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# From Ecodesign to Sustainable Product/Service-Systems: A Journey Through Research Contributions over Recent Decades

**Tim C. McAloone and Daniela C.A. Pigosso**

**Abstract** Corporate approaches towards sustainability integration into product development have significantly evolved since the early 1990s. Ecodesign, defined as the integration of environmental issues into product development, arose in the 1990s as a key concept for the enhancement of products' environmental performance. An intense development of ecodesign methods and tools could be observed in the 1990–2010 period, leading to successful pilot cases in industry, in which environmental gains were demonstrated. In the 2010s, the need for a systems perspective to solve the environmental crisis has been highlighted, and the concept of product/service-systems started to gain momentum due to the high potential for enhanced environmental performance and improved competitiveness, by means of new business models and dematerialization. Recently, a transition towards Circular Economy and the integration of social innovation into sustainability initiatives can be observed, which leads to strategic and holistic sustainability considerations in the design of complex systems. In this chapter, the evolution of sustainability concepts and their integration into product development is presented and exemplified in three periods: 1990–2010; 2010–2020 and 2020–2030. While the first two periods present the actual development of the field, the last period represents the evaluation and projection of the trends developed by the authors. By analysing the three periods, the authors aim to discuss the journey from ecodesign to sustainable product/service-systems over the last decades, experienced by academia and practitioners, and to highlight their views on how the field is going to develop over the next 10 years.

**Keywords** Ecodesign · Product/service-systems · Sustainable innovation · Circular Economy

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## 1 Introduction

Since the early 1990s academics and practitioners have been placing increasing focus on sustainability awareness in the product development process, by means of tools, methods and targeted projects towards sustainability enhancement. In the early years, the focus was on designing better for environmental concerns, from which period we see the beginnings of what today is a huge catalogue of approaches towards life cycle assessment and ecodesign, to name just two of the very popular environmental improvement approaches. The important questions are: how does it look today? In which dimensions have we developed our knowledge? How has the world changed since we began to work with ecodesign? And are we effectively developing our competencies, in order to be more effective in our approach to continued sustainability enhancement?

In an attempt to answer the above questions, the authors have carried out a review and reflection of the previous and current decades, before projecting our thoughts onto what we see may be the foreseeable future for sustainability enhancement through business- and product development. To help to make this reflection, three time periods and nine dimensions have been identified, so as to characterize the general sustainability focus, over time. The time periods in focus are 1990–2010 (characterised as the rise and establishment of ecodesign); 2010–2020 (a systems perspective on ecodesign); and 2020–2030 (perspectives for a sustainable and Circular Economy). The nine dimensions identified for the review and reflection exercise were the following:

- **Main goals/objectives:** This dimension was included to highlight what was the main sustainability design object of the company, in the given time period, ranging from very concrete artefact-focused objectives to more cognitive objectives seen in more recent times.
- **Expected results:** This denotes the main focus of industry/society in each given time period, also indicating the level of proactivity towards sustainability within the given period.
- **Main aim:** This dimension marks whether the main aim of the sustainability effort is towards building, implementing, or fully integrating tools into the organisation.
- **Basic approach:** This dimension helped the authors to differentiate, whether the general approach to sustainability improvement could be characterised as being singular problem-focused, system-oriented, or holistic.
- **Envisaged cost-benefit:** The general attitude of industry, towards sustainability's value contribution was charted in this dimension, to provide a candid image of the general level of expectation towards sustainability.
- **Sustainability ambition:** This dimension denotes which combination of the three so-called pillars of sustainability (environmental-social-business) were most in focus in the given time period.

- **Business mindset:** This dimension was included in order to differentiate between incumbent take-make-waste (or 'linear') business mindsets, or whether a more circular mindset was evident in a given time period.
- **What are we changing:** This dimension was added to place focus on what the main objective of sustainability efforts typically was in a given time period, whether it be to make direct product improvements, more systemic process improvements, or a generally holistic focus on the competencies of the professionals in the product development organisation.
- **Decision-making level:** This final dimension was used to mark which dominant part of the organisation was most instrumentally being engaged, in a given time period.

