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Review Article

Environmental implications of planned obsolescence and product lifetime: a literature review

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Abstract

The aim of this paper was to explore the implications of planned obsolescence (PO) and the associated product lifetime on the environmental impact of products. To achieve this task, a literature review was performed to assess both the historical context and recent situation of planned obsolescence. A search in scholarly journals was performed to evaluate to what extent product lifetime and PO have been discussed in the recent literature. Based on the findings, selected cases of PO are discussed and trends in the practice of limiting product lifetime are identified. Factors considered to have a significant influence on product lifetime have been identified and discussed. The discussion of case studies made it possible to establish the links between product design, manufacturing and associated impacts of lifetime. The role of the actors along the value chain is also considered to propose a business scheme, where the influences the definition of different scenarios are given. These strategies may serve to increase the reliability of environmental assessment throughout a product life cycle.

Keywords:

Planned obsolescence | product lifetime | environmental impacts | designer | business models

Introduction

Products are developed in a sense to provide answers to needs identified in society. Besides responding to needs, the product development process should acknowledge the need for ease of manufacture, ease of distribution and use. Manufacturers adopt new strategies to sell more products, more frequently, to fulfil customers' needs, demands and wants. The strategy of shortening a product's lifespan is called planned obsolescence (PO).

The term PO was coined in the United States in the late 1920s (Slade 2009). PO or built-in obsolescence in industrial design is a strategy of planning or designing a product with a limited useful life, so it will become obsolete, unfashionable or no longer functional after a certain period of time (Bulow 1986). Creating goods with a limited lifetime led to increased consumption. It was a business strategy to create mass consumption, which the country needed in a time of economic crisis. Producers who once were producing quality products started to find ways to make goods either more fragile, or difficult to repair so that people would be forced to replace the older version sooner. Processes and devices have been created with a predetermined lifetime to maximize economic outputs.

This work aims at reviewing and discussing the implications of PO[1] on product design and the environment. Given the low number of papers considering the impact of lifetime on the environment, particularly in life cycle assessments studies in which the product life is most often fixed, the aim is to highlight the importance of properly defining the product lifetime in order to minimize environmental impact. This paper seeks to identify ways to better integrate product lifespan into the product development process and identify opportunities to inform and trigger adaptable design perspective, to study the ways in which obsolescence can be managed to reduce the environmental impacts of the product. The manuscript proposes methods and solutions to integrate PO into the product design process.

A result of shorter lifespan[2] is that more waste is produced which in many circumstances ends up in landfills. From a life cycle thinking[3] perspective, the resource efficiency of such systems is said to be very low (King et al. 2006). The consideration of product lifetime at the early design stage is then recognized as an important factor. At the same time, the end-of-life[4] stage is equally crucial to the life cycle as it is when materials could be recovered. This short description of a product lifespan demonstrates the need for product life cycle management[5] to better design closed systems.

Despite the relevance of product lifespan, there is debate about how to best determine the life duration of products. Lifetime is intrinsic to the product, and also depends on consumer attitudes towards their products, for example, their role in product maintenance (Van Nes and Cramer 2006). While the environmental impacts associated with product lifetime are important, the majority of studies in the literature have focused on the economic implications of manipulating lifetime from a monopolist's point of view (Bulow 1986; Waldman 1993; Choi and Thum 1998; Guiltinan 2009). In this sense, more production leads to more profits. Another limitation of PO focused studies is that societal aspects are not taken into consideration. In recent years, studies in the field of "sustainable consumption and consumer behavior" started to appear in the literature (Lorek and Spangenberg 2014; Reisch and Thøgersen 2015). These studies focus on the important role of consumer behaviour mainly from a "choice" perspective and economics, and not directly quantifying the impact on product lifetime.

The problem with short product life arises since massive production generates large quantities of waste, which are not totally repaired, recovered, reused and reinserted into the production development streams. In most developed countries, electronic devices are not properly recycled, and are simply dumped (Latouche 2012). In many cases these devises are shipped to developing countries where the metal components are recovered in unregulated work environments. These recovery activities lead to sanitary and health problems. Increasing the recovery efficiency is then identified as an important aspect of the product life cycle to lower waste and unwanted health problems (Cooper 2002).

The objective of this paper was to perform a literature review that focuses on PO with special attention to the environmental impact and implications associated with product lifetime. The first step was to explore the definition of PO as used in society. The goal of this step is to understand its origins, how it has been applied and how it has evolved. The context of obsolescence in industry is described. Four types of PO are summarized and the appropriateness and consequences of their planned lifetime are discussed. To help in the development of the discussion, historical cases of PO are presented.

The second part of this manuscript attempts to make a link between product design and planned obsolescence. For this purpose, the implications of PO on design as well as manufacturing are reviewed and discussed. Here, the main influences of PO on design and manufacturing practices are identified. Special attention is given to the broader implications of obsolescence, which are assessed to proposed ways for improving current design practices.

While the problem of PO is not new, it is understood that changes in business-as-usual activities are needed if the implications of product lifetime are to be given more attention by industry. The third and last part of this study leads to a proposed business framework that provides the basis for product lifetime optimization through design and eventually new business models.

Product obsolescence

This section aims at reviewing the concept of PO as it has been used in the literature to date. There are four types of planned obsolescence. The first one is called technological or functional obsolescence as described by (Levinthal and Purohit 1989; Rai and Terpenny 2008) whereby a product becomes out of date because consumers are more interested in products with improved performance as a result of improved technology. Some examples are video games or computer software.

