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Design Science

Thirty years of design for sustainability: an evolution of research, policy and practice

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Abstract

This paper builds on the lead author's keynote address to the Design Society's 22nd International Conference on Engineering Design in 2019, and in doing so provides a personal perspective on the development of the field of design for sustainability. It begins by describing some of the history of the research from the late 1980s until the present day. This is followed by an analysis of the way in which design for sustainability has been reflected within the International Conference on Engineering Design over the last 30 years, highlighting the way in which the focus has shifted over this time from a focus on recycling and end of life to today where sustainability is playing a leading role in the research. The analysis compares the evolution of the subject with the wider policy and practice perspectives linked to global recognition of the need to move towards Sustainable Development. Finally, the paper reflects on the lessons to be learned from this work and their implications for design research illustrating that engineering design has an opportunity to take more leadership within design for sustainability research and use this to enable change within industry.

Key words: Design for Sustainability, Ecodesign, Environment

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1. Introduction

Design for sustainability has been an area of research that has developed significantly over the last 30 years. After the first definitions of sustainable development emerged in the late 1980s (WCED 1987), design was recognized as an area of major importance in the journey towards more responsible and sustainable production and consumption models. Products were at the centre of the discussions around sustainable development due to the evidence that illustrated that negative impacts in the environment and society were linked to the way in which products were produced and consumed (McAloone & Pigosso 2017). During those years, the academic and professional discourse linked to industry concentrated its attention mainly in identifying environmental concerns and in developing different approaches to clean up the problems that industry had caused. These actions, associated with the industrial activity, were mainly applied at the end of pipe as corrective measures to clean up any environmental problems that had been create during the manufacturing process (Rainey 2006).

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Later, a life cycle vision of products was established and it was recognized that negative impacts could come from all the stages of the product life cycle, from extraction of materials to final disposal. This realization meant that during the 1990s, many approaches pursuing sustainable development were mainly focussed on products (Ceschin & Gaziulusoy 2016); their efficiency, performance, materials, energy, use and disposal were some of the areas scrutinized. During this time, ecodesign (Brezet 1997; Brezet & Van Hemel 1997; UNEP 2006) emerged; an industrial approach aiming to 'reduce the environmental impact of each stage of the product life cycle' (Bhamra & Lofthouse 2007). ecodesign has been one of the most widely adopted concepts in industry in the area of design for sustainability and it is still valid and used today. A study showing how the concept of ecodesign has changed over recent decades was undertaken by McAloone & Pigosso (2017). In this study, the authors presented the development of different tools and methods from 1990 to 2010 aiming to help industry to apply ecodesign principles in their operations. During this period, ecodesign was framed mainly as a product oriented approach working on linear models of production and consumption. However, in this same study, the need for a more systemic view of the solutions emerged and methods used to pursue more sustainable development were outlined. During the 2000s, many other authors and organizations have outlined the same need and research has focussed on a systemic view of the environmental and social challenges faced in the search of a more sustainable society (Manzini & Vezzoli 2002; UNEP 2009; Bhamra, Hernandez & Mawle 2013).

In both the academic and industrial discourse, this need for a systemic view was translated into new approaches with a holistic understanding of the problems and the solutions required to achieve more sustainable development. One of the different approaches that emerged, for example, was Sustainable Product-Service Systems as a very promising alternative (Roy 2000; Tukker & Tischner 2004; Hernandez, Bhamra & Bhamra 2012). The idea behind these systems was to provide users and consumers with the utility they wanted to satisfy their needs, but with fewer physical products, relying more on services and alternative ways of using products but without the consumer owning them. This period, that started around 2000 and continues until the present-day, gave birth to new ideas in the design field. During this time, and partly because of the evolution of design for sustainability, design as a discipline extended its boundaries into new territories of such as service and social design.

A study of the evolution of different design approaches related to design for sustainability was published by Ceschin & Gaziulusoy (2016). In this study, the authors present a framework that locates the approaches developed over recent decades from green design to design for systems innovation and transitions (Ceschin & Gaziulusoy 2016). An interesting part of this framework is the plotting proposed to locate and understand the approaches. In this plot, there are four levels: product level, product-service system level, spatio-social level and socio-technical system level. Those levels and the way they are proposed backs up and complements the progression seen in the tools and methods presented by McAloone & Pigosso (2017), including the need to change from product oriented approaches to systemic interventions.

Despite the fact that product-service systems (PSS) has shown a great deal of potential to lead to more integrated solutions with less burden on the environment and society than traditional approaches (Manzini & Vezzoli 2002; Hernandez,

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Bhamra & Bhamra 2012; Vezzoli *et al.* 2015), their implementation has been slow and there are many industries that have not embraced this new way of thinking (Tukker 2015; Hernandez 2019). One reason why PSS has not been adopted widely is that the linear production and consumption system in place does not favour these type of systems (Hernandez 2019). PSS are solutions relying on the interactions between different actors and on concepts such as reuse, reconditioning, closed cycles, leasing, sharing and other schemes to use products in a non-traditional way. In this context, the system 'take-make-discard' inhibits the relations and dynamics PSS need to operate successfully. In recent years, a new concept has emerged as a possible solution to produce the right environment for PSS to flourish (Hernandez 2019), this concept is the circular economy (Ellen MacArthur Foundation 2012). Circular economy is an approach that collects many previous ideas related to design for sustainability and puts them together in a structured package. Some of these previous ideas include cradle-to-cradle (Braungart & McDonough 2002), ecoefficiency (Bhamra & Lofthouse 2007) and ecodesign (Brezet & Van Hemel 1997), amongst others.

