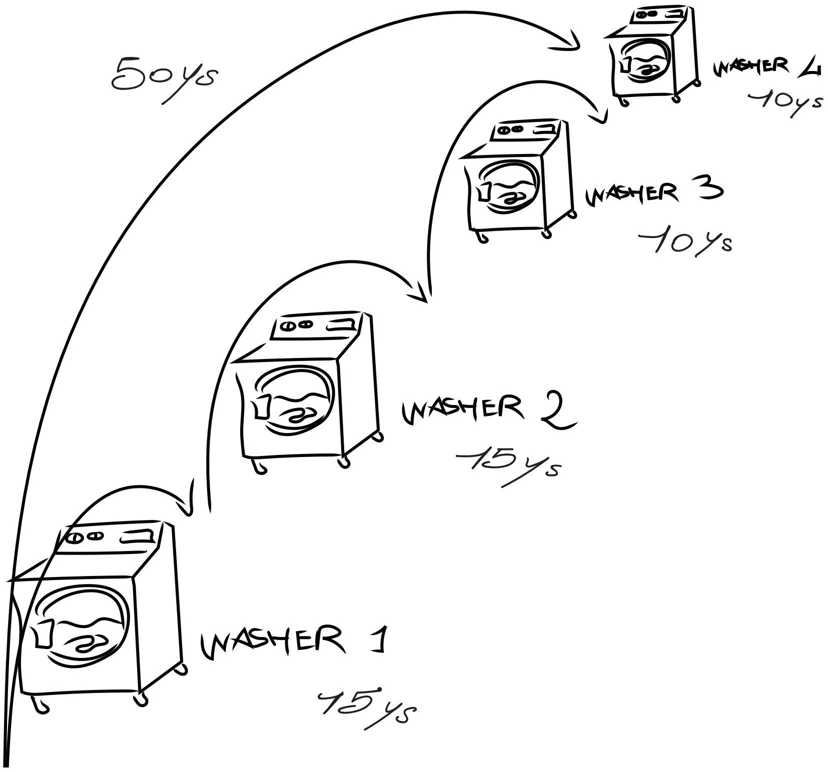
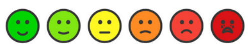


Figure 2. Example of a circular washing machine scenario.

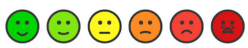
to see? How might my company and products facilitate it? For each loop, try to hypothesize which strategy you are going to use to get back the product and which is the estimated time the product can be maintained in service in a specific loop. The only design strategies that make your product circular are *Design for Reuse*, *Design for Refurbish*, *Design for Remanufacturing*, *Design for Recycle*.

List questions. Next, tray to be pessimistic. Ask: How could we will fail? transform your fears into questions you could answear this week. List them on a whiteboard.

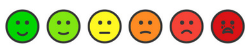
13:00
Lunch brack. Eat together if you can (it's fun).



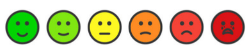
14:00
Overview of the system. Now drow a timeline and divide it for all the loops you want to reach. Then, divide it again for each phases of the life-cycle of the product (Fig.3).



14:30
Pick a target for each loop. Define your most important customer for each loop that will be willing to buy your product. The team can weight in, but the Decider makes the call.



15:00
Product Journey Pain Points Analysis.
Now, try to see all the different loops holistically and discuss with your group which are the main good and pain points for each loop to achive all the defined circular strategies with your customers in mind.



Define your scope. Tray to solve evrything is quite impossible. For this reason you need to concentrate your energy on the most *riskiest assuption* you want to validate. Pick it by voiting. Each component of the group has two votes.

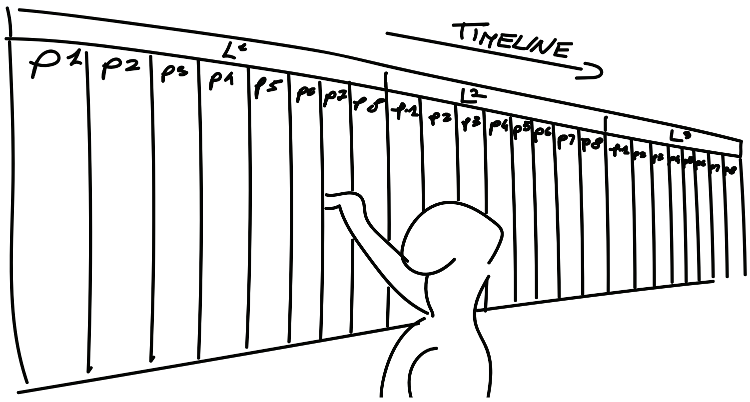
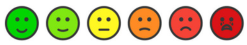
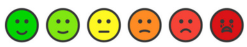


Figure 3. Timeline drawing.

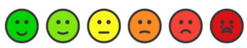


15:30 - 17:30
Ask the experts. In the circular economy there are different experts for different product stages. Depending of your aims, tray to define who is the main expert for your project who can help you to clear your doubts. Is it an expert from my company? Is it a repair shop? Is it a waste manager? or is it an expert from a second-hand company?

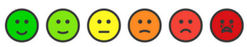
CIRCULAR DESIGN WORKSHOP
DAY TWO



09:30
Expain How Might We notes. Distribute whiteboard markets and sticky notes. Reframe problems as opportunities. Start with the leter “HMW” on the top left corner. Write one idea per sticky note. Make a stack as you go.



10:30
Organize How Might We notes. Stick all the How Might We notes onto the timeline. Move similar ideas next to one another. Label themes as they emerge. Don’t perfect it. Stop about ten minutes.
Vote on How Might We notes. Each person has two votes, can vote on his or her own notes, or even the same note twice. Move winners onto your map.



12:00
Lunch brack.

13:00

Get inspired. With your gorup explore all the alternativies strategies that other companies have used to create circular products. You can use the Circular Design Tool (www. circulardesign.it) to get inspired and understand how a company can manage different design strategies. Also, use your own sources of inspiration.

1. By yourself decide which design strategy inspirined you the most even outside of your industry or field. Answear to the question "What's the design strategy here that might be useful?" (30 minutes)
2. Organize 3 minutes presentation for your colleagues to get inspired from good ideas of others
3. A voluntary, meanwhile other are presenting, should sketch the ideas onto a whitboard

15:30

Horizont scanning, the Future Cone. No one can predict the future, but as a designer, you can shape it in a certain way to make something possible. In designing for a circular system, you are required to design for a long span of time, for this reason, you must ask yourself more questions compare to an ordinary designer. Through the construction of a future cone, you can validate your assumption (Fig.4).