The second type is psychological or style obsolescence and exists since the early 1950s. It consists of designing products to trigger the desire to buy more, or to buy the newest version of a product. It is based on fashion and marketing principles. When people consume newer versions of a product, the outdated version loses value in the market. The retired products are discarded very quickly and produce much waste. Any two types of obsolescence is a means to create a demand for new goods. The demand could nevertheless trigger a false sense of need since it is induced by the sellers, and does not come from the customers themselves.

Systemic obsolescence consists of altering the system in which the product is used to make it more difficult to use, or by cancelling maintenance services for the product. This is the case for many associated products, which depend on each other to provide a function. It happened when videotape readers or cassette readers stopped being manufactured, while CDs and DVDs were being marketed. Electronic devices can be cited as another example. For some of them, only a few components of the system become obsolete like the batteries, however if the replacement[6] supplies are discontinued, or hard to find, the whole product is usually disregarded and upgraded with a new version (Singh and Sandborn 2006; Feldman and Sandborn 2007). It is often found that disposed products are often repairable and/or reusable (Van Nes and Cramer 2006), but repairing an electronic device is rarely done because it is often cheaper to buy a new product (Cooper 2002).

The last type is obsolescence due to product failure or breakdown. This type of obsolescence is associated with devices that are purposely designed with one or more conditions such that the product will stop working after a predetermined number of cycles (Latouche 2012). Several objects are deliberately made of lower quality material which chips easily. Plastic toys are often of low quality and break even when used under normal conditions. Some products parts are assembled by sealing two parts together for a single use purpose only; for example, some disposable cameras and watches. This is the ultimate level of obsolescence that can be found. This type is poorly documented in literature – this paper attempts to retrieve as much as possible the relevant information available.

It is also important to realize that it is likely that some products can be found in more than one category, for example, mobile phones. Mobile phones are designed to last an average of two years (Wilhelm 2012). A reason to replace a mobile phone is said to be the opportunity to have a more recent one given by the service provider – style obsolescence (Huang and Truong 2008). The second reason is the availability of new improved functions on newer phones – functional obsolescence. The third reason is because the battery was not working, or another repair was required – systemic obsolescence.

An important term related to PO is “expiration date”. The expiration date appears in products labels to indicate the date when they should be discarded. It is a date after which the manufacturer no longer guarantees the quality of the product. After that date a product may fail, show reduced efficiency, quality or taste (in case of food or any other perishable goods). Hewlett-Packard (HP) printers, for example, are designed with ink cartridges which have a given expiration date after which they stop working whether full or empty. HP claims that this measure is meant to preserve a good ink quality. A microchip inside the ink head will control this date; the cartridge needs to be replaced for the printer to work again. There is also a documented case for medications, where it has been reported that the “active ingredients” are still functional after several years (Cantrell et al. 2012). Medical laboratories do not inquire about the duration of active ingredients after 1–5 years. This leaves much doubt as to whether expiration dates are to be trusted, or whether they are made as such to significantly increase sales. In some circumstances, there are policies that producers need to comply with. Either a strategy for boosting sales or for liability reasons (protecting themselves from legal issues), “expiration date” is a controversial aspect associated with PO.

Recent use of PO in the literature

Based on the previous section, a task was put on to learn how product lifetime factors, including environment criteria, have been reported in the literature. The goal was mainly to identify if product lifetime has been given proper consideration in design and the technical literature. Three time periods were selected: 1980–1989, 1990–1999 and 2000–2014. A “title search” was performed on electronic database scholarly journals, including Google Scholar and Science Direct, for keywords associated with product lifetime to ensure that these topics were the explicit object of the screened articles.

The results show a considerable difference between databases (Table 1). For all keywords, Google Scholar showed a much higher number of published articles. It is acknowledged that there are differences in the way articles are indexed by each database. However, a general trend is evident in that the amount of published research covering these keywords has increased significantly in the last three decades. No evidence was found in the literature describing the evolution of PO in industry to date. While works on product lifetime have increased by 8100%, not much information has been published regarding the implications of fixing and modifying a product’s lifetime.

aspects of products, and is mainly discussed in economic, management and business journals. Obsolescence has basically not been given much attention in engineering and design journals. While it was not possible to identify a trend on the specific areas of research that have witnessed an increase, it is seen positively that more scholars are thinking about broader products aspects associated with obsolescence.

Table 1. Literature search for keywords associated with product lifetime.

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Historical cases of product obsolescence

Around the early 1870s, people were already using disposable shirt collars in the United States. This practice extended to prophylactics in the 1880s, and then to other products concerning personal hygiene such as sanitary pads, tampons Kleenex and even razors (Latouche 2012). This practice of producing short-lived products was further extended to cars and light bulbs. Since the 1930s, PO became a real way to do business. A strategy at that time was to produce commercials targeted at women since they were thought to consume more personal goods than men. In the 1950s, Motorola created one of the first portable radios, which could not be repaired thus paving the path for the purchase of new versions (Latouche 2012). As described by Vance Packard, in the early years of mass production, society was consistently being manipulated to always develop desirability for what it does not have (Packard 1960).

In the next subsections other historical cases of obsolescence are reviewed.

Light bulbs

The first documented case of PO is the light bulb. Bulbs were produced in Ohio, USA in 1895, and the filament invented by Adolphe Chaillet lasted 1500 h. In 1924, filaments technology improvements made the lifetime reach 2500 h. A strategy was put in place to impose a lifetime of 1000 h on all light bulbs produced. While technology made it possible to produce more durable bulbs, the decision of producers was to restrict the bulb lifetime by modifying the filament. Patents, which enabled the bulb to work over 1000 h, were rejected (Dannoritzer 2010). In this sense, sales of bulbs were drastically increased.

