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Design for Sustainability: An Evolutionary Review

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Abstract: In this paper we explore the evolution of response from design discipline to sustainability issues. Following a quasi-chronological pattern, our exploration provides an overview of the Design for Sustainability (DfS) field, categorising the approaches developed in the past two decades under four innovation levels: Product, Product-Service System, Spatio-Social and Socio-Technical System. As a result of this overview, we propose an evolutionary framework and map the reviewed DfS approaches onto this framework. The proposed framework synthesizes the evolution of DfS field, showing how it has progressively expanded from a technical and product-centric focus towards large scale system level changes in which sustainability is understood as a socio-technical challenge. The framework also shows how the various DfS approaches contribute to particular sustainability aspects and visualise linkages, overlaps and complementarities between these approaches.

Keywords: Design for Sustainability; evolution; design research

1. Introduction

The Brundtland Report defines sustainable development as “the development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). Although this definition had an explicit anthropocentric focus, with an emphasis on social justice and human needs, for decades of the environmental movement, the operational emphasis of sustainability has explicitly been on the environment (Gaziulusoy, 2010). Studies have shown that our theoretical understanding of the concept has evolved from understanding sustainability as a static goal to a dynamic one and moving target responding to our ever increasing understanding of interdependencies between social and ecological systems and due to the realisation that operationalisation of sustainability required time and space bounded indicators and that there cannot be an overarching all-encompassing specific sustainability target to strive for (Faber, Jorna and Van Engelen, 2005; Hjorth and Bagheri, 2006).

The current understanding suggests that sustainability is a system property and not a property of individual elements of systems and achieving sustainability requires a process-based, multi-scale and systemic approach to planning for sustainability guided by a target/vision instead of traditional goal-based optimisation approaches (Holling, 2001; Bagheri and Hjorth, 2007). With the alarming estimates of economic and social costs of inaction for addressing global, persistent and pressing environmental issues (MEA, 2005; Stern, 2006) the present common view in the discourse of sustainability is that there is a need for radical transformational change in how human society operates (Ryan, 2013). This radical change is accepted to require not only technological interventions but also social, cultural/behavioural, institutional and organisational changes (Geels 2005a; Loorbach, 2010).

In line with the contextual changes and theoretical developments that has taken place, the business response to sustainability issues has evolved in the past decades, with an increasing pace in the past ten, fifteen years. The overall evolution of business understanding can be observed in consecutive reports published by the World Business Council for Sustainable Development (WBCSD): promoting product innovation and efficiency as a strategy to address environmental problems (WBCSD, 2000); framing sustainability risks as systemic mega-risks that pose unprecedented challenges to companies and government alike (WBCSD, 2004); proposing a vision for transformation (WBCSD, 2010). Currently, studies challenging the traditionally accepted role and responsibilities of business in society and proposing new models for value generating is on the increase (e.g. Loorbach and Wijsman, 2013; Metcalf and Benn, 2012; Parrish, 2007).

Design theory and practice has engaged with sustainability discourse sporadically since mid-twentieth century. More systematic engagement has started in early 1980s with the beginning of active interest from industry in environmental and social issues. The aim of this paper is to explore the evolution of response from design discipline to sustainability issues which marks the broad field of design for sustainability (DfS). Our exploration follows a quasi-chronological pattern. In the following sections we shortly present the DfS approaches emerged in the past decades. The description is coupled by Table 1 which provides, for each DfS approach, additional information regarding limitations and potential future research directions. DfS approaches are categorised in four different innovation levels:

- *Product innovation level:* design approaches focusing on improving existing or developing completely new products.
- *Product-Service System innovation level:* here the focus is beyond individual products towards integrated combinations of products and services (e.g. development of new business models).
- *Spatio-Social innovation level:* here the context of innovation is on human settlements and the spatio-social conditions of their communities. This can be addressed on different scales, from neighbourhoods to cities.

- *Socio-Technical System innovation level:* here design approaches are focusing on promoting radical changes on how societal needs, such as nutrition and transport/mobility, are fulfilled, and thus on supporting transitions to new socio-technical systems.