1. Draw a cone and divided it into four parts. Possible. Plausible. Probable. Preferable.
2. Add four lenses after the cone. Technological. Ecological. Social. Political. Economical.
3. Try to predict based on your knowledge, how your product will look like in the future and how to anticipate, avoid or facilitate possible scenarios during the life cycles of your product.

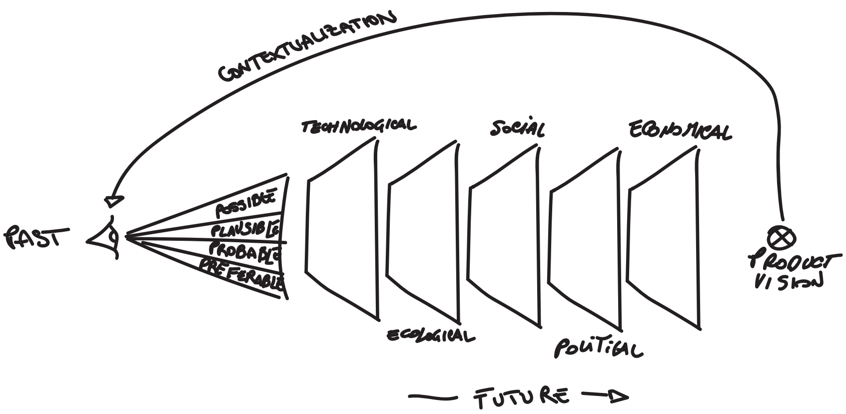


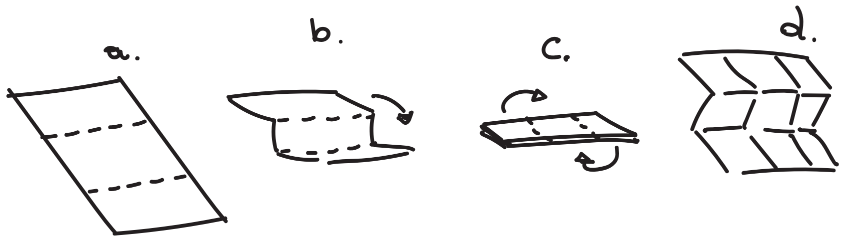
Figure 4. Future Cone.

16:30

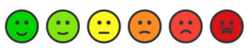
Lotus Blossom Creative Technique. Sketch down potential solutions by yourself. For each identified circular goal, each person folds an A4 paper so you have 9 panels (Fig.5). The centre square of each blossom contains the circular goal, the around squares of the central square are related to each of the eight phases of the loop.

1. Gather notes based on the inspirin step. (20')
2. Think about a potential system for the circular goal. You have 8 minutes for each blossom. Then, the same process is repeated for each loop.
3. Final sketch. Sum up a potencial product or service that will be show to the others. Keep it anonymous. Ugly is okay. Words matter. Give it a catchy title.

Figure 5. How to fold the A4 paper.

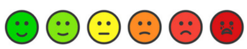


CIRCULAR DESIGN WORKSHOP
DAY THREE



09:30
Sticky decision. Follow these five steps to choose the strongest solutions:

1. Art museum. Tape the solution sketches to the wall in one long row.
2. Heat map. Have each person review the sketches silently and put one to three small dot stickers beside every part he or she likes.
3. **Speed critique.** Three minutes per sketch. As a group, discuss the highlights of each solution. Capture standout ideas and important objections. At the end, ask the sketcher if the group missed anything.
4. Straw poll. Each person silently chooses a favorite idea. All at once, each person places one large dot sticker to register his or her (nonbinding) vote.
5. Supervote. Give the Decider three large dot stickers and write her initials on the sticker. Explain that you'll prototype and test the solutions the Decider chooses.



11:30

1. Divide winners from “maybe-laters.” Move the sketches with supervotes together.

2. Rumble or all-in-one. Decide if the winners can fit into one prototype, or if conflicting ideas require two or three competing prototypes in a Rumble.
3. Fake brand names. If you're doing a Rumble, use a Note-and-Vote to choose fake brand names.
4. Note-and-Vote. Use this technique whenever you need to quickly gather ideas from the group and narrow down to a decision. Ask people to write ideas individually, then list them on a whiteboard, vote, and let the Decider pick the winner.

13:00
Lunch.

14:00
Make a storyboard. Use a storyboard to plan your prototype.
1. Draw a scena for each phase of the Timeline. You can draw one or more scenes for each phase product or service. Keep your opening scene simple: web search, magazine, article, store shelf, etc.
2. Fill out the storyboard. Move existing sketches to the storyboard when you can. Draw when you can't, but don't write together. Include just enough detail to help the team prototype on Thursday. When in doubt, take risks.

CIRCULAR DESIGN WORKSHOP
DAY FOUR

09:30
Prototype!
1. Pick the right tools. Don't use your everyday tools. They're optimized for quality. Instead, use tools that are rough, fast, and flexible.
2. Divide and conquer. Assign roles: Maker, Stitcher, Writer, Asset Collector, and Interviewer. You can also break the storyboard into smaller scenes and assign each to different team members.

09:30
Lunch

09:30
Prototype!
1. Stitch it together. With the work split into parts, it's easy to lose track of the whole. The Stitcher checks for quality and ensures all the pieces make sense together.
2. Do a trial run. Run through your prototype. Look for

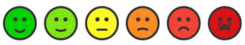
mistakes. Make sure the Interviewer and the Decider see it.
3. Finish up the prototype.

Throughout the Day
Write interview script. The Interviewer prepares for Friday's test by writing a script.
Remind customers to show up for Friday's test.Email is good, phone call is better.

Key Ideas
Prototype mindset. You can prototype anything. Prototypes are disposable. Build just enough to learn, but not more. The prototype must appear real.
Goldilocks quality. Create a prototype with just enough quality to evoke honest reactions from customers.

CIRCULAR DESIGN WORKSHOP
DAY FIVE

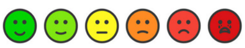
09:30



Makeshift Research Lab
• Two rooms. In the sprint room, the sprint team will watch a video feed of the interviews. You'll need a second, smaller room for the actual interviews. Make sure the interview room is clean and comfortable for your guests.
• Set up hardware. Position a webcam so you can see customers' reactions. If your customer will be using a smartphone, iPad, or other hardware device, set up a document camera and microphone.
• Set up video stream. Use any video-conferencing software to stream video to the sprint room. Make sure the sound quality is good. Make sure the video and audio are one-way only.

