Characterization of the State-of-the-art and Identification of Main Trends for Ecodesign Tools and Methods: Classifying Three Decades of Research and Implementation

Pigosso, Daniela Cristina Antelmi; McAloone, T. C.; Rozenfeld, H.

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REVIEWS

Characterization of the State-of-the-art and Identification of Main Trends for Ecodesign Tools and Methods: Classifying Three Decades of Research and Implementation

D.C.A. Pigosso[1], T.C. McAloone[1] and H. Rozenfeld[2]*

Abstract | Ecodesign is a proactive management approach that integrates environmental considerations in product development and related processes (such as purchasing, marketing and research & development). Ecodesign aims to improve environmental performance of products throughout their life cycle, from raw material extraction and manufacturing to use and end-of-life. Over the last three decades, an intense development of new ecodesign methods and tools could be observed, but uptake by the industry remains a challenge. The purpose of this research is to perform a review of existing ecodesign tools and methods through a systematic literature review linked to bibliometric analyses, in order to explore the state of the art of ecodesign methods and tools and identify trends and opportunities in the field for the next decade.

1 Introduction

Products are essential for wealth of the society and for desired quality of life. However, the growing consumption of products is also directly or indirectly at the root of most of the pollution and depletion of resources society causes.[1] Every product, in some way or the other, causes environmental impacts, from the extraction of raw material and its production and use to the management and final disposal of waste.[2]

Ecodesign, a proactive approach to environmental management, involves the consideration of environmental issues in the product development process in order to minimize environmental impacts throughout the product's life cycle, without compromising other essential criteria such as performance, functionality, asthetics, quality and cost.[3,4]

In the last decades, several ecodesign methods and tools (any systematic way to deal with environmental issues during the product development process) were developed to evaluate environmental impacts, revealing potential problems and conflicts and facilitating the choice between different aspects through the comparison of ecodesign strategies.[2,5–8] Although several ecodesign methods and tools exist, they are still not used systematically in the development of new products.

The objective of this research is to perform a review of ecodesign tools and methods through a systematic literature review linked to bibliometric analysis, in order to explore the state-of-the-art of the ecodesign field and identify trends and opportunities.

The next section describes the methodology employed in the systematic literature review and bibliometric analysis. Section 3 describes the main results of the bibliometric analysis and is followed by Section 4, which discusses the major results in terms of the evolution of ecodesign methods and tools. Section 5 highlights the trends for ecodesign tools and methods in the next decade. Final remarks and conclusions are presented in Section 6, followed by the bibliographic references.

Environmental impacts: Changes to the environment, whether adverse or beneficial, wholly or partially, resulting from an organization's activities, products or services.

Ecodesign: Approach that integrates environmental considerations into product development in order to minimize environmental impacts across the product's life cycle.

Product's life cycle: Comprises the stages of a product life, often defined as raw material extraction, manufacturing, use & maintenance, and end-of-life.

[1]DTU, Denmark.
[2]USP, Brazil.
*danpi@dtu.dk

2 Methodology

Given the objective of exploring the state-of-the-art of ecodesign methods and tools, the research performed can be characterized as exploratory.[9] The main technical procedure employed in the research was a systematic literature review, which was combined with bibliometric analysis.

Exploratory research: Type of research adopted to explore a given research field. It often results in the development of concepts, classifications and definitions.

Research work involving systematic reviews follows a well-defined sequence of methodological steps, according to a previously developed protocol.[10,11] The systematic review model comprises three phases, namely: (1) planning (Section 2.1), (2) execution (Section 2.2), and (3) analysis of the results[11] (Sections 2.3). Bibliometric analysis was employed as a tool to support the analysis of the results.

2.1 *Planning*

The focus of interest of the systematic review, i.e. the research objective of the review, was the exploration of the state of the art of research dealing with ecodesign methods and tools.

Bibliometric analysis: Enables the observation of the state of science and technology through the overall production of scientific literature, at a given level of specialization (OECD, 1997).

The database selected in this review is the ISI Web of Science. The criterion employed to evaluate the data sources was their international scope in the area of research and availability of data for the bibliometric analyses.

The selection of keywords and logical terms was performed iteratively. To begin with, there was a set of 21 articles that were extracted from the initial keywords. As the review proceeded, new keywords emerged and were added to the initial set, resulting in new searches in the databases using the newly included keywords.