The overview on DfS approaches is followed by our reflections on the evolution of the DfS field.

2. Product Design innovation level

2.1 Green Design and Ecodesign

The early examples of **green design** practice (Burall, 1991; Mackenzie, 1997) focused on lowering environmental impact through redesigning individual qualities of individual products. This period also saw early designs focusing on use of renewable energy such as solar street lamps (Fuad-Luke, 2002). For others, considering environment in design meant efficiency focused approaches in product and process engineering (e.g. Fiksel, 1996). Guidelines and toolkits advocating Design for X (X standing for any of the “more preferable” attitudes in design from recycling to recyclability to ease of dismantling to repairability) were developed (for an overview see Chiu and Kremer, 2011).

Ecodesign has a main significant difference and strength over green design; i.e. a focus on the whole life-cycle of products from extraction of raw materials to final disposal (Tischner and Charter, 2001). In ecodesign, the environment is given the same status as more traditional industrial values such as profit, functionality, aesthetics, ergonomics, image and overall quality (Brezet and van Hamel, 1997). On a more practical side, a fairly complete set of ecodesign principles, guidelines and tools has been developed (e.g. Tischner and Charter, 2001; Bhamra and Lofthouse, 2007; Vezzoli and Manzini, 2008). With adoption of the Ecodesign Directive by the European Commission (EC, 2005), which mandates life-cycle assessments to be undertaken in association with environmental management systems, ecodesign has become a primary focus for companies, especially for those producing energy using products.

2.2 Emotionally durable design

Ecodesign offers several design strategies to extend product lifespan. However, for some product categories, the end of lifespan is not caused by technical issues but by psychological obsolescence (when a product is discarded for reasons such as changes in users’ perceived needs, desire for social status emulation, new trends in fashion and style) (Cooper, 2004). Therefore researchers have started to explore the user-product relationship and the role of design in strengthening that relationship in order to lengthen product lifetime (e.g. Brezet and van Hemel, 1997; Van Hinte, 1997; Chapman, 2005; Mugge, 2007; Chapman, 2009). Common labels used to define this field of research are *Emotionally durable design* and *Design for product attachment*. Mugge (2007) has identified four main product meanings as determinants affecting user-product attachment: *Self-expression*, *Group affiliation*, *Memories* and *Pleasure (or enjoyment).* Researchers have proposed design strategies seeking at stimulating product attachment through the previously mentioned determinants (e.g. Mugge et al. 2005; Chapman, 2005; Mugge, 2007). Examples are *Enabling product personalisation* (Mugge et al. 2005), *Designing products that 'age with dignity'* (Van Hinte, 1997), and *Designing products that allow users to capture memories* (Chapman, 2005).

2.3 Design for Sustainable Behaviour

The Ecodesign approach does not devote much attention to the influence that user's behaviour can have on the overall impact of a product. For this reason, design researchers, building upon various behaviour change theories, have started to develop approaches, tools and guidelines that explicitly focus on design for behaviour change (for example the *Loughborough model* [Lilley, 2009; Bhamra et al., 2011], *Design with Intent* [Lockton, Harrison and Stanton, 2010; Lockton, 2013] and *Mindful design* [Niedderer, 2007; 2013]). Even if a unified model of design for behaviour change is missing, four basic principles can be found in most of the approaches and tools developed (Niedderer et al. 2014): making easier for people to adopt a desired behaviour; making harder for people to perform a an undesired behaviour; making people to want a desired behaviour; and making people to not want an undesired behaviour. Examples of applications of design for sustainable behaviour that can be found in the literature are targeted at the environmental dimension (e.g. Tang and Bhamra, 2012) and/or the social dimension (i.e. enabling users to adopt a healthier behaviour, e.g. Ludden and Offringa (2015). Applications span from product to product-service system, mobile interaction and built environment design.