The following sections review and reflect on the activities, campaigns, research, industry examples, and key results gained from each of the three respective time periods. The above sustainability dimensions are used as way of structuring this reflection. A progression and a development can be observed, in the three time periods considered.

## 2 1990–2010: The Rise and Establishment of Ecodesign

Over the 1990–2010 period, companies have significantly evolved their approaches towards the integration of sustainability into their business activities, developing from a passive and reactive stance, towards the adoption of more preventive and proactive approaches.

The business concern related to sustainability issues in this period was directly related to the intensification of environmental awareness in the 1970s and 1980s. The increased awareness was a consequence of the pollution caused by a generally passive attitude until then adopted by industry, where almost no mechanisms for pollution control were in place.

Within the passive approach, industrial waste generated in the production processes by manufacturing companies was disposed directly in the environment without any kind of treatment, leading to a severe pollution of the environmental compartments (soil, air and water) and causing serious damage to both human health and quality of life.

In recognition of the pollution effects on human health and the environment, governments worldwide started to intensify their environmental legislation programmes in the 1980s, which aimed at regulating companies' activities concerning pollution control. From this development and strengthening of environmental legislation, companies started to shift from a passive stance towards the adoption of what we today would call reactive approaches, which focused on the so-called 'end-of-pipe' solutions.

The ‘end-of-pipe’ solutions aimed at reducing the pollution potential of industrial waste, so as to comply with the enacted legislation, by investing in technologies, which were chiefly intended for the treatment of industrial wastewater, solid waste and gases generated in the production processes. Due to the relatively high investments for the implementation of ‘end-of-pipe’ solutions, there was a strong tendency to understand environmental and sustainability issues as a cost to the organization, rather than as an opportunity.

In the early 1990s, a preventive approach emerged in a context in which companies started to improve their manufacturing processes, in order to minimize the increasing costs related to ‘end-of-pipe’ solutions, to comply with the ever-constraining legislation and to increase resource efficiency. Concepts such as Pollution Prevention and Cleaner Production were key in the period, when the preventive approach was at its highest. The aim was to reduce the waste generation directly at its source, i.e. in the production processes, thereby reducing treatment and final disposal costs (UNEP 2004; Ahmed 2012).

Besides being driven by legal aspects, this change in attitude was also due to the recognition of the real costs associated to the traditional ‘end-of-pipe’ approaches. In addition to the costs usually attributed to treatment and disposal, there are other costs that are usually not taken into account, such as, for example, costs related to the loss of resources (raw materials, water, energy, etc.), legal and regulatory non-compliance, corporate image, to name a few. Typically, for every dollar accounted for waste treatment or disposal, a further two to three dollars are ‘hidden’ or simply ignored, even in well managed and large companies (UNEP 2004).

Despite the innumerous benefits of reactive and preventive approaches to sustainability enhancement, they alone are not enough to deal with the sustainability challenges that our society was—and still is—facing, due to the ever-increasing production and consumption of products.

In the late 1990s, the recognition that products were at the origin of most of the pollution and resource depletion caused by our society became evident and a transition to a more proactive approach could be observed. At that time, companies started to realize that all products caused some sort of impact, not only during the manufacturing processes, but also throughout their entire life cycles, from raw material extraction through manufacturing, use and final disposal (Fava 1998).

In this context, ecodesign emerged as a promising approach for the integration of environmental considerations in product development processes, where the opportunities for enhancement of the environmental performance across the product life cycle was estimated to be around 80 % (through the definition of materials, suppliers, product performance, etc.) (Mcaloone and Bey 2009). The introduction of the life cycle thinking was associated with efforts to increase efficiency throughout the product life cycle (Brezet et al. 1999; Sherwin and Bhamra 1999; Stevels et al. 1999).

To enable ecodesign implementation in companies, several methods and tools were developed by industry and academia in this period. Several approaches for the


**Fig. 1** The rise and establishment of ecodesign (1990–2010)

evaluation of the environmental performance of products (e.g. through Life Cycle Assessment (LCA) and similar approaches) were developed and ecodesign guidelines for enhanced environmental performance of products were consolidated for different product types and industrial sectors (Caspersen and Sørensen 1998; Brezet et al. 1999).