Article contents Related research

Stockings

During the 1950s to the 1960s, DuPont Company started producing nylon stockings for women. This product had a big success since the stockings were sturdy and resistant. Based on that success, and the fact that they were long lasting, the nylon fibres were modified to make them more fragile. The stocking started to tear more easily and had to be replaced regularly (Dannoritzer 2010). Nowadays, nylon tights rarely last for more than two or three uses.

Plant breeding

Plant breeding is a well-known but not often cited example of PO affecting the seed industry. Farmers used to save seeds for seasons to come. Often crops are destroyed by plagues, and to control plagues, seed producers develop new varieties that are more resistant. The new seeds are commonly useful for shorter periods of time. Consequently, farmers are more often forced to buy seeds for every season (Rangnekar 2002).

Implications

The effects of PO on all pillars of sustainability[7] are not well documented. PO is not acknowledged by industries, and no public information describes their decision-making process regarding how they target or define product lifetime. Consequently, the problem of planning and designing in anticipation of obsolescence is not fully understood for most types of goods. The most documented cases are mainly found in books that focus on the history of planned obsolescence. For the time being, PO represents a real challenge for designers and engineers[8] as this practice generates more environmental impacts than it should. Business-as-usual practices tend to handle only the economic aspects of obsolescence as a means to increase sales (Cordero 1991; Sherman, Souder, and Jenssen 2000; Keeble 2013). Targeting the economic dimension opposes ecodesign,[9] which minimizes the impact of a product throughout its life cycle. A new holistic approach would be to link ecodesign and life cycle planning in order to optimize product lifetime.

From a design and production perspective, there is a need to learn about the impact of PO on the economy, environment and society. Additionally there is a need to understand how the development of such goods can be changed to better suit

Social dimension

The need for continuous improvement in corporate strategies is often seen as a way to introduce new pieces to existing products. Firms update their technology very often to reduce the risk of competition with used market goods (Guiltinan 2009). However, there is a risk for producers who incentivize the release of new products into the market. The incentive will be too high if the value of the older units decreases when the producer makes the new product available. Even when improvements are not obvious on the new product, people still feel that their product is “out of fashion” owing to continuous upgrading (Boone, Lemonb, and Staelin 2001).

Also, consumers’ purchasing behaviour is influenced by product lifetime. According to a study, consumers tend to consider that cheaper products will break sooner than more expensive products (Cox et al. 2013). Customers attribute a low value to such types of goods. Hence, the perception of product reliability[10] plays a very significant role on consumer behaviour.

At the same time, the consumer has a role for product lifetime. Their participation and responsibility for giving proper maintenance to products is critical to at least satisfy the expected product lifetime.

Economic dimension

The three historical examples describe cases of goods that are relatively cheap and affordable by different social levels. Consumers are usually not aware of the cost that needs to be accounted for during the use phase of the product (Kollmann 1992). Most people judge that a broken appliance cannot be repaired and therefore they end up buying a new one. Repairs have also become very expensive while for many products it is cheaper to buy a new version than to repair it (Cooper 2002).

Producers can be classified in two groups: monopolists and oligopolists. Monopolists are not threatened by other good producers and will therefore tend to produce goods with a shorter lifetime. This reduces the quantity of goods available in a second period, thus increasing the demand for that product. The producer can maintain the prices constant and high (Coase 1972). On the contrary, oligopolists compete among themselves since they have a smaller share of the market. Oligopolists compete by practicing psychological obsolescence. Their strategy is to make their own products obsolete

Finally, government has the power to control the price of energy and raw materials. Governments also play a critical role by establishing taxation programmes and providing incentives for the adoption of cleaner methods and technologies (e.g. the Energy Star programme in the USA for home appliances sponsored by the US Environmental Protection Agency, and the CAFE standards for automobile fuel efficiency). At the same time, governments establish regulations for waste disposal, for example, the European End of Life Vehicles Directive, limits to emissions of pollutants and usage of chemicals (REACH) and therefore are also concerned with the management of PO (European Chemical Agency 2010).

Environmental dimension

The underlying principles of PO are that the design process is explicitly in favour of more fragile goods. For that purpose, engineers are driven to design short-lived products. Products, and components, become outdated and unless there is an extended producer responsibility programme, these are disposed of and are rarely reused, with the exemption of some markets where remanufacturing plays a significant role, for example, the automobile industry.

From the three historical cases only a few types of lights bulbs are recyclable providing the opportunity to improve the environmental performance throughout the life cycle. Stockings are currently discarded as waste. The life cycle loop is not closed creating pollution both from the product and its packaging. While the environmental impact of stocking may not seem imminent as compared to toxic materials used in certain bulbs, they represent a clear example of an open product loop that ends up in a landfill.

Product design

The role of the designer is to translate the product functions and consumer needs into parameters that will allow him/her to integrate all the required aspects into a product. The main steps of the product development process include: (i) concept development: the needs are identified (requirements), the product specifications are defined (tells what the product has to do), the product concepts are generated and selected, (ii) system-level design: definition of the product’s architecture and preliminary design of key components, (iii) detail design: the definition and representation of geometry, prototypes, (v) production ramp up: manufacture of the product with the intended production system, (vi) qualification and (vii) validation (Ulrich and Eppinger 2000; Magrab et al. 2009).