2.4 Nature-inspired Design: Cradle-to-Cradle Design and Biomimicry Design

Among some practitioners in the DfS field, there has been a belief that imitating nature's materials and processes are the only way to achieve sustainability in our production-consumption systems. Two most prominent frameworks representative of this belief are **cradle-to-cradle design** (CTC) and **biomimicry design** (BM).

CTC has two interrelated concepts: food equals waste and eco-effectiveness (Braungart, McDonough and Bollinger, 2007; McDonough and Braungart, 2002). Eco-effectiveness puts emphasis on a regenerative approach by the industry. It is operationalised with the 'waste equals food' framework which defines two types of nutrients, i.e. biological and technological. The assumption underlying CTC is that if these nutrients are used in open (for biological nutrients) or closed (for technological nutrients) loops, the human society can continue production, consumption and economic growth indefinitely. CTC also puts emphasis on regenerative processes, non-human species and future generations.

The premise of BM is using nature as model, measure and mentor (Benyus, 2002). Using nature as a model involves studying the models and processes of nature and adapting these to solve human problems and using an ecological standard to judge the rightness of innovations. The rationale behind using nature as an ecological standard is that as a result of 3.8 billion years of evolution, nature has learned what works and what is appropriate. Using nature as a mentor puts emphasis on learning from nature rather than exploiting it. BM defines three theoretical and practical levels of biomimicry: first is mimicking *forms* of nature, second is mimicking *processes* of nature and third is mimicking *ecosystems*. BM, similar to CTC, advocates using waste as a resource and closing loops in production and consumption. A range of methods and tools to integrate BM into the product design process are available (e.g. Baumeister et al. 2013).

2.5 Design for the Base of the Pyramid

The Base of the Pyramid (BoP) is the poorest portion of the global population that, (in addition to a lack of income to satisfy basic needs, is characterised by a lack of access to basic services and by social, cultural and political exclusion (London, 2007). Prahalad (2004) and Prahalad and Hart (2002) showed that the traditional development aid strategy has not been effective to solve the problem of poverty, and suggested a market-based perspective through which companies can realise profit and at the same time bring prosperity. Different approaches have been proposed (Rangan et al. 2007): *BoP as Consumer, BoP as Producer* and more recently, *BoP as business partners*. Over the past years design researchers have explored the role of Design for the Base of the Pyramid (DfBoP) (e.g. Kandachar, de Jong and Diehl, 2009). Designing solutions at the BoP requires addressing specific issues that are different from those in high-income markets (Jagtap, Larsson and Kandachar, 2013; Jagtap and Kandachar, 2010). In this respect a number of manuals and tools have been proposed in the past years, providing a set of different and complementary approaches, such as: *Design for Sustainability, D4S* (UNEP, 2006) with a focus prevalently on sustainability and business development; *Human Centred Design toolkit* (IDEO, 2009), which provide guidance and tools on user-centred design; the *BoP Protocol* (Simanis and Hart, 2008), and the *Market Creation toolbox* (Larsen and Flensborg, 2011), which offer approaches and tools for business model co-creation. Recently the attention of design researchers on the BoP has moved from product design to PSS design (see section 3).

3. Product-Service System innovation level

The design approaches included in product innovation level are crucial to reduce the environmental impact of products and production processes but they are not on their own sufficient to obtain the radical improvements required to achieve sustainability. (Schmidt-Bleek, 1996). Within this perspective, several researchers have started to look at Product-Service System (PSS) innovation as a promising approach for sustainability (e.g. White, Stoughton and Feng, 1999; Stahel et Al. 2000; Mont, 2002). PSSs can be defined as *“a mix of tangible products and intangible services designed and combined so that they are jointly capable of fulfilling final customer needs”* (Tukker and Tischner, 2006): value propositions that satisfy users through the delivery of functions instead of products and shift the focus from a consumption based on ownership to a consumption based on access and sharing. The environmental potential of a PSS-oriented business model is that it can potentially decouple economic value from material and energy consumption. In fact, since manufacturers keep the ownership of products and deliver a performance to customers, they are economically incentivised in reducing, as much as possible, the material and energy resources needed to provide that performance (Halme et al., 2004). Being complex artefacts composed of *products*, *services*, and a *network of actors*, designing a PSS requires a systemic approach considering all these elements simultaneously. Design researchers have initially focused on **PSS design for eco-efficiency**, looking at the economic and environmental dimensions of sustainability (e.g. Brezet et al. 2001; Manzini, Vezzoli and Clark, 2001). More recently, researchers have looked at integrating also the socio-ethical dimension, referring to **PSS design for sustainability** (e.g. Vezzoli, 2007; Vezzoli et al. 2014). Another area where design researchers have been focusing is the application of **PSS design for the Base of the Pyramid** (e.g. UNEP, 2009; Jagtap and Larsson, 2013).