The most popular definition for the circular economy is that it is *'an industrial system that is restorative or regenerative by intention and design. It replaces the "end-of-life" concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems and, within this, business models'* (Ellen MacArthur Foundation 2012). This idea of having circular systems operating in closed cycles without producing waste in the process aligns very well with what has been identified as needed in terms of systemic change to achieve sustainable development. Circular economy is probably the most recent evolution of the design for sustainability area, but it concerns many more disciplines than just design. It is important to mention that not all circular solutions result in a sustainable alternative. There are a series of requirements associated with how those solutions are developed, some of them related precisely with the use of design, that should be followed (Ellen MacArthur Foundation 2012). Also, there are obstacles and challenges like the transformation of mindsets, building a critical mass, changing consumer behaviour, updating the legal framework and financing the transitions towards circularity, amongst others that have to be addressed (Raksit 2014).

In parallel to the development of approaches like ecodesign, ecoefficiency, product-service systems and lately circular economy; policies and directives have been also deployed worldwide to support the aim to achieve a sustainable way of living and satisfy our needs as society. Most of these directives and policies have been oriented to producers, but they have also produced indirect effects over consumers. Examples of these directives include the Waste Electrical and Electronic Equipment (WEEE) directive, the ecodesign directive and the Restriction of Hazardous Substances (RoHS) directive, all of them implemented in the European Union (EU) in recent years. Finally, there has been an additional ingredient in the development of the area of design for sustainability. The global agenda has recognized a series of social, environmental and economic issues that have to be managed locally and globally by all nations to assure a sustainable development. These issues have been translated by the United Nations, first into the millennium goals and recently into the sustainable development goals as areas of priority

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attention. Many of these human development goals have been tackled by design researchers and practitioners, pushing forward the area of design for sustainability.

The aim of this paper is to understand the evolution of design for sustainability mainly from the contributions made to the International Conference in Engineering Design (ICED) Conferences in the last 30 years, but also a key part of that evolution are the directives and policies that have affected the behaviour of industry and consumers over the years. Alongside the directives and policies, there have also been many events in the international context that have shaped the discourse and these are included in the discussion.

2. The engineering design response to sustainable development

Within engineering design, most research related to design for sustainability currently considers that engineering systems should be developed with a focus on innovation and, at the same time, consider a wide range of environmental and economic advantages across the whole product lifecycle (Stoffels *et al.* 2018). This is very much the incremental approach that was first considered in the 1980s and limits the potential of engineering design to contribute significantly in the shift towards sustainable development. Some authors are considering a more holistic approach and advocating sustainable product service systems and the circular economy (Tukker 2015; McAloone & Pigosso 2017) but this has not yet been adopted extensively by industry or even within academic engineering design research. Too often, the research focusses on sustainability as a technical problem to be overcome rather than a system and holistic approach to be adopted.

In recent years, more and more industry case studies have emerged that relate in some way to design for sustainability within engineering design have been identified. Recent analysis of some of these across a number of industrial sectors identified five key issues that they address, resource use, lifespan, understanding use, integrating data and defining system boundaries (Kim *et al.* 2020) illustrating that a largely incremental approach has been adopted to date. Whilst these only represent a subset of the issues that design for sustainability is concerned with it does show the direction of travel.

When examining the way in which the discipline of engineering design has embraced design for sustainability it is interesting to note that in this journal, Design Science, in its sixth year of publication at the time of writing, only had three papers out of the 105 published that were explicitly related to design for sustainability (2 in 2019 and 1 in 2020), less than 3% overall. Given the importance of this to industry and society as a whole this is surprising and perhaps illustrates that there is less research in this field.

The ICED series was established by the Workshop Design-Konstruktion (WDK) Society with the first conference being held in Rome in 1981. Subsequently after its formation in 2000, The Design Society took this on board as all the previous responsibilities of WDK were handed over to them. By this point, there had been 15 conferences thar were biennial until 1987 when they started to run annually for a number of years until returning to being biennial from 1991.

In this paper, we discuss how the evolution of the area of design for sustainability has been represented by the contributions presented at the ICED from 1989 to 2019. Moreover, we want to consider the importance that this conference has

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had in the development of this research field. At the same time, we consider how the evolution of the field and the contributions to ICED conferences are also linked to the international agenda around sustainable development over the last 30 years. The combination of academic contributions, tools and methods developed, public policy and directives established and industrial actions, together explains the exciting journey of design for sustainability over recent decades. Overall, there are two questions that we want to consider through this paper:

(i) How the contributions submitted to ICED conferences in the last 30 years in relation to design for sustainability helps to explain the evolution of this area of study?
(ii) What will be the future of design for sustainability and what are the terms that will emerge in this field in the coming future?