The main terms or keywords employed were: ("ecodesign" or "eco-design" or "design for environment" or "sustainable product development" or "sustainable product design" or "life cycle design" or "life-cycle design" or "green product" or "green design" or "environmental product design" or "sustainable product development") and ("tool" or "method" or "framework" or "model" or "technique" or "procedure" or "guideline").

The results were refined based on three main criteria: language (English), type of study (journal papers) and knowledge areas (engineering, environmental sciences ecology, business economics, materials science and operations research management science).

The studies to be included in the scope of the review were selected by applying the study inclusion/exclusion criteria. The selected papers were the ones that presented the development of ecodesign methods and/or tools, case studies of their application, and review studies.

2.2 *Execution*

The execution phase (2) involves searching for studies in databases using the pre-established review protocol, developed in the planning phase (Section 2.1).

The identification of studies in the selected databases was carried out in May and June 2015 and resulted in a total of 530 journal articles. Applying the inclusion/exclusion criteria (presented in Section 2.1.3), 350 studies dealing with ecodesign methods and tools were selected. The articles that did not fulfill the inclusion criteria were then reviewed to ensure that no relevant articles were excluded.

2.3 *Analyses of the results*

The selected studies were synthesized by extracting the relevant information in combination with a bibliometric analysis.

Bibliometric analysis is currently applied to a wide variety of fields and its application in scientific research is increasing exponentially. In order to perform the bibliometric analysis, the VantagePoint bibliometric software was employed.

In addition to the bibliometric analyses, the 350 papers were divided and analyzed according to the publication year in four groups: 1) 1993–1995; 2) 1996–2000; 3) 2001–2005; 4) 2006–2010 and 5) 2011–2015. The main topics were identified based on the analysis of each individual paper. The analysis of the results (Phase 3) are presented in sections 3 (bibliometric results) and 4 (evolution of ecodesign methods and tools as a knowledge area).

While the literature review enables an understanding of the evolution of the knowledge area over time, it provides limited evidence on trends and future research topics. In order to identify the trends for ecodesign tools and methods, the understanding of the literature review was complemented by the authors' tacit knowledge on the topic, their participation into conferences and related events (which often presents up to date research topics), accompaniment of political discussion in an international context and experience with ecodesign implementation in manufacturing companies. While this brings a high level of subjectivity, the authors believe the analysis can provide relevant insights to researchers in the field.

3 Bibliometric Results

This section presents the bibliometric results obtained in this research (Table 1).

3.1 *Number of papers per year*

In order to identify the evolution of the knowledge area over the years and its current relevance, the first analysis performed in this study was the annual distribution of the identified papers (Figure 1).

The values obtained indicate that there is a growing interest in developing and applying ecodesign methods and tools for the development of products with better environmental performance. The last 5.5 years (from 2010 to June/2015) account for 64.3% of the published papers over the last 22 years. The year with the highest amount of published papers is 2014, with 55 papers.

Based on the identified trend, it is expected that the number of papers will continuously increase in the coming years, indicating a continuous focus on the development of new methods and tools and their application in industry.

Table 1: Bibliometric analyses performed in this research.

Number of papers per year
Number of papers per author
Number of papers per Institution
Number of papers per Journal
Most used keywords
Most cited papers
Most cited references

3.2 *Number of papers per author*

The studies correspond to the work of 852 authors in total, which results in an average of 2.4 authors per paper. Figure 2 presents the 11 most productive authors of the sample of papers analyzed in this research.

Sixteen of the sixty papers by the 11 most productive authors were published in the Journal of Cleaner Production and five on the Journal of Engineering Design. In total, the papers were published in 20 different journals.

The distribution of the other authors in relation to the number of papers published are: 35 authors with 3 papers; 125 authors with 2 papers and 681 authors with 1 paper. With the increase in number of authors in the recent years, there is an indication of expansion of the knowledge area.

3.3 *Number of papers per Institution*

The sample of 350 papers selected in this research involve a total amount of 385 institutions. Figure 3 presents the 12 most influential institutions (with five or more papers in the sample).

From the 12 institutions, six are in Europe (3 in France, 2 in the United Kingdom and 1 in Denmark), five are in Asia (3 in Taiwan, 1 in Hong Kong and 1 in India) and one is in South America (Brazil).

An analysis of the full sample indicates that institutions from 44 countries were involved in the research. The papers published in the analyzed sample per country are presented in Table 2.