While these sequential steps provide a systematic way for developing a product, it follows the traditional approach that is too focused on the technical aspects of the product. As it is, the approach does not acknowledge the need for integrating the environmental dimension of the product. To date, scholars have argued that environmental aspects should be considered early in the product development process if environment performance is to be improved (Arena, Azzone, and Conte 2013; McLellan and Corder 2013; Hetherington et al. 2014; Wender et al. 2014). According to Ullman's design paradox, the planning process is the best moment to introduce environmental aspects, as it is the time where it is the least expensive. Otherwise, with the progress of the project, changes become harder and more expensive to introduce (Ullman 1992). Not only does the product development process has to be in line with the current technology, but it also needs to respect the specifications and the functions of the reference object (Kobayashi 2006; Feldman and Sandborn 2007).

The design of products and the integration of environmental aspects depends today on the availability of tools and methodologies that will facilitate linking product (e.g. material choice) to product performance (e.g. impact to human health, ecotoxicity). The complexity and usability of tools vary, and can be as simple as a checklist (Lindahl 2006). Whenever small- and medium-sized companies use design for the environment tools, they use them for specific cases. The use of such tools depends on the potential and expected benefits that the tool could provide. If the tools do not fit these criteria, they are often seen as unpractical and time-consuming, and therefore are not fully integrated in the usual design practices of the company (Lindahl 2006). Similar cases were previously reported, where the complexity of the tools as well as the ease of integration with actual design practices (mainly focused on the technical aspects) were identified as limiting factors (Baumann, Boons, and Bragd 2002).

Design for X, for example, has helped engineers to plan their designs before implementation (Huang 1996). To date, life cycle assessment (LCA) has become the tool of choice for assessing and comparing the environmental performance of products. The problem is that LCA applied after the design process is close to final. At this stage, when all decisions have been made, it becomes too costly to modify the product.

Hence, the potential of LCA to inform decision-making at the design level is not fully exploited.

Broader implications of planned obsolescence

Creation and longevity of supply chain

A more rapid diffusion of information between competitors, and the rapid evolution of customers needs is seen as one of the causes for shortening lifetime and increasing the availability of new products in the market. Products that took a longer time to develop are more likely to become outdated more quickly than expected (Ameri and Dutta 2005). Airplanes and military devices are made to last several years. However, in designing such sustainment dominated systems, one must ensure that the product can still be procured from its original source or will reach logistical obsolescence. There have been various proposed approaches to monitor obsolescence, and solutions to solve the problem of the obsolescence of electronic products and components have been implemented. Commercial tools exist for tracking the availability of electronic components (Feldman and Sandborn 2007). One approach for sustained supply chain is to implement efficient inventory and stocking management practices, in addition to having long-lasting communication with partner suppliers.

Another solution is to buy on aftermarkets if these exist, for example, remanufacturing markets for automobile components (e.g. radiators, starters).

Small businesses

Small businesses have different definitions depending on the country. The European Commission defines a small and medium business as

> The category of micro, small and medium-sized enterprises (SMEs) is made up of enterprises which employ fewer than 250 persons and which have an annual turnover not exceeding 50 million euro, and/or an annual balance sheet total not exceeding 43 million euro. (Verheugen 2005)

Most countries apply the upper limit of 250. The United States has fixed an upper limit of 500 employees (SBA. U.S. Small Business Administration 2014). SMEs are known to rapidly than larger firms. However, more SMEs fail to take the opportunity to innovate due to their strategy, company culture and management type. They are also more careful when taking risks as they are highly focused on the company's survival, rather than on growing their competitive advantage. This attitude towards risks often makes them more reluctant to renew their products as rapidly as large firms launch their products in the market.

Consumer behaviour

In the case of consumers, the durability of the product will depend on in situ functions; therefore design needs to be more user based to promote this durability. Durability is more often seen like a technical aspect rather than an environmental issue (Cooper 2004). This vision poses a real challenge when efforts are put in place to consider environmental aspects. Bakker et al. (2014) have emphasized that together with the functional durability, there were the emotional and aesthetical durability, which altogether could contribute to the product life extension. It is possible that one or more functions of the product induce planned obsolescence, and generate the replacement of the product. The functions often reveal what aspects really count for the user. By understanding functional priorities, lifetime could be adapted to reduce the feeling of obsolescence.

The emergence of remanufacturing markets provides an option to consumers. For example, buying a used or remanufactured component is cheaper than buying a new automobile motor. These markets are more common on developing countries where the acquisition power of society may play a critical role on their decisions and where people show greater personal attachment to products. For people with limited capital, buying a new car will be in many cases a prohibited option. In this sense, culture is seen as a critical factor regarding the product lifetime. By acquiring "new" components in aftermarkets, the consumer is extending the product lifetime. In a scenario like this it could be said that product lifetime extension is on the hands of the consumer, not solely the producer.

Life cycle assessment

LCA can provide information about the lifetime performance of products. A limitation of many LCA studies is that impacts are often calculated for a fixed lifetime or for a given distance, for example, the impact of a car is calculated for average driven distance or sufficient information for decision-making. However, the information do not account or capture the absolute impact that is attributed to the consumer. In the case of the automobile, it is the consumer behaviour that will influence much of the overall environmental impact in the use stage (Cheah 2013). For the automobile [internal combustion engine], the greatest environmental impact is associated with the use stage due to the burning of fossil fuels (MacLean and Lave 1998).

In general, LCA allows the quantification of all materials and resources input into facility to manufacture an automobile, however LCA as it is currently defined and used does not account for proper consumer behaviour. For example, in the work of Berger et al. (2012) the water consumed at the use stage for maintenance and washing was not taken into consideration. The uncertainty associated with neglecting this important natural resource hampers and limits such studies in a time when global water resources are starting to scarce.

Considering the relevance of consumer behaviour on the environmental impacts of a product, the impacts could be classified as “elastic”. Here, the term elastic is used to describe how the magnitude of such reported impacts will vary depending on many different factors including study boundaries (inclusion or omission of maintenance, for example) and consumer behaviour (driving and water use).