3. Method

In attempting to answer the question of how design for sustainability has evolved over the last 30 years and in pursuing the aim of developing a better understanding of the dynamic of design for sustainability within the engineering design community, we selected the proceedings from ICED to carry out an analysis. The purpose of this analysis was to explore the appearance of particular terms used in the design for sustainability area that could show us how the area had developed within the contributors and audience of ICED. Also to contrast the situation in the ICED conferences with other developments outside of this specific conference.

The selection of 30 years of ICED proceeding started with the ICED Conference held in 1989 and went through until ICED 2019 held in Delft, the Netherlands. The title of each paper included in these proceedings was reviewed looking for a set of defined terms. Only titles in English were used in the analysis as early ICED conferences also had papers written in German. The set of terms was compiled using our expertise and the historical development of the research area. The terms searched in the titles were:

(i) Green
(ii) Environment/ecological
(iii) Ecodesign
(iv) Sustainability/sustainable
(v) Circular
(vi) Recycling
(vii) Waste
(viii) End-of-life
(ix) Disassembly
(x) Remanufacturing
(xi) Recovery
(xii) Reuse
(xiii) Resources
(xiv) Life cycle
(xv) Lifetimes/durability
(xvi) Obsolescence
(xvii) Use
(xviii) Energy efficiency

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(xix) Eco-efficiency
(xx) Society/social
(xxi) Behaviour

In all cases, but particularly for terms such as 'Behaviour', 'Lifecycle' and 'Use', it was necessary to examine the way in which the term had been used in the title and the context to ensure it was related to design for sustainability as many words can be used with alternative meanings. For the review the terms were organized in a particular order partially following the evolution of the design for sustainability field. Later in the analysis, this order was helpful to interpret the results. In each title, all the terms were searched and the appearances registered in a matrix. In additional to counting the appearances of terms in each paper, the papers including these terms were also counted in relation to the total number of papers for each conference. In total, there were 5,706 papers considered and from them 332 papers included at least one of the search terms. Therefore, 5.8% of the papers reviewed included at least one term that relates them to design for sustainability according to the set of terms used. The complete count of papers for each year is presented in the results section.

4. Results

The count of all of the terms was collated in a matrix as illustrated in Figure 1 below.

Green	0	0	0	0	1	0	1	0	1	0	1	1	0	0	0	1	1	7
Environment/Ecological	0	3	0	8	7	11	8	1	5	3	2	3	4	1	5	3	2	66
Ecodesign	0	0	0	0	0	0	1	11	5	6	5	3	6	8	7	6	4	62
Sustainability/Sustainable	0	0	0	0	1	2	0	3	10	1	4	3	7	4	15	13	11	74
Circular	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	5	9
Recycling	0	4	1	4	1	4	4	0	1	0	2	0	0	0	0	0	1	22
Waste	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
End-of-life	0	0	0	0	0	1	1	0	0	0	2	1	2	1	0	1	2	11
Disassembly	0	0	0	0	3	3	2	0	3	1	1	1	0	0	0	0	0	14
Remanufacturing	0	0	0	0	1	0	0	2	0	0	1	0	1	1	1	1	2	10
Recovery	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	3
Reuse	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	2	4
Resources	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	5
Life Cycle	0	1	0	1	2	4	2	2	2	1	3	4	2	2	2	0	4	32
Lifetimes/Durability	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	3
Obselence	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Use	0	0	0	0	0	0	0	1	1	0	0	1	0	1	1	2	0	7
Energy efficiency	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	2	0	5
Eco-efficiency	0	0	0	0	0	0	1	0	1	0	1	2	0	1	1	0	0	7
Society/Social	0	0	0	0	0	0	0	0	0	1	2	0	1	1	1	2	2	10
Behaviour	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	3	7
	1989	1990	1991	1993	1995	1997	1999	2001	2003	2005	2007	2009	2011	2013	2015	2017	2019	
Papers related to keywords	0	9	1	13	14	21	19	23	28	14	27	18	23	21	36	31	34	**332**
Total papers this year	92	253	229	268	339	348	406	303	348	329	437	349	416	342	427	413	407	**5706**

Figure 1. Matrix of terms reviewed in the International Conference in Engineering Design proceedings.

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These results were then mapped graphically to represent the number of appearances found in the set of papers reviewed. This graphical representation is shown in Figure 2. In this graphic, we excluded two terms: waste and obsolescence, because each only had one appearance in the matrix. This graphical representation helped to identify patterns and clusters that are related to the way the area of design for sustainability has developed over the years.

The evolution of the area of design for sustainability is manifested clearly in the first five terms: green, environment/ecological, ecodesign, sustainability/sustainable and circular. In the beginning of the 1990s, the conversations were about the environment and the impact human activities were producing in general terms. At the end of the 1990s and beginning of the 2000s, the interest moved the discussion towards products, how they were made, consumed and disposed. Ecodesign was a major area of research and work during those years (McAloone & Pigosso 2017). The discussion moved again towards more holistic views of the issues related to design for sustainability and the conversations around 2005 were just about that, sustainability, services, product-service systems and other similar concepts. In the more recent years, the conversation has shifted again and now in the design for sustainability area, we are talking about circularity, and how design can contribute to develop this idea of circular economy with closed cycles of materials, no waste, and better use of resources. While at the beginning the discourse was more about how to clean up the mess we have made with our linear model of production and consumption, nowadays, we are talking about the creation of value in all possible perspectives including environmental and social point views.