An analysis of the most popular journals for each country shows that while the Journal of Cleaner Production is the most popular one for

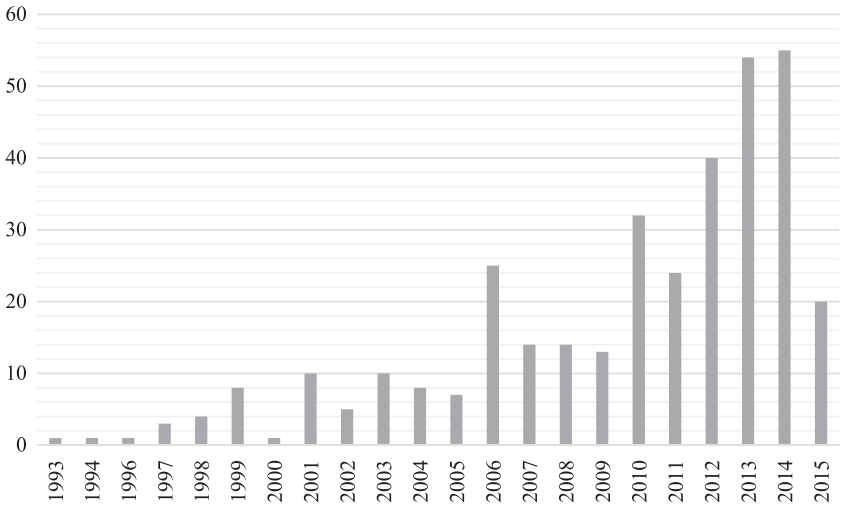

Figure 1: Annual distribution of selected papers.

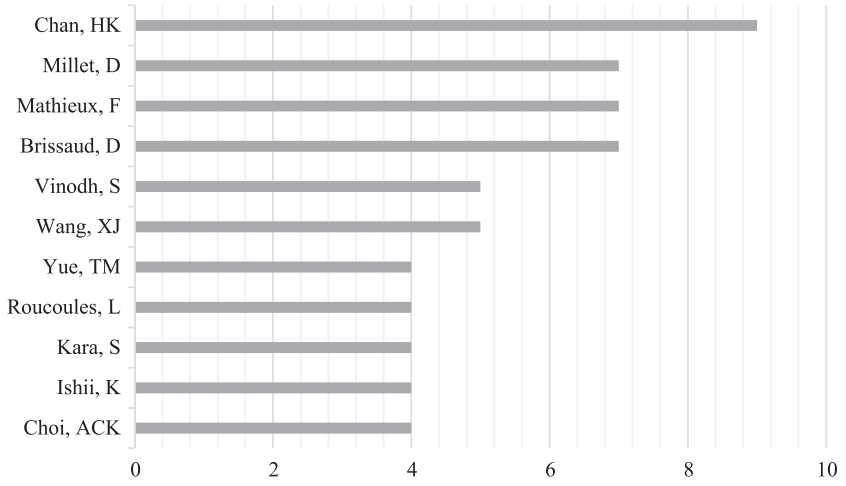

Figure 2: Most productive authors in the analyzed sample.

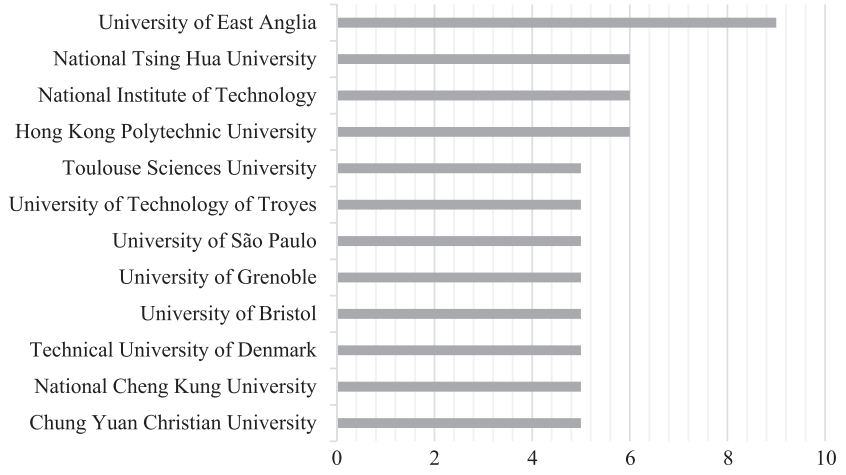

Figure 3: Most influential institutions in the sample.

most of the countries (including USA, France, Taiwan, England and China), the Journal of Life Cycle Assessment is more popular in Germany, Austria and Spain. The European Journal of Operations Research seems to be preferred by researchers from Canada.