Sustainable business models

A business model is the design of the value creation process that an enterprise will implement to deliver services and products to customers (Teece 2010). Bocken et al. (2013) presented a review of some current business practices that can be considered as sustainable. Among the practices the authors identified: eco-innovation, eco-efficiency, the creation of value from waste, the substitution of fossil-based resources with renewables counterparts and natural processes, the functional economy principle, the adoption of stewardship values and finally the encouragement of sufficiency. These practices provide ways for better management of product lifetime. While these practices provide a taxonomy that permits the decoupling of long predominating economic drivers, economic aspects cannot be ignored. However, a need for restructuring current economic models has been voiced in the literature (Boons and Baas 1997).

Specific limitations of the current literature on business model were identified. These limitations are believed to cause the stagnation of any effort for creating sustainable business. Among the limitations it was found that often businesses did not fully integrate sustainability into the whole context of the company. In other words, the business strategy, which is included in the mission and vision of the company, is not always transmitted to the tactical (managerial) and operational levels of the industry. It is in these “lower” levels that the business model is transformed and integrated into the product development process. Another limitation is that managers failed to see sustainability from a systemic point of view. A narrow view and valorization of sustainability reduces the chances to modify business-as-usual practices.

Managers need to commit to integrate the sustainability aspects in projects to build the foundation that will facilitate transitioning into new business models (Hallstedt et al. 2013). The environment should be seen as a part of the business strategy, and integrated as early as possible into the product development process. Tools need to be developed and implemented at different business levels that will allow the understanding of trade-offs among product alternatives both in the short and long terms. For a long-term planning, new business models may opt to price the fulfilment of a need, rather than the unit product (Boons and Lüdeke-Freund 2013). Beyond traditional environmental assessment tools like LCA, industries need to incorporate additional tools like risk analysis and multi-criterion assessment to be able to predict the broader consequences (both positive and negative) of their actions and decisions (Hallstedt and Isaksson 2013).

A critical limitation faced by industry deals with the end-of-life of their products. It is at this stage that significant waste and environmental impacts are made. These impacts are more of a concern when proper recollection networks are non-existent or not efficient. Product service systems (PSS) provide a framework to help in dematerializing the economy (Baines et al. 2007; Amaya, Lelah, and Zwolinski 2013). The environmental implications of PSS are related to waste generation. By providing a service, companies encourage people to consume the service provided by products while committing to return the product to the producer. This action is seen as a way to reduce the amount of waste, or at least to provide the basis for proper value recovery when the product performance is not as expected. This strategy fits with the so-called producer extended responsibility concept (Baumann, Boons, and Bragd 2002). On this framework, companies make their products last longer and provide more incentives for

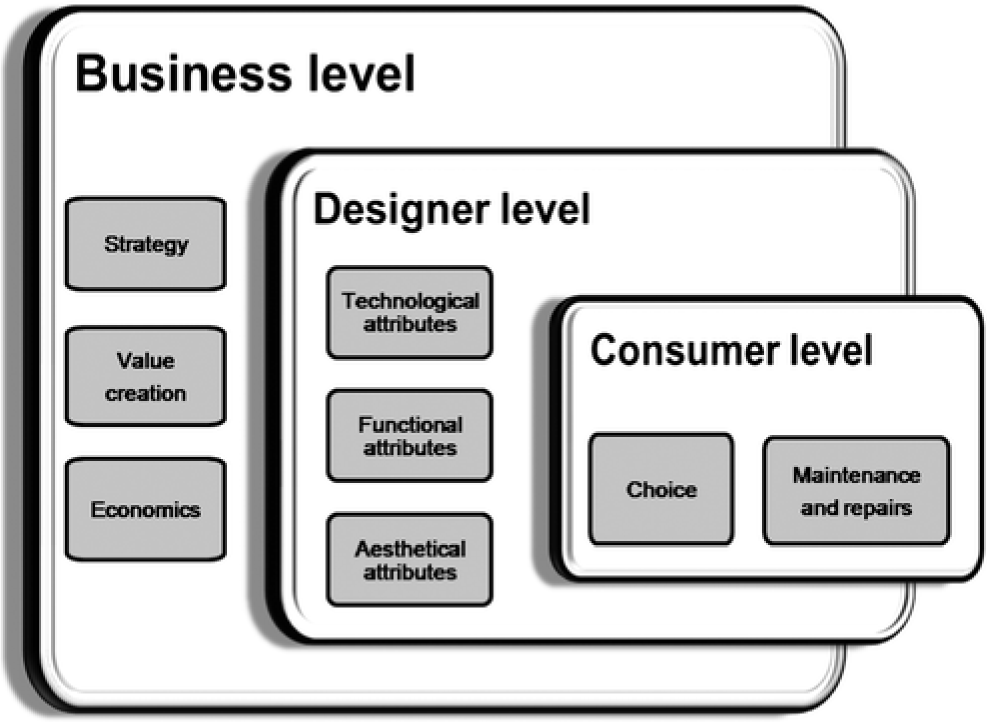
2002). This framework is at times seen as negative since higher responsibilities for the producer are required. Some companies see PSS as an extension of their existing services, while others use it as an innovative business asset. Here, it is argued that in order to provide services consumers' behaviour needs to be considered at the early stage of product development. The rational for integrating different actors responds to educational needs since "new mental models" will be needed in order to transition from a product to a service economy. For new PSS models to be adopted, the factors influencing product lifetime need to be understood.[11]