In terms of clusters, it is interesting to see two major groups in the figure. One from 1993 to 2003 formed by contributions where the terms with more appearances were: environmental/ecological, ecodesign and sustainable/sustainability. This group after 2003 decreased significantly until 2011, where another group emerged formed by papers using the terms: environmental/ecological, ecodesign, sustainable/sustainability and circular. It seems as there was a first wave of interest in the area of design for sustainability in the late 1990s and then the attention migrated to other topics until the beginning of the second decade in the 2000s. It is difficult to explain why this happened. One factor that might have had influence in this behaviour is the financial crisis of 2008. This crisis started around 2006 in the United States mainly in real estate and expanded globally until 2011, requiring strong measures and financial rescues of some EU countries. This financial pressure can potentially explain why the attention was diverted from topics such as sustainability and environment.

In Figure 2, it is also possible to see other interesting results. There are terms, such as 'Life Cycle', that has had appearances in almost all the years considered with small peaks in 1997, 2007, 2009 and 2019. In general, the term 'Life Cycle' has been important in relation to the methods and tools developed to measure the impacts products can produce throughout its entire life. There are also terms that were very active in the 1990s, but their use has declined, such as 'Recycling'; terms that were active in the mid-1990s and beginning of the 2000s, such as 'Disassembly'; and finally terms that have emerged recently and reflect the recent change focus such as 'Society/Societal', 'Behaviour' and 'Resources'. This group of terms were particularly active in the ICED conferences from 2015 to 2019 and might

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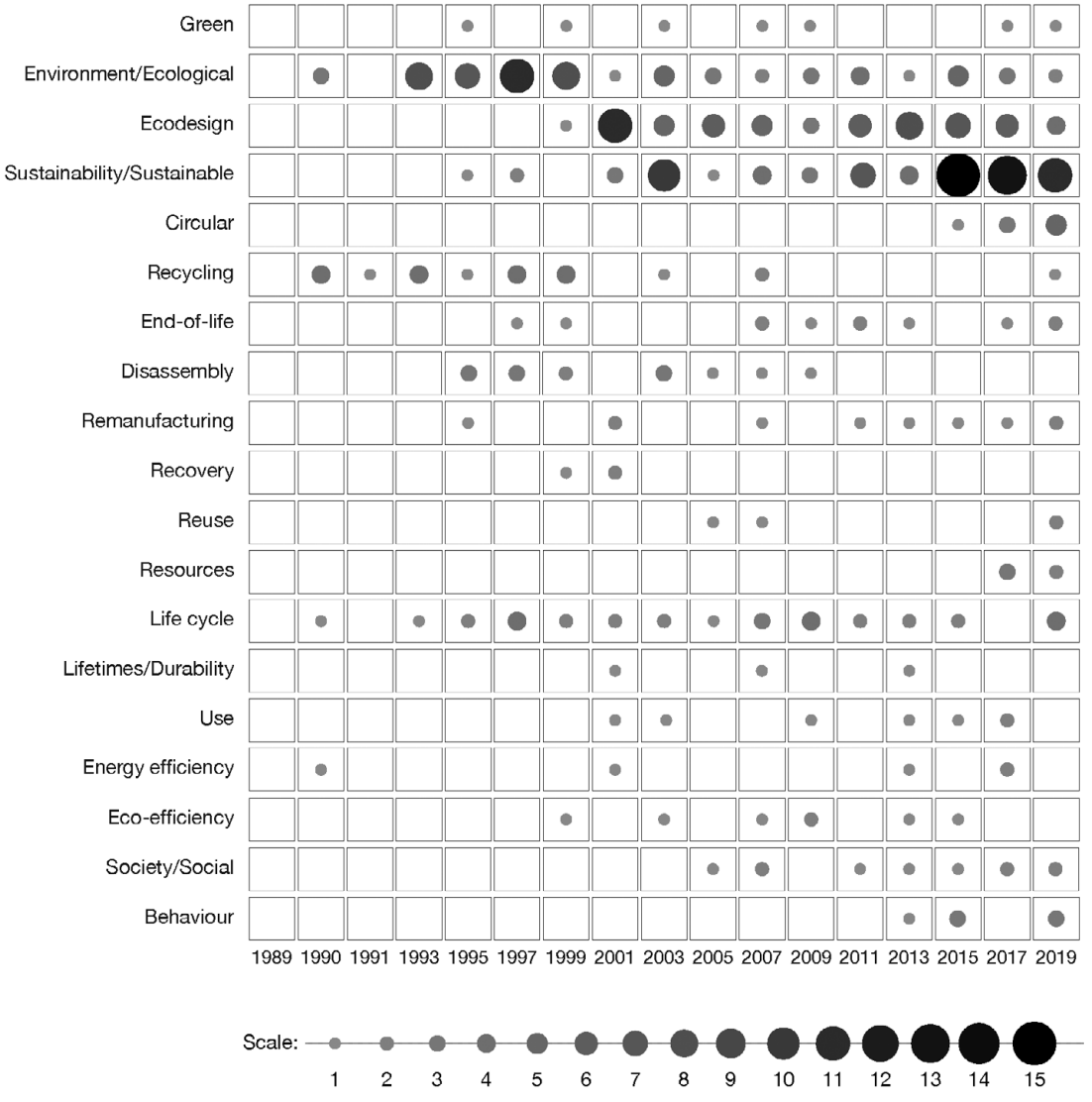


Figure 2. Graphical representation of terms appearances in International Conference in Engineering Design proceedings.

represent a new cluster that aligns well with changes observed in lifestyles and social crisis in many countries around the world.