3.4 *Number of papers per journal*

One hundred different journals were recorded, indicating the high multidisciplinary level of the knowledge area. Table 3 presents the number of papers published in the most recurrent journals of the sample.

The Journal of Cleaner Production started publishing ecodesign related papers in 2002. Over the last years, the number of ecodesign related published papers has systematically increased. 2014 is the year in which the highest number of ecodesign related papers has been published—17 papers.

The International Journal of Life Cycle Assessment published the first ecodesign-related paper in 2001, and inconsistent publication can be seen over the years (e.g. 2013 accounted for 6 published papers, while only one paper was published in 2014).

The Journal of Engineering Design had the first ecodesign related paper published in 1994 and had not published any paper in the area from 1995 to 2005 and in 2009–2010. Nevertheless, an increase trend in publishing ecodesign related papers can be observed in the last 4 years.

The Journal of Industrial Ecology seems to be expanding the scope for publishing ecodesign related papers: in 2014, 5 papers were published. The same can be observed in the Business Strategy

Table 2: Number of papers published per country.

Country	# Papers	Country	# Papers
USA	49	Singapore	4
France	39	Belgium	3
Taiwan	37	Greece	3
England	34	Poland	3
China	31	Switzerland	3
Germany	25	Wales	3
Italy	23	Ireland	2
Sweden	19	Luxembourg	2
Canada	16	Mexico	2
Japan	16	New Zealand	2
Spain	16	Thailand	2
Australia	15	Turkey	2
South Korea	15	Fiji	1
Brazil	9	Indonesia	1
Denmark	9	Iran	1
India	9	Israel	1
Malaysia	9	Latvia	1
Portugal	8	Oman	1
Netherlands	7	Romania	1
Austria	5	Scotland	1
Finland	4	Slovenia	1
Norway	4	Tunisia	1

and the Environment and International Journal of Production Economics.

3.5 *Most used keywords*

The most used keywords from the 1048 different keywords identified in the sample are presented in Figure 4.

Words commonly used synonymously with ecodesign can be observed in the list of most common keywords (design for environment, sustainable product development, life cycle design and eco-innovation). Other keywords that indicate the overall context for the study can also be observed, including sustainability, product design, product development, design and sustainable development).

On the other side, a high number of keywords dealing with specific areas of ecodesign are identified: Life Cycle Assessment (as a tool to measure the environmental performance), recycling and remanufacturing (as end-of-life strategies).

3.6 *Most cited papers*

350 papers from the sample received a total of 1988 citations (average of 5.7 citations per paper). The most cited papers are presented in Table 4.

Ten out of the twenty most cited papers were published in the Journal of Cleaner Production. The others were published in 10 different journals. Most of the most cited papers were published in 2006 (4 papers).

3.7 *Most cited references*

The 350 papers that comprise the sample analyzed in this research summed up 10514 cited references. The 10 most cited references are presented in Table 5.

4 Evolution of Ecodesign Methods and Tools as a Knowledge Area and Major Achievements

The evolution of the ecodesign methods and tools field over the three decades was analyzed in order to 1) identify the main topics addressed by the papers; and 2) identify the evolution of the topics addressed throughout the years. In total, 30 main topics related to ecodesign methods and tools were identified. The results of the analysis are summarized in Table 6.

Recycling: Recovery of materials in the end-of-life so as to make them suitable for use in manufacturing processes as raw material

Remanufacturing: End-of-life strategy that conserves the product components and bring the product back into an "as new" condition by carrying out disassembly, overhaul, and replacement operations

Table 3: Most recurrent journals in the analyzed sample.

# Papers	Journal
89	Journal of Cleaner Production
28	International Journal of Life Cycle Assessment
12	Journal of Engineering Design
12	Journal of Industrial Ecology
9	International Journey of Production Research
9	Material Design
8	International Journal of Advanced Manufacturing Technology
7	Journal of Mechanical Design
7	Resources, Conservation and Recycling
6	Expert Systems with Applications
6	International Journal of Computer Integrated Manufacturing
5	CIRP Annals - Manufacturing Technology
5	International Journal of Precision Engineering Manufacturing
5	Journal of Electronics Manufacturing
5	Robotics and Computer Integrated Manufacturing
4	Advanced Engineering Informatics
4	Business Strategy and the Environment
4	International Journal of Production Economics
4	Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture

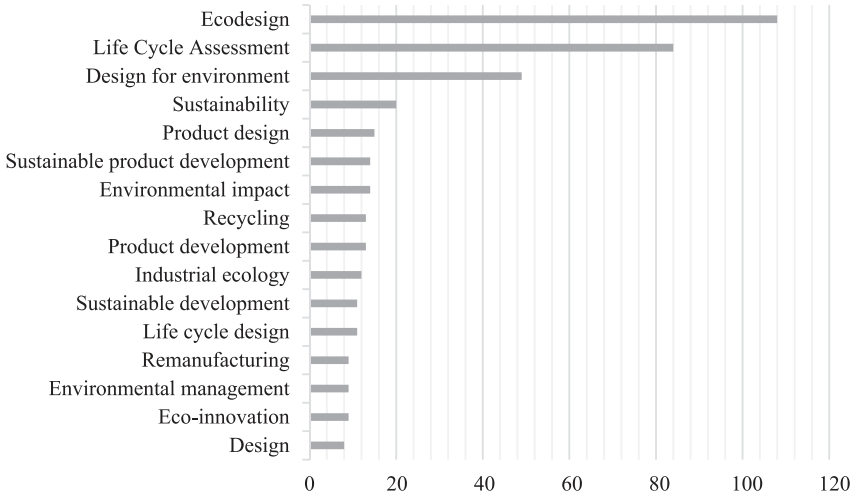

Figure 4: Most used keywords.

The early-nineties were characterized by papers dealing with the serviceability as a way to increase the environmental performance of products and in the first reviews of existing tools to integrate environmental issues in product development. Major achievements during this period were related to the transition from a preventive approach, focused mainly on end-of-pipe attitudes, to a more proactive approach, which aimed at integrating environmental issues in the product development process, and therefore, minimizing the impacts at its source.

It was not before the late-nineties, however, that the ecodesign knowledge area started to

Table 4: Most cited papers in the analyzed sample.

# of citations	Title	Reference
109	Developing sustainable products and services	12
105	EcoDesign and The Ten Golden Rules: generic advice for merging environmental aspects into product development	13
87	Design for the environment: A quality-based model for green product development	14
86	A strategic design approach to develop sustainable product service systems: examples taken from the 'environmentally friendly innovation' Italian prize	15
84	Linear programming in disassembly/clustering sequence generation	16
78	Service Engineering: a novel engineering discipline for producers to increase value combining service and product	17
77	Evaluating the environmental impact of products and production processes: A comparison of six methods	18
76	Eco-innovation and new product development: understanding the influences on market performance	19
72	Ecodesign of automotive components making use of natural jute fiber composites	20
71	Managing 'green' product innovation in small firms	21
61	Handling trade-offs in ecodesign tools for sustainable product development and procurement	22
53	Adopting and applying eco-design techniques: a practitioners perspective	23
53	Life-cycle based methods for sustainable product development	24
52	Integration of environmental aspects in product development: a stepwise procedure based on quantitative life cycle assessment	25
52	Sustainability in electrical and electronic equipment closed-loop chains	26
49	Mainstreaming Green Product Innovation: Why and How Companies Integrate Environmental Sustainability	27
48	The new product design process and design for environment - "Crossing the chasm	28
45	Materials selection for optimal environmental impact in mechanical design	29
43	Design for environment - do we get the focus right?	30
43	Ecodesign tool for designers: defining the requirements	31

flourish. From 1996 to 2000, several authors started to explore ways to tackle integration of environmental issues into product development from different angles. Studies started to be developed for the establishment of CAD tools with the incorporation of ecodesign features, and approaches were developed to support material selection. The beginning of the concern with end-of-life (EOL) issues could be observed with the development of approaches towards design for disassembly and design for recycling. During this period, the first studies with proposals of approaches to evaluate the environmental performance of products were published, including mainly Life Cycle Assessment. Design for production optimization and the need for a systemic approach also appeared as main topics from 1996–2000. The overall integration of environmental issues in Research and Development (R&D) and product development started to be discussed. Major results obtained in this period are related to the establishment of LCA as a robust tool to support decision-making and communication of environmental performance of products; on the increased focus on end-of-life strategies and on the understanding that the highest opportunities for increasing the environmental performance of products were in the initial stages of product development.

By the turn of the millennium, ecodesign was established as a more consolidated research area. Without losing the focus on the main topics

End-of-Life (EOL): Life cycle stage that occurs when the product does not fulfill any longer the function to which it was designed for

Table 5: Most cited references in the analyzed sample.