Product elimination practices are common in companies, whereby products, which do not fulfil a set of previously predetermined criteria are often discontinued. Product discontinuance is also driven by market changes, innovation, arrival of new and enhanced models and by changes in business strategies. Based on situational, product-related or organizational variables; and depending on the different cases, the elimination strategy will include corrective actions and evaluation stages. Two common strategies are (1) drop immediately and (2) phase out slowly (Avlonitis 1983). The strategy by which the product is discontinued depends itself on various factors such as competition, customer acceptance and stock of raw materials available among others. The strategy is considered critical to maintaining the financial and organizational longevity of the company (Avlonitis 2000). The final aim is to reap the maximum benefit from the remaining stocks, while efficiently reorganizing resources and services in the least disruptive way for customers' acceptance. However, consumers are most often unaware of future discontinuance and are informed of the product elimination by the seller not the producer. The role of the seller in communicating producers' decisions is seen as a critical factor for the success of the elimination strategy. An efficient strategy may help companies increase their profits by as much as 20% (Hise and McGinnis 1975). Internally, the practices could also help R&D teams to focus on new products and markets, and in cases to expand production of successful products. While the cited work may be outdated, the reflections and patterns described are deemed descriptive of current practices and scenarios.

Few studies report the factors that could induce the obsolescence of the product through design (Van Nes and Cramer 2006). Three distinguished factors affecting PO are: (i) the business strategy within the company; (ii) the design and technological aspect of the product including the aesthetics; and (iii) the consumer behaviour (Cooper 2004; Waage 2007). Other important factors include product characteristics these factors three important stakeholders associated with product obsolescence are identified: businesses, designers and engineers and consumers.

Targeting and implementing the above-mentioned practices required a solid network of key actors and/or stakeholders (Baumann, Boons, and Bragd 2002). A three-actor model is presented in Figure 1.

Figure 1. Description of proposed three-level model: business, designer and consumer.



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Discussion

Normally, longer product lifetime usually means that upstream environmental impacts are less significant (Van Nes and Cramer 2006). However, if there is a large consumption of material or energy during its use, then a short product life may be advisable (Jacquemin, Pontalier, and Sablayrolles 2012). Environmental impacts can further be understood if products are classified as static goods or dynamic goods. Static products require more energy during the manufacturing /production stage such as bridges and highways. The use phase of static products may also be significant due to their energy intensity such as buildings which have significant requirements for among some resource intensive features and appliances (Aktas and Bilec 2012). Bakker et al. (2014) studied refrigerators with long lifetimes of 20 years and laptops, which last 4–7 years. The authors found that it was more adapted to choose a strategy as adequate as possible to economic constraints and market pressures. For objects with relatively static design changes, a product life extension could be considered. However, for laptops that are rapidly changing, it was more viable to choose remanufacturing and recycling strategies. Dynamic products often use more energy during the use phase (e.g. automobiles).

A scenario could be considered where the designer responds to a business strategy that fixes product lifetime to X number years (based on experience). While the designer will have no choice to influence product lifetime, he/she will have the freedom to exploit end-of-life aspects to maximize value recovery and reduce impacts. Among the options, the designer could consider material selection and disassembly logistics. While these two options are seen as potential ways to influence product lifetime, care should be taken since win-win routes for full lifecycle environmental improvement are not always guaranteed, nor the process is straight forward. For example, substitution of steel for plastics and composites in the automobile resulted in more complicated disassembly processes (Van Hoek 2002).

Optimization of end-of-life practices involves several actors including customers, product collecting entities and value recovery entities. In some cases it could be seen as if the producers passes along the product responsibility to these “after-use” actors. It could be stated that such practices are not sustainable, but it describes current practices that may be a consequence of the absence of proper value recovery networks. The envisioned future is that these end-of-life practices will allow the establishment of such networks, and once in place the business models will have to adapt to provide economic and social benefits along the product life cycle. The importance of the recovery network is critical since infrastructure is put in place afterwards and is mainly driven by economics. For example, when a new product is imported to a country, the recovery network is non-existent. In the best scenario, the existing networks of that country may be easily adaptable to recover the new product. This is the case of products made of steel and aluminium for which recovery networks are largely available. Recovery is also feasible when there is a market for the recovered materials and sufficient materials could be collected in a continuous basis to ensure the longevity of recovery operations.

In terms of design approaches, design for "end-of-life" will make material recovery easier. At the same time it will strive for making disassembly operations economically feasible to allow the establishment of recovery networks and infrastructure. Such efforts may lead to lower environmental and social impacts. In ideal scenarios, these networks could also be established in developing countries to contribute to social development through acceptable work practices and job creation. A need to optimizing material flows is deemed important to ensure the sustained operation of these networks. The successful implementation of recovery networks will hence provide ways to mitigate the environmental and social impacts of product obsolescence.

The traditional product design process focuses mainly on product technical functions and costs. No coordination was found in the literature between the traditional approach and current sustainability needs. From a sustainability perspective, a designer on the twenty-first century is expected to go beyond traditional boundaries to incorporate as much as possible environmental and social criteria into the design process. In response to these needs, the literature shows a promising increase in research that aims at narrowing the gaps between design and sustainability. Looking for solutions at the "root of the problems" has the greatest potential for helping in narrowing this gap.

Engineers continue to experience difficulties due to the complexity of mixing technical, environmental and other criteria into the product development process. It is this situation that is considered a "root of the problem". In response to these difficulties, designers often pursue a streamlined analysis and hence focus on a few particular aspects of the product instead (Lindahl 2006). Hence, there is a need for developing tools that will facilitate the integration current tools and facilitate the consideration of different sustainability criteria. The tools should also provide the basis to characterize the current system, perform backcasting analysis and scenario analysis to provide a more holistic description of the past, present and expected future (Waage 2007).