If we analyse the trends of the most frequent five terms, we can see how some decline when others increase and identify the peaks for each term over the 30-year period, see Figure 3.

In Figure 3, it is most clear that something happens between 2003 and 2011 where the interests in the area of design for sustainability represented in the contributions presented to the ICED conferences decreased significantly. An additional interesting analysis could be to see if other publications and conferences

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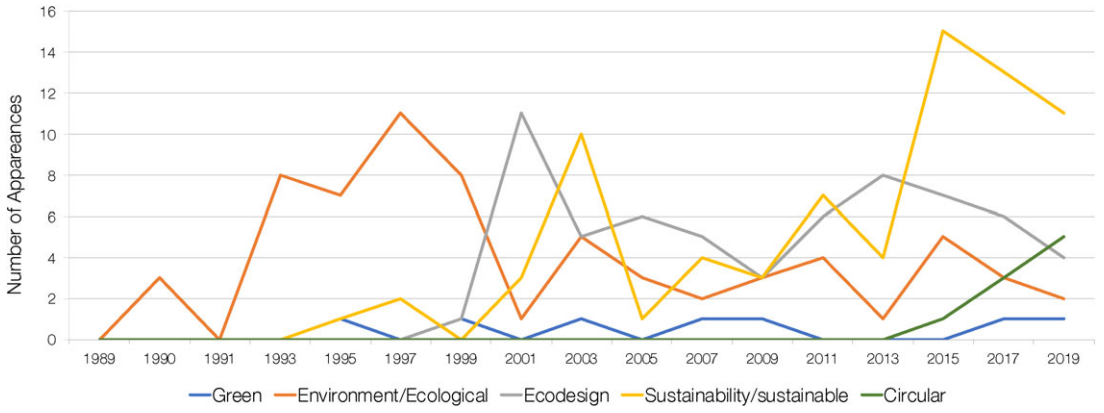


Figure 3. Changes in the most frequent five terms.

considering contributions in the area of design for sustainability had the same trend or it was just the case of the ICED conferences. It will be also interesting for a further study to see if there might be a migration of contributions from the ICED conferences to other more specific conferences and publications in the area of design for sustainability during this period of time.

4.1. International events and evolution of the area

In relation to the events that have dominated the international agenda around the environment and sustainable development in recent decades, we can see that there is a relationship between how the area of design for sustainability has been evolving and these events. For instance, at the end of the 1980s, the discussion was centred on acknowledging environmental problems caused by human activity. During those years, most of the discussion concerned understanding the environmental phenomena and developing the first tools and indicators to measure environmental damage. A milestone in that time was the publication of The Bruntland Report (WCED 1987), where it for the first time the term 'sustainable development' was defined. It is interesting to see that despite this being a major global event, the first appearances of terms related to environment in the ICED conferences were in 1990, 3 years later (see Figure 2). It seems there was a transition period from the scientific discussion about sustainable development to the area of design for sustainability in terms of contributions from the ICED community. In the following years, the first ideas of green design emerged and one of the most cited documents became the 'Hannover Principles of Design for Sustainability' prepared for EXPO 2000 (McDonough & Partners 2000). This document presented 10 principles explaining how things should be designed and constructed for the EXPO considering a more sustainable future. This was in some sense when a new philosophy of design and architecture was born.

In Figure 4 it is possible to see the major international events related to the environment and sustainable development from 1987 to 2019. Along this timeline, there are many more important events. For almost each of these major events, there is a counterpart in the area of design for sustainability and a thematic development in the area that can be seen in the terms explored in the ICED proceedings. While

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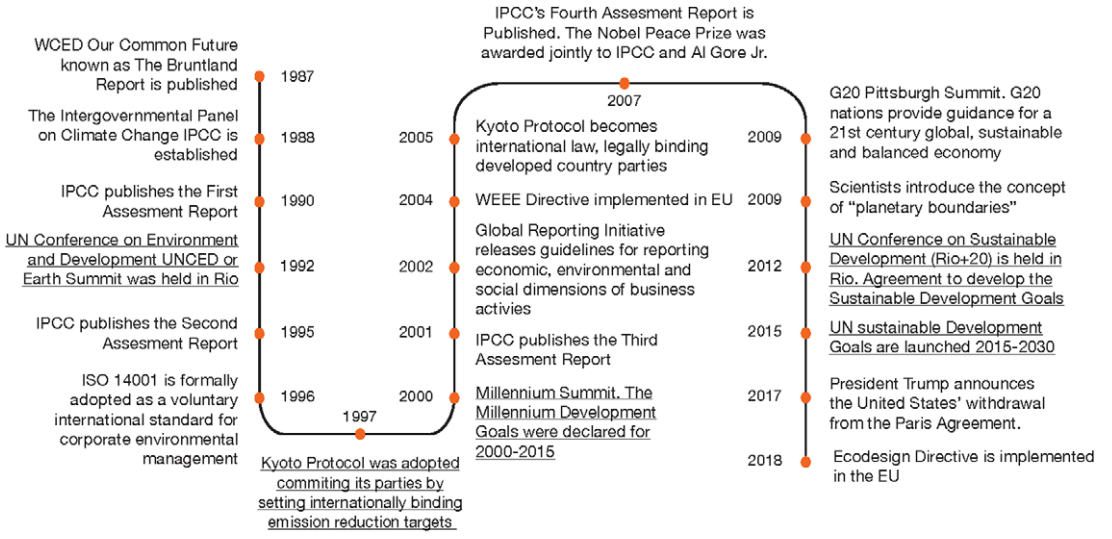