Key Ideas
• Five is the magic number. After five customer interviews, big patterns will emerge. Do all five interviews in one day.
• Watch together, learn together. Don't disband the sprint team. Watching together is more efficient, and you'll draw better conclusions.
• A winner every time. Your prototype might be an efficient failure or a flawed success. In every case, you'll learn what you need for the next step.

Five-Act Interview

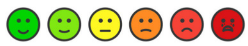


• Friendly welcome. Welcome the customer and put him or her at ease. Explain that you're looking for candid feedback.
• Context questions. Start with easy small talk, then transition to questions about the topic you're trying to learn about.

• Introduce the prototype. Remind the customer that some things might not work, and that you're not testing him or her. Ask the customer to think aloud.
• Tasks and nudges. Watch the customer figure out the prototype on his or her own. Start with a simple nudge. Ask follow-up questions to help the customer think aloud.
• Debrief. Ask questions that prompt the customer to summarize. Then thank the customer, give him or her a gift card, and show the customer out.

Interviewer Tips
• Be a good host. Throughout the interview, keep the customer's comfort in mind. Use body language to make yourself friendlier. Smile!
• Ask open-ended questions. Ask "Who/What/Where/When/ Why/How. . . ?" questions. Don't ask leading "yes/no" or multiple-choice questions.
• Ask broken questions. Allow your speech to trail off before you finish a question. Silence encourages the customer to talk without creating any bias.
• Curiosity mindset. Be authentically fascinated by your customer's reactions and thoughts.

Observing Interviews
Before the First Interview:



• Draw a grid on a whiteboard. Create a column for each customer. Then add a row for each prototype or section of prototype.
During Each Interview:
• Take notes as you watch. Hand out sticky notes and markers. Write down direct quotes, observations, and interpretations. Indicate positive or negative.
After Each Interview:
• Stick up notes. Stick your interview notes in the correct row and column on the whiteboard grid. Briefly discuss the interview, but wait to draw conclusions.
• Take a quick break.
At the End of the Day:
• Look for patterns. At the end of the day, read the board in silence and write down patterns. Make a list of all the patterns people noticed. Label each as
positive, negative, or neutral.
• Wrap up. Review your long-term goal and your sprint questions. Compare with the patterns you saw in the interviews. Decide how to follow-up after the sprint. Write it down.

APPENDIX E

Workshop 2 - Proteins for all

The supply chain begins with the selection of seeds that are then grown sustainably and biologically. With a future perspective, where arable land will be less and less, technology will help to develop alternative methods of cultivation to complement the traditional ones, with less consumption of raw materials and water. The company considered is rooted in the territory, uses s short supply chain and only sustainable energy to produce portioned meals. Once the raw product arrives on the company from farms, it is transformed into different food products and packaged in single-portion reusable and stackable glass jars. All the water used during the working processes will be purified and put back into circulation, while Biological waste will be composted or used in the production of energy with biomass.

The company is oriented in two commercial directives: large-scale distribution and online sale with home delivery. The large-scale distribution model (managed by third parties) is based on sorting the products in the various sales points where the customer can choose to buy portioned meals in the supermarket, in a traditional way or by receiving them at home. Another possible way is to book portioned meals from the app and directly receive them at home.

After the consumption of the products the customer takes care of jars by cleaning the empty vases and, in case of purchase within the supermarket, he will also undertake their return. When the purchase happened through the app, the jars will be taken back in the next delivery from the delivery guy. In any case, the cap, made of 100% recyclable sheet, will be thrown by the user in the special recycling bin. To facilitate the delivery and recovery of vessels students have created a box that, through special hinges, reduce the volume by one-third of the empty jars. After the withdrawal of the jars by the operator (both at the supermarkets and in the residences of customers), the jars are sent to the company where they are washed, sterilized and used again as food containers that will then be redistributed. This way you have a complete one circular economy of the product that can ideally last up to six cycles of use at the end of which it will be melted and recycled to be ready for one new production.

All within the application the customer can take advantage of additional services such as a recipe section (complete with degrees of difficulty and timing) also from other countries, a section dedicated to recommended diets and an interactive part is dedicated to children.

Figure B.1. Protein for all team group working on their project and presenting to professors.

CRITERION	EVALUATION
1) Has the product been resolved under multiple design perspectives? How?	Yes, the group focused on the business model and how this could influence the design of the final product. Moreover, they had particular attention to materials and transportation processes.
2) Did the participants consider multiple product life cycles?	Yes, the group focused on how the fan could be upgraded and reused by the same user, or other users. They understood also that once the product will reach the end of life, parts and materials can be reused for new fans.
3) Were the participants able to integrate different strategies?	Yes, the participants integrate multiple design strategies such as servitization of the product, customization, reuse of materials, etc.
4) Did the participants understand that different design strategies are required for each product life cycle?	Yes, they did.

Table E.1. Protein for all evaluation.

Workshop 2 - Rewind

Starting from a medium-low range fan designed for a linear economy system, students analyzed the life cycle and the various issues related to this object such as the frequency of "Damage" related to the poor quality of the materials and the methods of production. Often this object lasts a few years and comes abandoned or thrown in the landfill. Students have therefore tried to redesign the product for the circular economy system.

The final project has been designed with recyclable materials that can be rent nationally for a certain period of time. Doing so, the company can offer a high-quality service and users can buy a good fan without investing much money on the product. For the maintenance or return of the product, students thought to create an app in order to support and facilitates these processes, also offering the possibility of product customization with it. Once returned, the status of the product will be evaluated and updated by the company and reintegrated into the system in order to be reused by another customer. When the product will no longer be reusable, the various parts will be disassembled sent to companies involved in the recycling of materials.

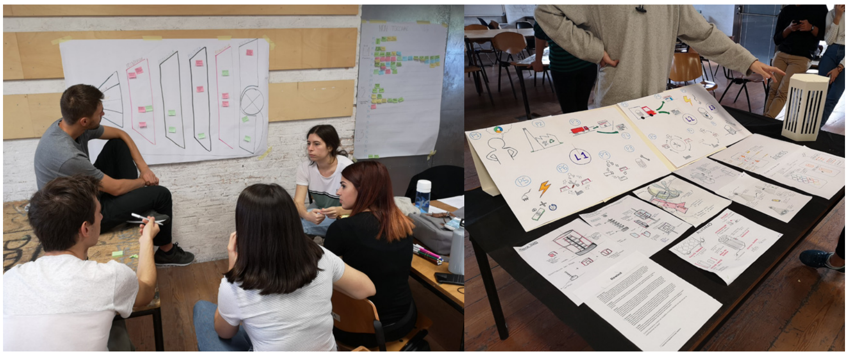


Figure E.2. Rewind team group working on their project and presenting to professors.