The training and competences of the designer are critical for the successful design of a product. In terms of product life, designers and engineers are commonly trained to perform fatigue analysis. This technical subject is commonly taught in engineering schools. Fatigue analysis aims at predicting material failure following loading cycles, though often done for single components. Fatigue analysis is used to design critical elements or parts, which could help to prolong the lifetime of a system. The problem arises when the designer is faced with the design of complex systems, for which components and their interactions. Fatigue analysis is not only affected by the load (weight or mass). The duration of the load and type will also influence the lifetime. Exposure to corrosive environments may lead to failure. Failure mechanisms will also depend on material type and on exposure temperature (e.g. melting of plastic components) (Stephens et al. 2000). For a complex system, expert experience and judgment becomes vital. When exploring the design of products there are factors that serve to guide the consideration of product lifetime. Five suggested factors are:

(1) The functions of the product.

(2) The design framework of the product.

(3) The parameters which need to be integrated into the system.

(4) The economic aspect.

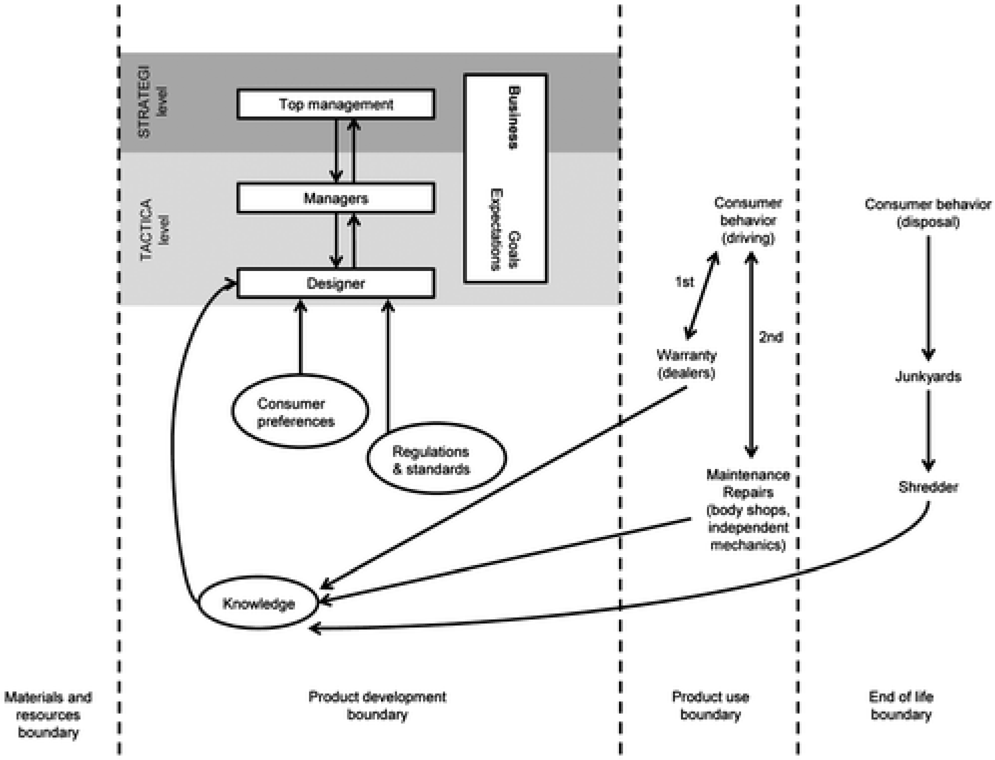
(5) The drivers which lead to renewal of the product.

Each actor in Figure 1 serves a role in the product life cycle (from development to use to disposal). Business and product/service roles are included that would permit the incorporation of non-traditional practices. This model states that the business strategy influences all the other factors, as it determines the way a product is made. Secondly, the designer who is influenced by the management’s decisions will use the required criteria, and designs the product accordingly. The designer therefore may, or may not be able to take durability into consideration. Finally, the consumer behaviour is important in the use phase of the product since behaviour will modify the environmental performance. At this stage the consumer also collects knowledge about the product, knowledge that in the best scenario will make its way back to the business.

In developing the model (Figure 1) it is acknowledged that determining a product life is no easy task; much of it comes from experience due to the complexity of products. In some cases, historical data could be used to learn about product failure through the application of lifetime distribution models. These models allowed the designer to estimate the percentage of products (from a production batch) that may fail in a time span (Almalki and Nadarajah 2014). However, such approach is limited to known cases with collected performance data. This case confirms the importance of establishing useful feedback networks with consumers.

Figure 2 shows the different interactions that exist among the actors of the value chain marketed, sold, used and disposed of. The scheme establishes the hierarchy of the system; namely that of top managers on product designers. The bottom of the chain includes consumers and waste managers, which influences the lifetime of the product at the use and disposal stage, respectively. This organization may be optimized to minimize the environmental impacts of each stage, namely through a change in the type of interaction dominating the business structure. With more consumer feedback, a designer will be better prepared to anticipate the current and future uses of a product, as well as failure mechanisms. As there are significant risks involved when making predictions, many scenarios should be considered. Through creativity techniques, new life cycles can be designed to explore their potential environmental impact thus allowing the designers to make informed decisions (Niemann, Tichkiewitch, and Westkamper 2008).

Figure 2. Representation of knowledge and interactions between actors of the value chain.