Figure 4. Major events in the international agenda linked to environmental action and sustainable development.

environmental and social discussions were held at international meetings; academics, researchers and practitioners on design and engineering developed this new area of design for sustainability.

A major cornerstone in the discussion on environment and sustainable development was the United Nations (UN) Conference on Environment and Development held in Rio de Janeiro in 1992. This meeting is a reference point because it was the first global encounter after the Bruntland Report to discuss topics related to environmental management and conservation, but also to talk about poverty, health, human development, agriculture and waste amongst other things. At this time, as can be seen in Figure 2, the discussion at ICED regarding design for sustainability was centred on environment and ecological references. Actually, at that time the community was not talking about design for sustainability yet, this term will be used commonly some years later. Probably the most important influence of the Rio meeting for design for sustainability was that it highlighted the necessity to talk about these issues concerning environment and development outside of the political sphere and to put the issues in more operational terms.

The UN Conference in Rio in 1992 was also important because it established for the first time between the international community the necessity to limit the emissions of greenhouse gases across the globe. This idea was later taken forward in 1997 through the signing of the Kyoto protocol, where emission reduction targets were set for all the signing parties. At that time, the discussion between academics and practitioners was shifting from environmental and ecological issues to ecodesign (see Figure 2). Ecodesign was probably the first approach centred on products and how they should be designed. Before ecodesign, the approaches were mostly corrective at the end of the pipe to clean up the problems production was causing. Ecodesign was about changing the design of the products to avoid pollution, waste and environmental damage. A major step forward during these years was to start understanding the product throughout its life cycle rather than

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just focussing on the impacts produced at the end of their life. In this sense, ecodesign proposed different measures to be taken in the design of products, thinking of each step of the product life cycle, including design, fabrication, use and disposal. For the first time, products were seen as part of bigger systems and not as isolated objects. These changes can be seen in the correlation between terms in Figure 2. Ecodesign was in some sense the reason why other terms such as disassembly, end of life and remanufacturing started to appear in the field.

In 1997, alongside the signing of the Kyoto protocol, a collaboration between the United Nations Environmental Program (UNEP) and the Design for Sustainability program at Delft University of Technology emerged with the publication of the ecodesign manual. A document based mainly on the experiences in the field in Europe and the United States (Brezet & Van Hemel 1997). This manual was crucial for the work of the following years, understanding and producing tools to operationalize the ecodesign concept among practitioners and industry in Europe, but also in developing economies. The signing of the Kyoto protocol can explain to some degree the high number of contributions in the ICED conference of 1997 including the terms environment and ecological. This year is the highest point in appearances for these terms in the sample considered from 1989 to 2019. The publication of the ecodesign manual in 1997 can also be the reason why the contributions including the term ecodesign started to appear in the ICED conferences from 1999 onwards. The publication of this manual is recognized in the area of design for sustainability as a departure point for the study of how to include environmental concerns into product design, and it is still well used today.

A few years later, in 2000, another milestone in the history of design for sustainability took place. At the UN Millennium Conference, a set of eight major objectives known as the Millennium Development Goals were established all with a target date of 2015. The eight objectives were: eradicate extreme poverty and hunger, achieve universal primary education, promote gender equality and empower women, reduce child mortality, improve maternal health, combat HIV/AIDS, malaria and other diseases, ensure environmental sustainability and establish global partnership for development. Something those objectives made clear was that the idea to have a sustainable future was a very complex problem that was not for one discipline to solve. Design and its human centred approach was seen as one of the disciplines that could make important contributions not only to achieve better environmental performance of products, but also to develop more equal and prosperous social scenarios. In the following years, much of the work carried out in the design for sustainability area was related in some way or another to the Millennium Development Goals. Around 2001, the terms sustainability and sustainable (see Figure 2) begin to appear at ICED within the contributions submitted. These terms had a peak in 2003 and later again in 2015. These peaks could also respond to the publication of the Millennium Goals in 2000 and the review of these goals in 2015, where a new set of objectives for human development was established.

Around 2004, another boost to design for sustainability resulted from the emergence of laws and directives in the EU asking producers to extend their responsibility over their products beyond the act of sale. One of these directives was the WEEE. In this directive targets were set to collect, recycle and recover electric and electronic equipment after their use to assure an appropriate disposal

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and the recuperation of valuable materials. This directive was aligned with the actions proposed by the ecodesign manual and also but other approaches developed during this time like design for remanufacturing and design for recycling. Another directive set around the same time was the RoHS that restricted the use of certain materials in products commercialized in the EU. These directives can explain the appearances of terms like eco-efficiency, durability and reuse in the years 2005, 2007 and 2009 as shown in Figure 2.