CRITERION	EVALUATION
1) Has the product been resolved under multiple design perspectives? How?	Yes, the group focused on the business model and how this could influence the design of the final product. Moreover, they had particular attention to materials and transportation processes.
2) Did the participants consider multiple product life cycles?	Yes, the group focused on how the fan could be upgraded and reused by the same user, or other users. They understood also that once the product will reach the end of life, parts and materials can be reused for new fans.
3) Were the participants able to integrate different strategies?	Yes, the participants integrate multiple design strategies such as servitization of the product, customization, reuse of materials, etc.
4) Did the participants understand that different design strategies are required for each product life cycle?	Yes, they did.

Workshop 2 - Reborn

Reborn aims to raise awareness on the issue of ecology and make people more aware of their actions, towards the environment. Woody by Reborn is a rocking horse born with the aims to transmit to children the idea of circularity, providing a more careful and conscious reflection regarding the life cycle of the products, within the current consumerist system. Woody by Reborn encourages the reuse of materials and points to reduce the waste of primary resources, in order to make productions more durable. Woody is in fact made by local artisans from waste materials originate by local processing, which is why each horse comes with different peculiarities and finishes. In this project, students concentrated on the differences between each horse, and they said that "everyone" will have a story to tell. Focusing on the concept of storytelling, students decided to offer to the user the possibility of personalizing the single product, telling in a booklet supplied by the company the adventures spent between the hobbyhorses and the child. The booklets will be in fact more than one, customized by each user, in order to encourage the idea of exchange by exploiting the curiosity of children.

By means of an online platform, the company provides the user with the possibility of renting a Reborn toy, without having to necessarily purchase it, thus avoiding unnecessary accumulation of objects and space problems, thus encouraging 'sharing', the principle behind the concept of circular economy, which prefers the recirculation of objects rather than the possession of the same, in order to fully exploit their durability, and avoid overproduction and waste of resources. The rental implies an initial cautionary sum of € 40, which will then be returned at the end of the rental period, or at the return of the product to the company, which must take place within a maximum of 4 years, these € 40 will add up to € 20, or the equivalent price for each year of rental, as needed. The design stems from the desire to maintain the historicity of a symbolic object that is the rocking horse, handed down good times, proposing it in a modern key in order to keep up with the demands and demands of today's market. Modularity and simplicity are the basis of the project, in order to be able to guarantee the rapid replacement of the components, thanks to our assistance service, in order to expand the catchment area.

The possibility of being able to flip the rocking shoes by inserting wheels at the base provides a second way of using them, clearing the classic and timeless piggyback, giving it an extra sprint. Overall, Reborn aims to reduce production by favoring the exchange of the same objects, from user to user, in order to maximize the value and possibilities provided by them.

Figure E.3. Reborn team group working on their project and preparing their prototype.

Table E.3. Reborn evaluation.

CRITERION	EVALUATION
1) Has the product been resolved under multiple design perspectives? How?	Yes, participants have designed the product with multiple design perspectives, for instance, by proposing alternative business models and studying the transportation system that could be applied to the toy.
2) Did the participants consider multiple product life cycles?	Yes, the group focused on how the toy could be upgraded and reused by the same or different user.
3) Were the participants able to integrate different strategies?	No, the group used different design strategies, but most of them were related only to the users.
4) Did the participants understand that different design strategies are required for each product life cycle?	Yes, they did.

Workshop 2 - Typo

Typo was born from the present needs of flexibility and continuous demand for new working environments. Typo is a furnishing system of metal "U" joints that can be used to fix wooden supports with different lengths to create various types of compositions according to your space and needs. The advantage of Typo is the easy dis-assemble and replace with new components whenever the customer needs. For example, if the company grow lushly and needs more tables and shelves, they can simply order a number of joints from the company and build all their furniture by themselves. The circularity of the product is also guaranteed by the collection service that the company is able to provide. Each part can be reconditioned and put back on the market for many and many loops.

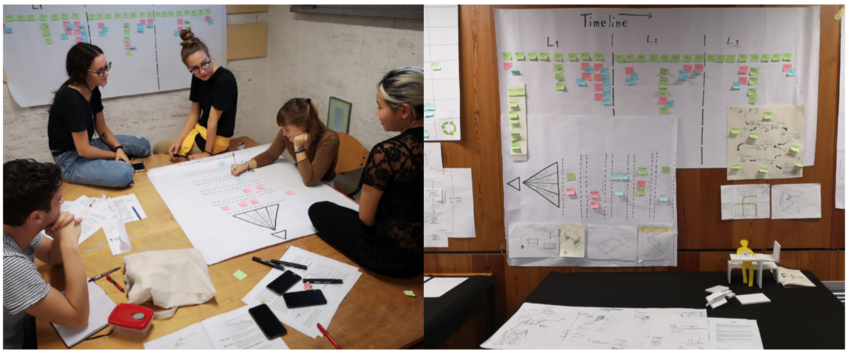


Figure E.4. Typo team group working on their project and their prototype.

Table E.4. Typo evaluation.

CRITERION	EVALUATION
1) Has the product been resolved under multiple design perspectives? How?	No, the group focused mainly on the design of the joint.
2) Did the participants consider multiple product life cycles?	Yes, the group focused on how the multiple life cycles of the product, however, they have neither made further assessments in the subsequent cycles nor have they presented any more precise definitions of project.
3) Were the participants able to integrate different strategies?	No, the group were not able to add multiple design strategy.
4) Did the participants understand that different design strategies are required for each product life cycle?	No, they didn't.