Cited by # papers	Title	Reference
39	C. Luttropp, J. Lagerstedt, EcoDesign and The Ten Golden Rules: Generic advice for merging environmental aspects into product development, J. Clean. Prod. 14 (2006)	13
34	J.C. Brezet, C. Van Hemel, Ecodesign: A promising approach to sustainable production and consumption, 1997	32
28	H. Baumann, F. Boons, A. Bragd, Mapping the green product development field: Engineering, policy and business perspectives, J. Clean. Prod. 10 (2002)	2
27	ISO, ISO 14040: Life Cycle Assessment—Principles and Framework, Environ. Manage. 3 (2006) 28	33
22	S. Byggeth, E. Hochschorner, Handling trade-offs in ecodesign tools for sustainable product development and procurement, J. Clean. Prod. 14 (2006)	22
20	R. Karlsson, C. Luttropp, EcoDesign: What's happening? An overview of the subject area of EcoDesign and of the papers in this special issue, J. Clean. Prod. 14 (2006)	34
19	P. Knight, J.O. Jenkins, Adopting and applying eco-design techniques: A practitioners perspective, J. Clean. Prod. 17 (2009)	23
18	ISO 14040, Environmental Management–Life Cycle Assessment–Principles and Framework (revised in 2006), ISO 14040 (1997)	35
18	J. Fiksel, K. Cook, S. Roberts, D. Tsuda, Design for environment at Apple Computer: A case study of the new PowerMacintosh 7200, Proc. 1996 IEEE Int. Symp. Electron. Environ. ISEE-1996	36
17	ISO/TR 14062—Environmental management—Integrating environmental aspects into product design and development, Tech. Rep. 2002 (2002).	37

that started to be addressed during 1996–2000, research started to be developed on new issues that showed potential to enhance ecodesign application in industry, such as information and knowledge management, strategic considerations and life cycle costing. Special attention started to be taken on how to integrate ecodesign in the conceptual design (including the selection of concepts and analyses of trade-offs), bringing customers and stakeholders' requirements into account early in the design process and starting to consider the managerial issues related to ecodesign implementation. Despite the availability of a large variety of tools, the researchers identified that companies were still not fully embracing the concept. The understanding of the need to integrate ecodesign with strategic decision-making, marketing research and economic issues to strengthen its implementation in companies can be highlighted as a major development in the field. Furthermore, the need to evaluate trade-offs between environmental criteria and the traditional product development criteria (such as costs, esthetics, quality, etc.) became evident.

Conceptual design: Phase of a product development process in which alternative concepts and solution principles are developed based on the identified requirements for the product under development

The period 2006–2010 was characterized by the consolidation of knowledge and tools for the evaluation of the environmental performance of products and technologies, on methods and tools to deal with EOL and on material selection approaches and techniques. Furthermore, there was a strong focus on the integration of ecodesign in the early stages of product development and a better understanding of the managerial and strategic issues required for a successful ecodesign implementation. At that point, several tools and methods were already available, but not necessarily applied by industry, and research started to be performed to provide guidelines on how to develop more applicable tools, to support their selection and implementation into companies. Furthermore, the recognition of the complexity related to the traditional LCA tools led to the development of simplified guidelines and checklists that would more easily support designers to take decisions, especially in the early stages of product development. At the same time, and because of the increase of product-related environmental regulations, research was focussed on supporting companies to comply with those new policies, legislation and standards by developing tailored tools and methods. Initial research started to be carried out on increasing the robustness and extending the lifetime of products, through modularization. Green marketing practices started to be explored, as a way to ensure a high demand for the ecodesigned products.

Robustness: The ability of a system to resist to change

Table 6: Main results obtained over the last three decades: An evolution of the ecodesign methods and tools knowledge area.