The environmental manufacturing movement has made limited efforts to integrate social aspects. It is vital that technical aspects are well coupled with environmental and societal aspects. A multi-criterion approach will allow engineers to consider the best set strategic, the technical and the societal/environmental. The strategic level is concerned with all the aspects related to the marketability of the product, and its ability to generate profit for the company. The technical level is concerned with the technical feasibility of the product, by taking into account the cost of production. Life cycle costing has been the traditional factor controlling at the decision-making stage. The societal/environmental level is concerned with customer's expectations, taking into account the environment. This set of criteria is not fixed as each company has its own notion of what is important to their business and the places where they operate, sell and provide services.

While the designer, training, competences, knowledge and experience are critical for extending the product life, a smooth transition towards a more holistic product design process requires the understanding of drivers and business roles. Paving the road in this direction is challenging since strategies for managing obsolescence are not that well understood and documented. At the same time, evaluating the lifetime of products is no easy task and proper knowledge and tools are needed.

Actors (e.g. producers, consumers, intermediaries, government) should acknowledge their responsibilities and their roles if impacts throughout each life cycle stage are to be reduced. At the industrial level, a call is expressed for the design of business models that respond to concrete goals and that have a strong foundation on benchmarking. These models need not only be implemented at top industrial levels, but transmitted and injected into all levels of the industries (strategic and tactical) using top-bottom approaches (Zhang et al. 2013). At the same time designer should push for bottom-up approaches to influence top managers. The models need to be designed in a way that they provide room for adaptation to new knowledge, new markets and new visions while leaving old, holding habits behind. By acknowledging the dynamics of industrial, environmental and social systems, businesses will position themselves on the right track for a positive, forward looking transition.

Conclusions

The goal of this manuscript has been to highlight the important role of product lifetime in product obsolescence and to identify key actors, limitations, factors and opportunities to ignite a conversation around the subject of "product lifetime".

Using the literature, a presentation and discussion of PO served as the foundation to identify and follow the historical context of product lifetime. The effect of lifetime on technological devices was explored, and part of the analysis attempts to see the consequences on society. This work has reaffirmed that the environmental impact directly associated with a product lifetime is given limited consideration in the product development process. Minimizing products lifetime impacts is not the sole responsibility of the designer, but producers, consumers, government and business and service providers. It is acknowledged that the complexity of the product development process, understanding of industrial drivers and will, the innovations cycle, marketing, system dynamics and knowledge availability among others should all be taken into consideration for a holistic analysis of product systems.

The main conclusion of this work is that more attention should be given to the broader impacts of product lifetime through the life cycle. Such attention should first start at the management level. Strategies to improve overall performance should be reflected in business models and communicated downstream, injected into the tactical and operational levels. Business models should clearly define the path and role of design in order to facilitate the translation of the strategies into action. To concretize the business models, designers and engineers should be given proper tools and opportunities to inform decision-making. An initial step may include a look at design tools and methods, role of policy, customer perception and cultural factors. Ease of usability, adaptation and modularity of design tools should be elements considered when tools are developed or selected. It is expected that new business models will trigger changes in other business models along the supply chain and service provider networks.

Recent studies of product lifetime have been reported for electronics and household products. More cooperation is needed from industry to gain a better understanding of knowledge flows, products performance data and close-loop knowledge (Figure 2). The effect of marketing on product lifetime should also be studied. The best intentions of engineers and designers to design and manufacture improved products may be overshadowed by the business strategy, a strategy that is driven by profits goals. Therefore, transparency is critical to product development.

In order for all these factors identified in this manuscript to be considered, the environment should be intrinsic to all business operations through the given life cycles, as producers. A combination of low price and short life makes the ideal scenario for businesses to exploit product obsolescence. New challenges associated with resource scarcity are expected to force businesses to novel business models that look deeply at the way they create, deliver and capture value from a system perspective. Landfill space is also becoming critical. Hence, new paradigms are needed to value all types of resources at every stage of the product life cycle.

This work positions product lifetime as a critical element of the product development process. However, certain limitations were identified that need to be overcome. Case studies are needed to provide the necessary evidence to judge to what level the development process could be improved by considering the factors described in this manuscript. It is expected that this work will prove useful for designers and industry, and that new initiatives and methodologies that consider lifetime will be developed.

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Notes

1. Terms product lifetime, lifespan and obsolescence are used interchangeably throughout this manuscript. They all refer to the time when a product's initial function is no longer achievable.

2. Lifetime and lifespan are used interchangeably in this manuscript to describe the expected product life.

3. Considering the whole life cycle of products and associated implications, from

(recovery, reuse and disposal).

4. End-of-life is the stage when the original function of the product is to some extent no longer achievable and the product exits in the use stage; the product enters a new stage for material recovery, reuse or to be in a landfill among some management options.

5. Life cycle management is a strategy to reduce the product environmental impact (Cooper 2002).

6. This situation is referred to as procurement life: the period for which the part or component was (or will be) available for procurement from its original manufacturer after purchase (Sandborn, Prabhakar, and Ahmad 2011).

7. Sustainability has three pillars: social, economic and environmental.

8. The words “designer” and “engineers” are used in this manuscript to describe the actions taken for the development of a product; these actions may be taken by one person, a group, a centralized or decentralized team.

9. Ecodesign integrates all the aspects of the life cycle into the product design and development processes with the goal of reducing the environmental impacts (ISO 14006 2011). However, one limitation of ecodesign is that it does not take into account individual consumer behaviours and other network externalities related to new products as they are too complex to predict and analyse. Network externalities refer to the value consumers attribute to a given product (Katz and Shapiro 1985).

10. Reliability refers to the performance of a product after purchase. It describes how well a product satisfies its function over consecutive use periods.

11. Factors for PSS are further discussed in: Tukker 2004, Eight types of product-service systems: eight ways to sustainability? Experiences from SUSPRONET.

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