Workshop 2 - Reshoes

Reshoes - Kintsugi is a runner shoe and not only, designed to last up to 10 years. In fact, it is a shoe that can survive up to 4 life cycles and used by 3 different customers, to be then recycled and become a resource and material for the production of a new shoe. The shoe is composed of only 3 parts: the external part, the upper and the laces. The upper, made of elastic fabric, breathable and light, has been designed as removable and replaceable at any time, with possible color variations that meet the tastes of the customers. The easy separation of the part in contact with the foot from the rest of the shoe solves problems of hygiene and it is the solution that convinces everyone, even the least inclined users to wear used clothes, to buy this product. The external part which also includes the sole has been designed taking inspiration from the shapes of nature and the interlocking mechanism of the cells of the bees. The result is a durable formed hexagons shape mesh that together wraps and protect the upper part, giving lightness, dynamism and grip. The production and repair processes of the structure take advantage of the technology's potential 3D printing for fast, precise and direct maintenance in the same stores. A strategy that reduces logistics costs and eliminates the passage of the product from the stores to the factory, which translated into environmental terms means a reduction in Co2 emissions. Only at the end of each life cycle, the shoe is transferred to the factory to be refurbished, during which the outside of the shoe is washed and then put back on sale at a lower cost, as a second-hand shoe.

The passage of life cycles starts from the pro runner who buys the new product and needs the best performance in the race, reaching the amateur interested in a sports shoe that is cheaper but still and high-quality shoe, to then be completed with the average user who only wants a comfortable shoe for walking every day. The added value of Kintsugi is the possibility of impressing its own history on the shoe. In the maintenance phase of the external part, the customer can customize the replaced piece with color, creating his own patch. In this way, with the passage of time and the change of ownership, different patterns of colors and textures are constructed that represent experiences and life stories that are handed down in a single product, in a single-story, in a single pair of shoes with the inestimable final value.

Figure E.5. Reshoes team group working on their project and setting up the prototype and tables for the final presentation.

Table E.5. Reshoes evaluation.

CRITERION	EVALUATION
1) Has the product been resolved under multiple design perspectives? How?	Yes, the group focused on the business model, transportation and how the product can be maintained. For example, they imagined how the shoe should be maintained in shops around the world with new and advanced technologies.
2) Did the participants consider multiple product life cycles?	Yes, the group considered 4 product life cycles and for each cycle, they imagined a different customer.
3) Were the participants able to integrate different strategies?	Yes, the participants have integrated different design strategies for each loop .
4) Did the participants understand that different design strategies are required for each product life cycle?	Yes, they did.

Table E.6. Questions on understanding the circular economy.

Survey workshop 2

15 participant responses.

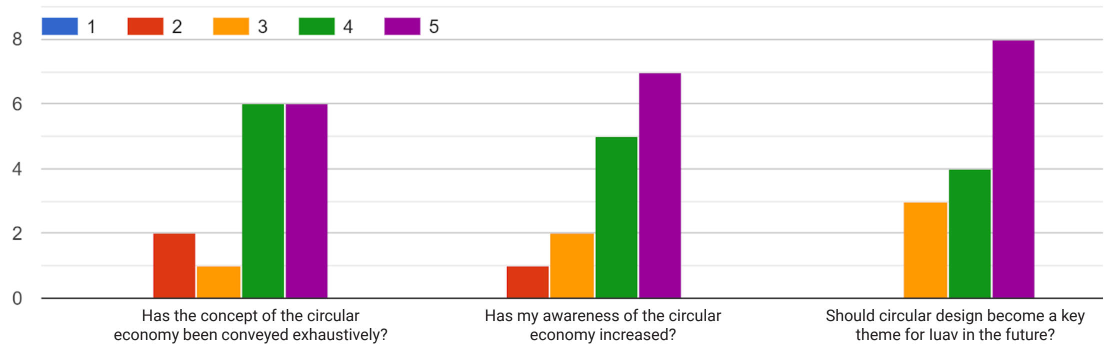


Table E.7. Questions about group collaboration.

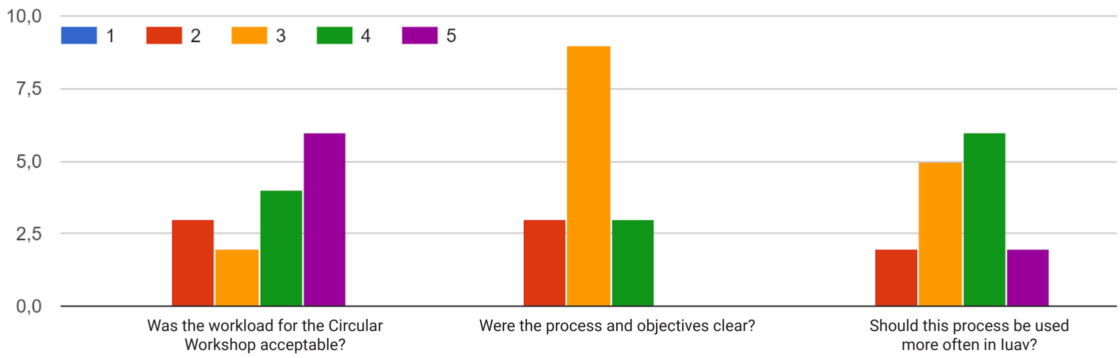


Table E.8. Questions about the results obtained during the workshop.

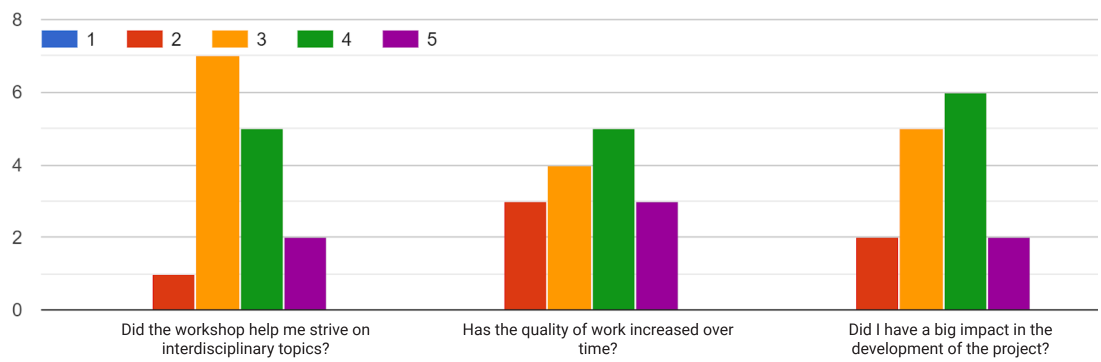


Table E.9. Questions related to the understanding of the multi-hierarchical fremwork approach.