Main topics	1990–1995	1996–2000	2001–2005	2006–2010	2011–2015
Products and services	38		15,39,40	17,41	42–44
CAD tools		45	46,47		48,49
EOL methods		50–55	56–61	26,41,62–74	75–93
Evaluation of environmental performance		94–97	25,61,98–110	20,24,63,68, 111–130	131–175
Material selection		176	177,178	126,129,179–181	152,182–190
Design for production optimization		191	192	193–197	76,198–203
System approach		204		26	92,205
R&D and product development integration		21,28,206	107,207–209	210–214	137,215–222
Information and knowledge management			223	123,224,225	226–231
Conceptual design, selection and trade-offs			232,233,234	22,235–241	132,242–24481, 149,151,174, 230,245–250
KPIs			156,251	68,252,253	166,254–256
Strategic considerations			257	258–261	262–268
Life cycle costing			104,269	63,115,116	150,170,270
Customers and stakeholders requirements			107,110	19,127,271–275	43,136,137,226, 276–284
Managerial integration			285,286	27,260,287–292	162,228,263,293–300
Development, selection and implementation of tools				23,31,301	6,302–306
Simplified guidelines and checklists				13,68,117, 307–310	183,311
Policy and standardization				120,122,243, 312–315	143,254,298,316–319
Support for SMEs				314,320	321
Extending lifetime and modularization				322–325	326–331
Robustness				332	333,334
Green marketing				335	336–341
Supply chain involvement					82,133,205,267, 270,336,342–346
Ideation tools					137,169,347–350
Decision support systems					146,249,294,351–358
Monetization of environmental impacts					359,360
Portfolio management					361
Use-oriented design					362
Territorial resources					363

Major achievements in the period 2006–2010 are related to the understanding that existing ecodesign tools and methods were not necessarily useful for companies, and that there was a need to improve, simplify and customize existing methods and tools for effective implementation by industry. Furthermore, the understanding of the importance of identification of internal and external drivers for ecodesign implementation (such as customers' requirements and legislative compliance) became key success factors for the application of the concept.

The last 5 years (2011–2015) are characterized by increased research and consolidation of ecodesign as a multidisciplinary research area that is continuously optimizing the foundations and expanding the borders. Increasingly, research is being conducted on the intensification of supply

chain involvement in the product development process, both upstream and downstream—ecodesign is increasingly going beyond the company borders. Furthermore, tools and methods are being developed to support the generation of ideas that have the potential to originate radical improvements in the environmental performance of products and services. Decision support systems are being explored in recognition of the difficulties to take decisions that will have influences on different environmental impact categories and business areas/functions. As an attempt to involve and engage top management, there is ongoing research on the monetization of environmental impacts and on portfolio management considering ecodesign parameters for a comprehensive decision-making. Furthermore, in order to increase the perceived value by consumers, research is programs are being initiated to develop on use-oriented design. Major results of this period are related to the expansion of ecodesign from product development to the other processes in the organization that will have significant influence on the environmental performance of products, such as supply chain management. Furthermore, the understanding that radical improvements on the environmental performance of products are required can be seen an important achievement, which will be further deployed in the next developments in the knowledge area.

Upstream: Stakeholders of a value chain involved in the early-stages of the product's life cycle (raw material extraction and manufacturing)

Downstream: Stakeholders of a value chain involved in the later-stages of the product's life cycle (use & maintenance and EOL)

Life Cycle Assessment (LCA): Quantitative method for the assessment of potential environmental impacts of products and services

Life Cycle Costing (LCC): Method to evaluate the direct and indirect costs related to a product's life cycle (from raw material extraction to end-of-life)

Value chain: Network of companies/organizations directly or indirectly involved in the product's life cycle (includes suppliers, service providers, recyclers, etc.)

5 Trends for the Ecodesign Tools and Methods in the Next Decade

Over the next decade, an intensification of focus in following nine main areas related to ecodesign tools and methods is expected by the authors:

I. Development of products and services: The development of product/service-systems has been increasingly explored in ecodesign research due to its potential to significantly minimize resource consumption by dematerialization, which would lead to an extension of the products' lifetime and enable EOL strategies, such as recycling and remanufacturing. Research is currently being developed, for example, to measure the environmental improvements of PSS business models compared to traditional products;

II. Focus on sustainable design: The growing importance of the sustainability concept, which entails the balance among the environmental, economic and social dimensions, is currently being explored in ecodesign research, mainly for the integration of social sustainability principles into design and product development. Research is currently being developed to identify how design could contribute to increase sustainability in the product level (in opposition to a corporate level);

III. Development of comprehensive tools to evaluate the sustainability performance of products: There is a clear trend for development of unified tools that can measure the sustainability performance of products considering the environmental, social and economic dimensions –research focus has been, for example, on the integration of Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Social Life Cycle Assessment (S-LCA)—the creation of common units for measure has been explored;

IV. Increased focus on systems thinking for understanding relations and interactions among elements: Systems thinking is emerging as a promising approach to support the consideration of sustainability into product design and development—a systems perspective has the potential to enable a better understanding of the effects of decisions taken during product development on the sustainability performance of products, and would enable the complex consideration of user behavior;