The basic approach at this moment was focused on specific product issues (e.g. minimization of weight, elimination of hazardous substances, enhancement of energy efficiency, etc.). At this time, and due to the previous experience with end-of-pipe approaches, which were costly and mainly there for legislative compliance, sustainability was chiefly viewed as a necessary cost, with only very few companies being able to demonstrate the business benefits linked with ecodesign implementation.

The take-make-waste paradigm of the linear economy was the main paradigm in most of the companies at this time, although initial discussions regarding the impacts and importance of the end-of-life of products started to enhance towards the end of the 2010s (Rose et al. 2002). Most of the actions taken for ecodesign implementation were at an operational level, looking mainly at the product level and from a strict design perspective, linked to material and energy efficiency.

By the end of the 2010s, more than 100 different methods and tools were developed, but the broad uptake by industry was not as expected (Baumann et al. 2002) and new challenges started to be observed by society (Pigosso et al. 2015). At that time, there was a need to evolve the ecodesign concepts and allow for a broader implementation and uptake by industry. Figure 1 provides a summary of the main characteristics of corporate sustainability in the 1990–2010 period.

## 3 2010–2020: A Systems Perspective on Ecodesign

In the period 2010–2020 (which encapsulates the current time of writing), a shift can be observed in society, away from the more reactive, tool-building and singular problem-focus of the first era. In this period, a new wave of globalization is in full flow, enabled by technology and near-instant availability of products and services, all around the world. As the world gets smaller, so to speak, singular products often become commoditized, with their perceived value reducing to a minimum. For instance, the increased rate of commoditization can seem like a vastly negative trend, environmentally, due to ever-shortening product lifetimes and large bouts of waste, within a linear economy. However, two counter-developments have emerged, namely the embedding of high value in high quality products; and the emergence of product/service-systems onto the market. High-value, high-quality products (e.g. premium-priced smartphones and high-end portable computers) indeed provide some of the answer to the previous era's problem with commoditization and product waste. Product/service-systems, PSS (which effectively are purposely co-developed product and service bundles) are also increasingly normal in both B2B and B2C markets. PSS come with new business models, which often focus on providing more value-add from one installed base of a product, by means of some form of product life extension (often through sharing), and therefore dematerialization of the physical artefacts, which are component parts of the PSS under offer (Bey and Mcaloone 2006).

It is in this time period that many companies are starting to formulate sustainability goals, together with ways in which these will be measured, be they environmental, social and/or business-oriented. The very intensive period of tool building has slowed in this decade, with more emphasis being placed on how to actually successfully select from the large lists of tools and methods and implement the most suitable tools within the company (Pigosso et al. 2011; Bovea and Perez-Belis 2012). This is a positive development, as we can identify over 800 ecodesign best practices already (Pigosso et al. 2014)—the focus must now be on how to ensure successful implementation of these tools and methods into the business- and product development processes of the enterprise.

Together with the shift from products to PSS as a standard sustainability design object, the basic approach has shifted, so as to incorporate more sustainable decision points at a given time, thereby encompassing a systems approach towards sustainability enhancement. Nevertheless, many companies are not yet realizing the full benefit of their efforts towards sustainability improvement, often rendering sustainability as an activity that may not any longer be seen as a net cost to the company, but is still not a sufficient value-creator in itself.

In this decade, social sustainability is a clear focus point for the organization and a number of projects (often in collaborations between academia and enterprises) have been completed, where social sustainability methods and metrics have been developed, tried and tested (Ny et al. 2006; Boström 2012).


**Fig. 2** A systems perspective on ecodesign (2010–2020)

Western society is beginning to pay increasing attention in this decade to closing loops, rather than operating in a linear economy. Focus is increasingly being placed on takeback schemes, Design for Recycling activities, new business models to revalorize waste, and new forms of artefact sharing systems (e.g. bike-sharing, car-sharing, tool-sharing, to name but a few) (McDonough and Braungart 2010). We are by no means circular in our approach, but closed loop activities are beginning to be favoured over linear economy activities.