Later in 2012, one the major events was the UN Conference on Sustainable Development held in Rio, and called Rio + 20 making reference to the meeting held also in Rio in 1992. A very important outcome from this international encounter was the agreement that a new set of objectives, called 'Sustainable Development Goals' should be declared for the period 2015–2030. In this new set of objectives, there is a clear call to producers, consumers and governments to change the way needs are satisfied. It was not the first time that production and consumption were mentioned as the areas where actions were needed, but it was the first time explicit objectives were declared as major issues in the governments' agendas.

Within the Sustainable Development Goals, there are some that are strongly related to the development of design for sustainability. Goals associating with having clean water and sanitation systems, affordable and clean energy, sustainable cities and communities and responsible consumption and production, are all directly and indirectly linked to design and design for sustainability. As the objectives and global goals evolve, the topics and approaches on design for sustainability also evolve. Design as a discipline has claimed new territories and during these last 30 years design for sustainability has gone beyond the design of products to become more holistic. It has evolved from green design and ecodesign, to design for sustainable behaviour, design of sustainable product-service systems and more recently to design for circular economies. Probably the terms that will emerge in the coming years will have to be within this idea of circular socio-technical systems where materials are highly valuated, where the concept of waste disappears and the leftovers from one industry become the supplies of another industry. Then the emerging terms may be circular design, cultural design and smart rematerialization.

5. What is the future of design for sustainability?

In the coming years, the development of new technologies but also social and economic trends will mark the future of design for sustainability. In fact, the Ellen MacArthur Foundation (2019) affirms there are two megatrends that will intersect in the following decades. These megatrends will be artificial intelligence (AI) and the circular economy (Ellen MacArthur Foundation 2019). In both, design plays a crucial role.

Within this crossing of paths, the Ellen MacArthur Foundation mentions three ways in which AI will enable and also enhance the transition to a circular economy. First, in the design of products, components and materials there will be machine learning assisted design processes that will favour rapid prototyping and testing. Second, AI might increase the competitiveness of circular business models through pricing and demand prediction, predictive maintenance and smart inventories. Third, AI can also optimize circular infrastructure improving reserve logistics and

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helping to have closed loops of products and materials (Ellen MacArthur Foundation 2019).

In this context, design is explicitly mentioned as one of the areas where the intersection between AI and circular economy will have a direct impact. The evolution of design for sustainability will be strongly attached to that relationship between AI and circular economy. There are already areas identified where a positive contribution will take place, such as food production and supply, and consumer electronics. In those areas technologies such as image recognition, and robotics will have a major impact on the efficiency of land use, better use of space, recovery of products, e-waste recycling and better matching of supply and demand. But the future of design for sustainability will go beyond this particular crossing; there will be other technologies and socio-cultural movements that will define its future. Technologies such as the 'Internet of things' (IoT) will also define how products will be designed, produced, used and discarded. In terms of socio-cultural movements a new type of empowered consumer has been emerging in recent years. Consumers that want to know how their products work and how they can repair and renovate their products rather than throwing them away. *Cafe Repair Shops* and new directives mainly in the EU will give a push to this socio-technical trend that will affect design and design for sustainability in many ways (Hernandez, Miranda & Goñi 2020). Other approaches that are emerging from consumers and grass roots organizations, rather than industry, is a focus of more low tech approaches such as simplicity and open design. These are useful approaches to address concerns around resource depletion but become very difficult to implement within industry.

In recent years, we have begun to see increasing recognition within the design engineering community of the importance of considering the user more comprehensively within the design process. This has become much clearer when we consider the way in which design engineering has started to embrace behaviour change within design for sustainability. The focus has shifted towards the use stage of the lifecycle but with particular attention being paid to the user. This is a trend set to continue as many have now recognized that technological changes alone can only lead us so far toward sustainable development and therefore to make the step change needed people and their use of products, service and systems must rise to the forefront of the design process.

Beyond these emerging themes that will define the future of the area of design for sustainability, there are two major issues to discuss further regarding the analysis carried out. First, the limitations attached to the amount data collected and the reasons behind. Second, the few and sometimes weak links between what is published in the area of design of sustainability and what is applied and used in industry.

Regarding the amount of data, we recognize the data collected from the papers presented in the ICED conferences from 1989 to 2019 on design for sustainability is insufficient to draw strong conclusions. However, our conclusions emerged also from our experience and work in the area for many years. What is interesting to remark is that this data from the papers presented in ICED conferences might have different explanations. On one hand, there might be a bias in the studies presented in the ICED conferences due the nature of this conference. Design for sustainability is an area developed by different disciplines, among them engineering, but not exclusively. Moreover, the work done outside the engineering community has been

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very prolific and this is visible in the amount of publications in design journals and other journals outside of the engineering field.