V. Increased focus on circular economy as an overall strategy for sustainability: Circular economy is emerging as a promising approach to guide companies in the transition towards a stronger consideration of waste as resources in closed-loop economies. Ecodesign research is currently focusing on the identification of how product design and development can enable circular economy by the implementation of Design for EOL (e.g. design for recycling, design for remanufacturing, design for reuse, etc.);

VI. Enhanced link between product development and related business processes: There is a trend to expand the traditional ecodesign scope (product development) to additional organizational processes that can have significant influence on the environmental performance of products (such as marketing, purchasing, financing, services, etc.). Research is currently being conducted to enable a better understanding of the interface between internal stakeholders with an aim to enable the integration of ecodesign in companies' processes;

VII. Incorporation of planetary boundaries in evaluation of environmental and social

performance of products and technologies: There is an increasing trend for the consideration of absolute sustainability in evaluation of performance of products and services. An absolute sustainability mindset enables the consideration of the Earth's carrying capacity into product development, which has the potential to spark development of more innovative products;

VIII. Stronger focus on the managerial and strategic issues towards ecodesign implementation: There is a trend to expand the focus of ecodesign considerations from a strict technical arena to more managerial and strategic considerations. New approaches are being developed and tested to allow implementation of ecodesign in the strategic, tactical and operational levels of organizations, enabling a broader uptake and more significant results;

IX. Consolidation of existing tools, approaches and methods for a streamlined application by industry: The large number of tools and methods currently seen in ecodesign literature is being understood by a set of researchers as a barrier for ecodesign implementation—companies usually do not know which tools to select based on their current needs and situation. Consequently, the decision is often not optimum, leading to frustration on ecodesign implementation. Currently, research is being carried out to consolidate existing methods, tools and approaches to support selection and application by industry.

6 Final Remarks

This research mapped the state of the art and provided a classification of the last three decades of research on ecodesign methods and tools by means of a systematic review of the literature, combined with a bibliometric analysis. The research involved the analysis, consolidation and systematization of more than 500 studies, resulting in the categorization of 30 main topics in four periods (from 1990 to 2015).

The main findings from the bibliometric analysis are:

- Growing interest in the development and application of ecodesign methods and tools. It is expected that the number of papers will continuously increase in the coming years;
- Increased number of authors in the recent years indicates an expansion of the knowledge area, while the relatively low number of articles per author indicate that ecodesign might not be their primary research topic;
- Europe, Asia and South America hosts the institutions with the highest publication track on ecodesign methods and tools, while USA as a country holds the highest number of published journal articles;
- One hundred different journals were recorded, indicating high multidisciplinary level of the knowledge area, and establishing the Journal of Cleaner Production as the main journal for the publication of ecodesign-related methods and tools research.

In addition to providing an understanding of the ecodesign methods and tools knowledge area, the authors attempted to indicate nine areas where an intensification of research is expected over the next decade:

- Development of sustainable products and services;
- Focus on sustainable design, by means of the integration of social, environmental and economic issues in product development;
- Development of comprehensive tools to evaluate the economic, environmental and social performance of products;
- Increased focus on systems thinking for the understanding of relations and interactions between elements;
- Increased focus on circular economy as an overall strategy for EOL strategies and a sustainable economy;
- Enhanced link between product development and other business processes of organizations (such as marketing, purchasing, financing, services, etc.);
- Incorporation of the planetary boundaries in the evaluation of the environmental and social performance of products and technologies;
- Stronger focus on the managerial and strategic issues towards ecodesign implementation;
- Increased industry uptake by the consolidation of existing tools, approaches and methods for a streamlined application by industry.

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Daniela C.A. Pigosso is a senior researcher at the Technical University of Denmark (DTU). She received her PhD from the University of São Paulo (USP) in 2012, where she developed a maturity model to support companies on ecodesign implementation and management. Her first degree is in Environmental Engineering from the University of São Paulo in 2008.

Tim C. McAloone is a professor of Product/Service-Systems at the Technical University of Denmark (DTU). He received his PhD from Cranfield University in 1998, where he studied the integration of ecodesign strategies into industry. His first degree is in Mechanical Engineering from Manchester Metropolitan University in 1993.

Henrique Rozenfeld is a professor of Integrated Manufacturing at the University of São Paulo (USP). He received his PhD from WZL RWTH Aachen in 1988, with a research focused on computer-based process planning. His first degree is in Mechanical Engineering from the University of São Paulo in 1980.