Looking inside companies and universities, we can see increasing focus being placed on how to create better processes towards sustainable product development, rather than simply creating yet another tool or a method. With this elevation of activities to the level of PSS, systems thinking and closed loop operations, companies are increasingly engaging the middle-management (tactical) levels of their business- and product development activities, in order to understand how to leverage greater parts of the companies' value-adding activities, through more tactical deployment of sustainability thinking (Tukker 2004). Figure 2 shows a summary of the main characteristics of corporate sustainability in the 2010–2020 period.

## 4 2020–2030: Perspectives for a Sustainable and Circular Economy

An even more significant transition to corporate sustainability is expected in the upcoming decade. Although predicting the future is impossible, we have attempted to develop a scenario of how current initiatives might possibly deploy over the next decade, based on an analysis of current trends and past developments.

Increasing recognition of the need to mitigate the effects of population growth, wealth increase and human consumption is currently leading several international organizations to consensually highlight the need for a significant change in our economic system, in order to respect planetary boundaries (Steffen and Stafford Smith 2013; Häyhä et al. 2016). Some examples of sustainability-related initiatives include: the roadmap for developing energy efficient and low-carbon societies by 2050, developed by the European Union; the 'green growth' framework to foster economic growth while ensuring the availability of natural resources, by the Organisation for Economic Co-operation and Development (OECD); and the Sustainable Development Goals (SDGs), launched by the United Nations in 2016. In order to reach global and European development goals, the private and governmental sectors in Europe need to undergo a large and systemic transition.

Due to the recognition of the systemic sustainability challenge faced by our society, a change towards extended collaboration within and across value chains is expected. Collaboration must be focused on developing new solutions and economic systems, bringing together different stakeholders in society, that help addressing the planetary boundaries (Steffen and Stafford Smith 2013).

An increasing amount of businesses will be maturing their approaches towards sustainability and increasingly integrating sustainability into not just the high-level strategic goals of the company, but also the everyday business and product development processes. This will allow each and every decision in the organization to be taken based on solid and conscious sustainability considerations. It will also give rise to a holistic approach, in which the connections and interfaces among complex systems are considered and their dynamic natures understood.

Competences will be significantly enhanced to be able to cope with the understanding of complex problems and the collaborative development of efficient solutions. Sustainability will be defined and committed at a strategic level in organizations and the deployment into the tactical and operational levels will be enabled by the enhanced maturity of companies on sustainability enhancement.

At this point, companies will have the contents and the context to be able to understand that sustainability equals business, and that there is no other alternative way of being successful in a business context. In fact, such signs are already evident in the very leading-edge corporations, which have put a direct relationship between sustainability and business-enhancing innovation (Ellen MacArthur Foundation 2015a). First on achieving a critical mass of this type of company, recognizing the opportunities of business-driven sustainability action, will we see that the sustainability concept defined as the balance between the environmental, social and economic dimensions will finally be fully met.

In the next decade, problems and risks related to resource scarcity and product disposal will be minimized by an enhanced uptake of the concept of Circular Economy (Ellen Macarthur Foundation et al. 2015), which is currently being boosted in many parts of the world.

Circular Economy is increasingly seen as a key approach to operationalizing goals and supporting the transition by enhancing competitiveness, economic growth and sustainability in many parts of modern society. Circular Economy is defined by

the Ellen MacArthur Foundation as "*an economy that provides multiple value creation mechanisms, which are decoupled from the consumption of finite resources*" (Ellen MacArthur Foundation 2015a). Unlike the traditional linear 'take-make-waste' approach, the goal of Circular Economy is to seek to respect planetary boundaries through increasing the share of renewable or recyclable resources, whilst reducing the consumption of raw materials and energy and thus bringing down emissions and material losses (EEA 2016). Creating a Circular Economy requires fundamental changes throughout the value chain, from innovation, product design and production processes all the way to end of life, new business models and consumption patterns (EEA 2016).