About the transfer of what is published to industry, this is a major and complex issue that not only concerns the area of design for sustainability. In fact, there is a general view that today is much more is published than transferred to industry. In the case of design for sustainability, there is a wide recognition that the use of design methods in industry is limited as was highlighted by (Ernzer & Birkhofer 2002). For example, an important topic in the area of design for sustainability has been the design and development of Sustainable PSS, but currently there are not many Sustainable PSS already operating in the market (Tukker 2015; Hernandez 2019). However, topics such as ecodesign have begun to be implemented by industry and are still in use today. Also, it has to be acknowledged that many of the topics developed in academy, even if they have been not widely adopted are the basis of current schemes that are transforming our production and consumption systems, such as the circular economy.

Overall, we accept there are a lack of industrial case studies and maybe an excessive amount of publications on design methods and tools. We strongly recommend researchers in the area to make a substantial effort to try to test their ideas and tools in industry and to reflect on the insights gathered during that process to push the development of the area. This invitation has also to be extended to industry, and governmental agencies to facilitate this relationship.

6. Conclusions

In this paper, we identified that the terms searched and their appearances in the papers presented at the ICED conferences represent well the evolution of the design for sustainability area over the last 30 years, even if the amount of data found might be small compared with other areas. These appearances are also consistent with the main topics discussed within the wider international debate on environment and sustainable development. One term that has marked the history of this area of design for sustainability has been ecodesign. This area was very active from the start of the1990s and it still appears in the most recent conference proceedings. This popularity within papers on design for sustainability shows the impact that ecodesign has had in academia and industry.

At the three most recent ICED conferences (2015, 2017 and 2019) the appearance of the term sustainability/sustainable has increased significantly. This increase reflects the change in the discourse in design research in the search for more holistic approaches to understand the role design plays towards a sustainable society. It is disappointing, however, that despite its importance to the world, design for sustainability still appears to be a minor part of the discipline of engineering design. Less than 6% of ICED papers and less than 3% of *Design Science* journal papers published to date have been concerned with this broad topic. However, the recent call for papers on design for sustainable development (https://www.cambridge.org/core/journals/design-science/call-for-papers/design-for-sustainable-development) from the *Design Science* journal is positive step towards improving this and illustrates how the subject has gained in importance within the engineering design community in recent years.

Cooperation between academia and non-governmental organizations such as the UN and UNEP, has been crucial in the development of the area of design for

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sustainability. Another recent example of this type of collaboration pushing forward the development of the area is the one achieved between businesses, academia and specialists from the Ellen McArthur Foundation regarding the concept of the circular economy.

In the last 30 years, the discussion about sustainable development and issues such as poverty, waste management, health, access to water and industrialization between others, has revealed the importance design as a discipline has in achieving more sustainable ways of living. Design has been recognized as a determinant area in the organization, functioning and generation of impacts of our production and consumption systems.

In the near future as the area of design for sustainability is still evolving, common terms used are likely to be circular design, cultural design, smart sustainable systems and others that represent the change needed in our production and consumption systems from the traditional linear approach to circular economies. New technologies will partially define the future of design for sustainability. In particular AI and the Internet of Things (IoT) are recognized as game changers in the design practice and research that will impact the area of design for sustainability. Those technologies will bring very important opportunities in areas like production and food supply, consumer electronics, health systems and waste management. This will become even more important in the post Covid-19 world where even more changes will be needed to ensure our economies continue to flourish within safer systems. The Covid pandemic has shown us that things can be done differently, that actions can be taken overnight if there is political will, and that we can adapt to very constrained ways of living. It is important to learn from these experiences and to transform them in to opportunities to find alternative ways of living that are more socially and environmentally responsible. If our living habits are changing, we need to produce solutions that have lower impact on the environment and respond to the restrictions we will have. Design for sustainability can play a protagonist role in the development of these solutions with high tech approaches and also with low tech initiatives.

In terms of the relationship between the area of design for sustainability and the development of the concept of the circular economy, there are recent directives and laws that will push forward this connection. Examples of these directives and laws are represented by the recent interest in the EU on increasing the rate and capacity to repair products with the 'Right to Repair' Initiative (Hernandez, Miranda & Goñi 2020), the French Law on Circular Economy oriented to reduce the consumption of plastics and encouraging reuse and recycling (Légifrance 2020), and the EU Circular Economy Action Plan (European Commission 2020), amongst others around world. All these initiatives, directives and laws will have an influence on how design for sustainability will evolve in the future, and in what the direction will be in research to explore the transfer of public policies to industrial actions. It will be interesting to track this evolution and to see what will be the emerging trends in the near future.

The analysis presented in this paper can be easily replicated with other related conferences within and beyond the engineering field. There is an important number of design researchers doing great work in this area, and important events are carried out each year where design for sustainability is well represented. Examples include the International Symposium on Environmentally Conscious Design and Inverse Manufacturing held every 2 years usually in Japan, the Design

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Research Society Conferences and the International Design Conference. The whole of design for sustainability across all disciplines will benefit greatly from these types of analyses.

Overall to be sustainable in the future engineering design needs to move away from just reacting to change and become more proactive and lead from the front based on what needs to be done to make a significant change. Therefore, design for sustainability must explore more fundamental changes in direction, and ensure it is focussing on being less incremental and passive, especially when interacting with economic and political systems. Traditional myopic approaches are now part of the problem, helping to reinforce the existing agenda and are not part of the solution. In the words of Papanek (1972) 'Design, if it is to be ecologically responsible and socially responsive, must be revolutionary and radical in the truest sense'.

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