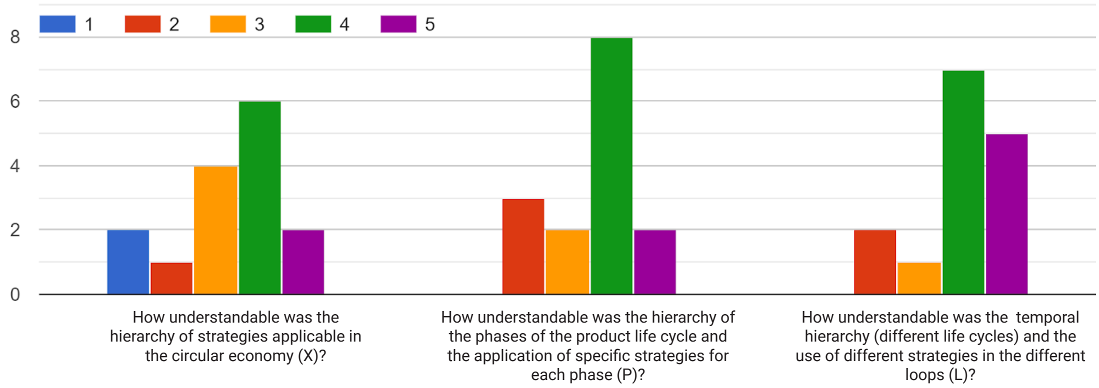


Table E.10. Did the sprint design approach meet your expectations?

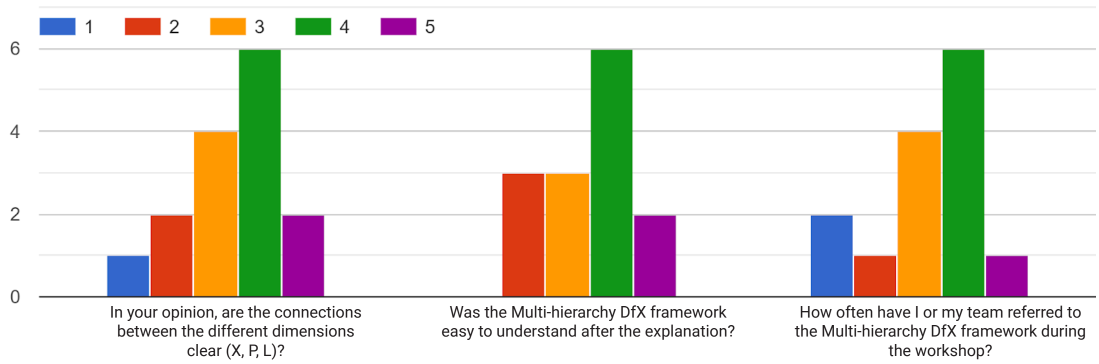


Table E.11. Questions related to the understanding of the Future Cone process.

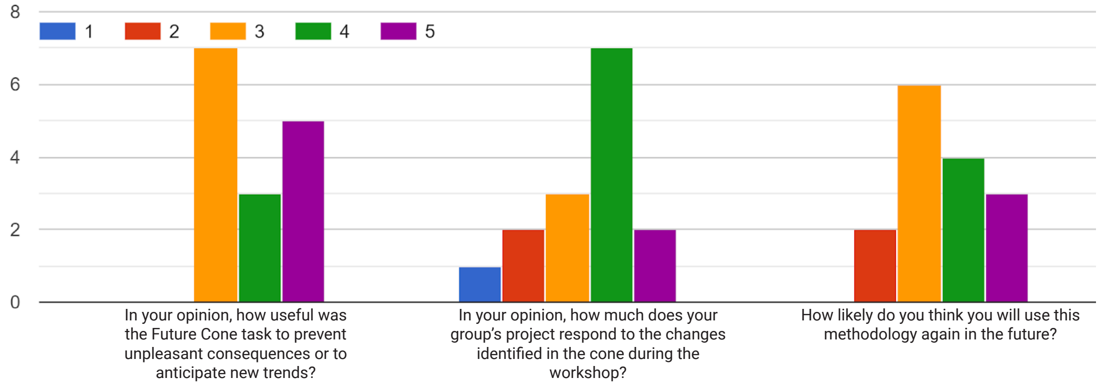


Table E.12. Self-assessment of participants on knowledge of future changes related to technology, ecology, society, politics, economics to face the Cone of the Future process.

How adequate was your level of knowledge to face the Future Cone?

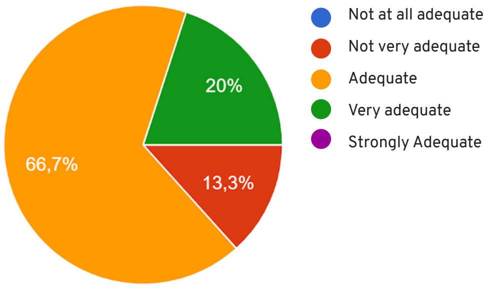
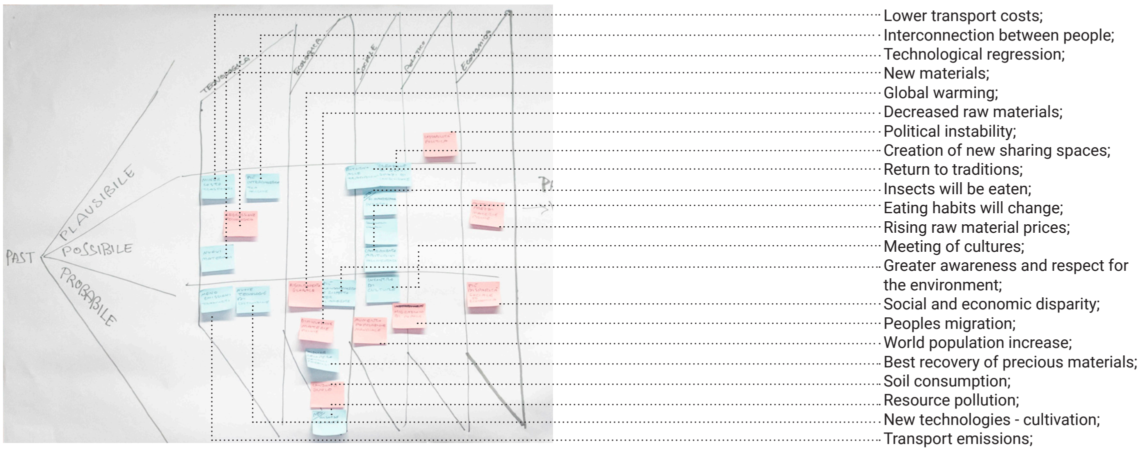


Figure E.12.1. The cone of the future created during the workshop by the Protein for All group.