Large and established, as well as small and start-up players in the industry are increasingly recognizing the need to commercialize secondary raw materials, to ensure spare-parts availability and to actively begin to devise alternative and innovative business models, disruptive to their current ways of working (2016). Among the strategies being addressed are: expansion of high value-added services; focus on Total Cost of Ownership (TCO) over the product lifetime; outsourcing agreements and rental offerings; technical leadership; and optimized product quality. Manufacturers are increasingly positioning their offerings, such as equipment financing; training for the best use of machines; fleet management; and equipment relocation services, as ways in which to enhance their value propositions to their customers. The positive news is that these new value propositions by the industry are potential components of a circular business model approach.

A successful transition to Circular Economy requires a systemic change in the way companies understand and do business, with sustainability as a strong foundation. Circular Economy will be enabled by the combined application of three component elements: (i) Business Model Innovation; (ii) Sustainable Design and Ecodesign; and (iii) Internet of Things coupled with Digital Transformation.

One of the most powerful enablers of a circular economy is sustainable business model innovation (Chun and Lee 2013; Pigosso and McAloone 2015; Reim et al. 2015). Business models that successfully incorporate Circular Economy principles have a direct and lasting effect on the social, economic and environmental systems (EEA 2016). Taking a sustainable business model view on Circular Economy promotes the integration of suitable approaches such as ecodesign, reuse, sharing, leasing, repair, refurbishment and recycling. By integrating the most suitable of these approaches to one's business- and product development will play a significant role in maintaining the utility of products, components and in realizing circular business models (EEA 2016).

Circular Economy business models can only be realized by the development of products, services and Product/Service-Systems that can be easily disassembled, remanufactured, recycled and reused (Bakker et al. 2014; Tukker 2015). Common approaches for the design of circular products includes the application of Design for Recycling, Design for Remanufacturing and Design for Disassembly methods, tools and guidelines (Sundin and Bras 2005; Pigosso et al. 2010; Achillas et al. 2013). Nevertheless, in order to ensure a superior sustainability performance of products, the entire life cycle of products need to be considered.


**Fig. 3** Perspectives for a sustainable and circular economy (2020–2030)

Circular Economy can benefit greatly by equipping products with intelligence, so that they can adapt and respond to change and remain fit-for-purpose over longer time periods (Ellen MacArthur Foundation 2015b). A whole new range of virtual services and sharing economy platforms support the prolonged technical lifetime (and sometimes also up-cycling) of products by monitoring the condition of individual components or whole product systems.

In this context, Circular Economy will lead to the development of innovative business models, products, value chains, partnerships, and technologies that will enable a much more and efficient closed loop of materials and energy—and ultimately a more robust economy.

Due to the significant undermining of planetary boundaries caused through the industrial activities of the past century, it is increasingly recognized that the sustainability concept will need to embrace restoratory concepts, so as to reestablish the planetary boundaries at safe levels and not undermine life on Earth (Fig. 3).

## 5 Summary and Final Remarks

This chapter has provided our reflection of the development and evolution of sustainability initiatives and approaches observed since the 1970s in a corporate context. The reflection has structured in three distinct periods, which are characterized by their own specificities, challenges and focus areas (Fig. 4).

Despite the common perception that we are still struggling with the same issues since the early stages of corporate sustainability initiatives, a clear change in patterns and a significant evolution of the discussion is observed. Governmental bodies, universities, non-governmental organizations, companies and the civil society have significantly raised and enriched the debate around sustainability.


**Fig. 4** A journey through research contributions over the recent decades (1990–2030)

Furthermore, industry interest and uptake at the strategic, tactical and operational levels is following a steady increase—although many challenges are still faced for full sustainability integration.

In order to be able to cope with the sustainability challenges faced by our society and respecting the planetary boundaries, the speed of change and actual uptake by industry and a varied set of stakeholders must enhance significantly over the next decade. At the same time that ambitious targets must be set, it is important that industry companies take a systematic and step-by-step approach towards enhancing their organizational maturity to be able to develop and perpetuate successful and sustainable businesses.

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