According to most of the workshop participants, their preparation, knowledge and interrelationship of possible future scenarios regarding technology, economics, political society, and economics was adequate, as shown in the example in figure E.12.1.

Table E.13. Understanding of the most stimulating aspects by the participants during the workshop.

What was the most stimulating aspect of the workshop?

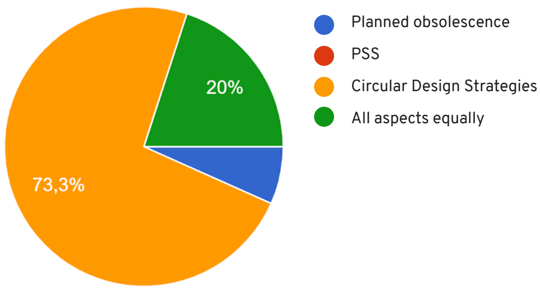


Table E.14. Understanding of the benefits obtained according to the participants

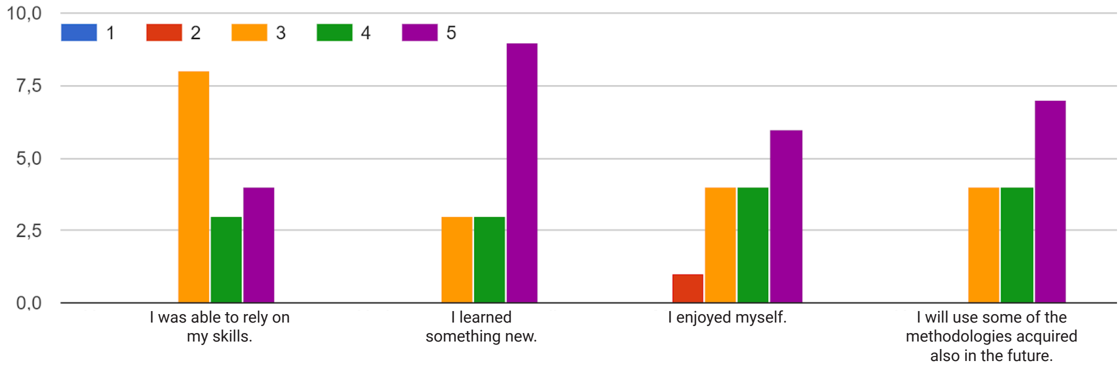


Table B.8. Questions about the results obtained during the workshop.

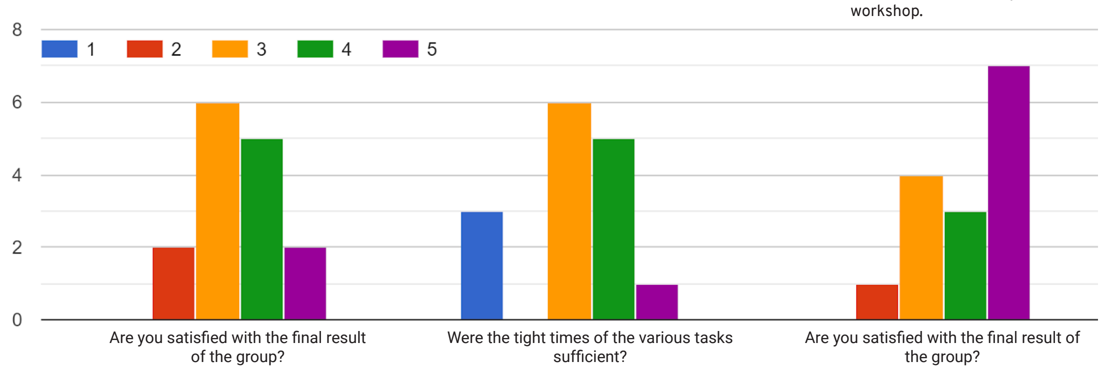


Table E.15. Did the sprint design approach meet your expectations?

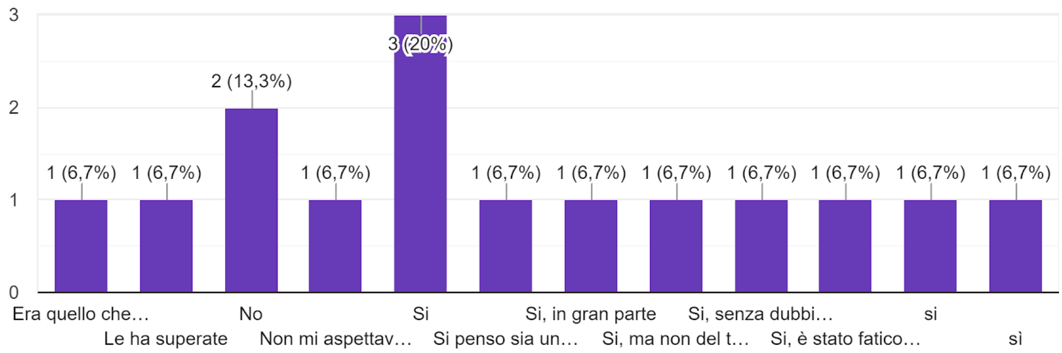


Table E.16. Student suggestions for workshop improvement.

IF NOT, WHAT WAS MISSING?
È mancata un'introduzione iniziale approfondita e il riferimento a più aziende/sistemi che già utilizzano un'economia di tipo circolare.
Uno studio sulla fattibilità della produzione di un oggetto secondo quei termini.
Niente.
E' stato un processo molto veloce che alcune volte costringe a prendere delle scelte progettuali troppo afrettate che magari in altri casi avresti pensato più a lungo a quel progetto.
Tempi troppo serrati nella fase di progettazione dell'oggetto.
Purtroppo il poco tempo e la poca voglia di alcuni elementi del gruppo ha inficiato negativamente ostacolando talvolta il lavoro.

Table E.17. Student suggestions for workshop improvement.

WHAT WORKED AND WHAT DIDN'T?
Ha funzionato bene la preparazione iniziale e la spiegazione anche se molto veloce, non ho compreso totalmente il nesso tra gli oggetti che dovevamo portare a cui siamo affezionati e il tema del workshop a parte capire che ci si affeziona per la storia con l'oggetto e non per valori economici.
Ha funzionato bene la progettazione consapevole e persino le tempistiche nonostante uno scetticismo iniziale.
A livello di insegnamento ho imparato molto, per quanto riguarda il risultato effettivo avrei voluto lavorare di piu sulla presentazione e in generale la comunicazione visiva.
Funzionale per il fatto di riuscire a produrre un progetto in 5 giorni, purtroppo dopo le interviste non è stato possibile migliorare ulteriormente il progetto.
Sicuramente un fatto positivo è stato quello di avere sempre delle tempistiche limitate. Ciò ha evitato uno spreco di tempo e ci ha costretto ad essere più concreti nei nostri pensieri e nella nostra progettazione anche se mi aspettavo che ad alcune fasi (quelle della progettazione dell'oggetto vero e proprio) venisse assegnato più tempo. Un altro aspetto che mi è piaciuto di questa metodologia è stata il fatto che ci si rende conto di come, anche in un periodo di tempo molto limitato, si possa riuscire ad ottenere un prototipo pronto da testare con gli utenti e che può essere poi sviluppato, migliorato oppure corretto più facilmente senza dover rimpiangere un dispendio troppo elevato di risorse o di tempo.
Ha funzionato la collaborazione nel gruppo e lo scambio di idee.
Tempi troppo stretti.
il metodo era molto interessante, ma un po' disorganizzato (almeno per quanto riguarda i tempi).
Non mi è stato molto chiaro lo schema delle x, p e l.
Lavorare in gruppo non è facile, lo si sa, ma combattere contro dei muri lo è ancora di più. Nonostante questo siamo riusciti ad ottenere dei buoni risultati, anche se il malumore verso la fine della settimana hanno prevalso. Inoltre credo che la preparazione dell'insegnante sia stata sottovalutata. Sono convinta che, da una persona preparata, gentile, disponibile ci sia solo da imparare..magari evitando di pensare di saperla più lunga ostacolando i progressi del gruppo. Un po' di umiltà e ascolto sarebbero necessari ad alcuni compagni.
Ha funzionato il metodo, ma serviva più tempo dedicato alle spiegazioni.
A volte è stato ripetitivo ed è rimasto poco tempo per pensare bene al progetto finale.

Secondo il mio punto di vista le conoscenze che molti di noi avevano erano insufficienti per poter approfondire al meglio l'argomento e sviluppare un progetto concretamente realizzabile, dal momento che molti studenti avevano finito solamente il primo anno.
Era necessario piú tempo e maggior conoscenza dell'economia.

Table E.18. Student suggestions for workshop improvement.

WHAT COULD BE DONE BETTER?
Spiegazione dei vari step del procedimento.
La parte di ricerca era da approfondire maggiormente.
Esporre dal principio tutte le fasi, dare più materiale sugli argomenti.
Avrei voluto una spiegazione più ampia e completa che purtroppo è stata concentrata in poco tempo.
Sviluppando il tema della circolarità si potrebbe sprecare meno carta.
Per me si avrebbe potuto creare gruppi di lavoro più eterogenei (riguardo agli anni di studio) in modo da avere componenti del gruppo con più esperienza e informazioni in grado di supportare il singolo team in caso di carenze conoscitive degli altri membri.
Ho avuto difficoltà all'inizio a capire come funzionava la gerarchia delle strategie applicabili all'economia circolare. Forse doverebbe essere spiegata con schemi ed esempi su i prodotti.
Avere qualche esempio in più.
La spiegazione iniziale fatta più lentamente, andare a capire la fattibilità dei progetti (alcune cose a mio parere non erano producibili in questo momento) sarebbe stato interessante vedere qualche esempio attuale di aziende che mettono in pratica sistemi circolari l'impressione a volte era quella di dover progettare un prodotto o un servizio che nessuna azienda sarebbe disposta a produrre.
Credo che si possano migliorare le fasi iniziali del percorso progettuale, che a tratti mi sono sembrate confuse, in modo da visualizzare il prima possibile l'obbiettivo finale del nostro progetto.

Table E.18. Student suggestions for workshop improvement.

HOW IS IT POSSIBLE TO IMPROVE THE GENERAL APPROACH TO THE WORKSHOP?
Sarebbe stato più interessante e penso efficace la presenza di professionisti di economia o altre figure diverse dal designer all'interno del gruppo, soprattutto per definire più dettagliatamente il cono del futuro.
È stato interessante e mi ha dato molto su cui riflettere, sarebbe utile dare da leggere a casa del materiale per avere una base più solida sugli argomenti.
Non saprei cosa suggerire. Ho già risposto sopra riguardo l'atteggiamento dei partecipanti. Riguardo al docente non ho nulla da suggerire per migliorare. Mi piacerebbe partecipare ad altri suoi workshop o conferenze.
Avrei voluto attingere a tutto il sapere del prof :)
E' stato molto interessante partecipare a questo workshop, sia per il fatto di approfondire aspetti che non conoscevo dell'economia circolare o che avevo analizzato con altre materie per esempio(LCA) e grazie al fatto che ho imparato una nuova metodologia che mi servirà in futuro. Ho focalizzato l'attenzione non solo sull'aspetto estetico del prodotto ma ho iniziato ad analizzare più punti di vista di quest'ultimo per esempio la funzionalità, la produzione, il riuso, il riciclo che sono fattori che possono migliorare il prodotto a livello di sostenibilità.
Le sensazioni sono state molto positive, il processo semplifica molto un concetto che

altrimenti sarebbe di difficile spiegazione, anche graficamente semplifica la ricerca di riferimenti, forse una cosa a sfavore è che sono poco intuitivi, le sigle X, P, L mi hanno messo in difficoltà perché dovevo ricordare per cosa stavano, forse dei termini completi renderebbero più chiaro lo schema, sempre che l'obiettivo sia avere chiarezza, capisco che sia importante anche la parte grafica... Un'altra cosa sarebbe spiegare il motivo di ogni fase, nel caso dei crazy 8 ho capito l'utilità perché lo avevo già fatto in passato ma in genere ogni esercitazione personalmente la affronto con più interesse se ne intuisco lo scopo finale. Grazie per l'esperienza sono soddisfatto e felice di aver partecipato a questo workshop.

Purtroppo credo che il fatto di aver praticamente perso la prima giornata per il nostro percorso progettuale abbia influito negativamente sui giorni successivi del workshop. Penso che la presentazione riguardante l'economia circolare e l'obsolescenza programmata sia interessante e necessaria per il workshop e magari possa essere fatta sfruttando una giornata della settimana precedente, come fanno alcuni workshop per la visita aziendale, in modo da dedicare tutto il resto necessario alla progettazione svolta seguendo la metodologia sprint.