4. Spatio-Social innovation level

4.1 Design for Social Innovation

Literature on social innovation in general and on design for social innovation specifically has been just emerging in the past decade. Social innovations, are either those innovations aiming to solve social problems (Schaltegger and Wagner, 2008) such as poverty and access to safe drinking water, or those targeting behavioural change and social well-being (Manzini, 2007). More broadly social innovation is a creative re-combination of existing assets (Manzini, 2014). In social innovation a key role is played by people and communities sometimes in collaboration with grassroots technicians and entrepreneurs, local institutions and civic society organizations (Meroni, 2007; Jégou and Manzini, 2008).

Manzini (2014) defines design for social innovation as “a constellation of design initiatives geared toward making social innovation more probable, effective, long-lasting, and apt to spread (p. 65)” and points that it can be part of top-down (driven by experts, decision makers and political activists), bottom-up (driven by local communities), or hybrid (a combination of both) approaches. Even if social innovations are often driven by non-professional designers, professional designers can play a significant role in promoting and supporting them (Manzini, 2015).

4.2 Nature-inspired Design: Systemic Design

Systemic Design is another nature-inspired approach that, differently from CTC and BM, focuses on the third level of biomimicry, i.e. mimicking natural ecosystems. It combines elements of biomimicry, Cradle to Cradle and industrial ecology. Using the words of Barbero and Toso (2010), *“the Systemic Design approach seeks to create not just industrial products, but complex industrial systems. It aims to implement sustainable productive systems in which material and energy flows are designed so that waste from one productive process becomes input to other processes, preventing waste from being released into the environment.”*

Systemic Design adopts a territorial approach, looking at local socio-economic actors, assets and resources, with the aim of creating synergistic linkages among productive processes (agricultural and industrial), natural processes and the surrounding territory (Barbero and Fassio, 2011). This approach allows to design/plan the flow of material and energy from one element of the system to another, reducing the waste flow by transforming outputs of each system element into an input for another system element (Bistagnino, 2009; 2011), potentially resulting in new, locally-based, value chains (Barbero, 2011).

5. Socio-technical system innovation level

Some developments in the science and technology studies which took place in 1990s, such as projects that focused on sustainable need fulfilment with a long-term approach (Green and Vergragt, 2002; Quist and Vergragt, 2004; 2006; Weaver et. al, 2000) and in 2000s, such as development of the multi-level perspective of system innovation (e.g., Kemp, 1994; Kemp, Rip and Schot, 2001; Geels, 2005a, 2005b; Geels and Schot, 2007) and development of transition management theory (Loorbach, 2007; 2010) created opportunities for cross-fertilisation in the DfS field. Although recent and emerging, currently there is an observable body of work being developed by a handful of design scholars. Ceschin (2012; 2013; 2014a) and Joore (Joore, 2010; Joore and Brezet, 2015) have been exploring connections between PSS design and system innovations and transitions theories. Gaziulusoy (Gaziulusoy, 2010; Gaziulusoy and Brezet, 2015), on the other hand, has integrated sustainability science, futures studies and theories of transitions and system innovations to develop a theory of design for system innovations and transitions.

Design researchers have also started to investigate how to design socio-technical experiments to trigger and support socio-technical changes. Ceschin proposed to design experiments as *Labs*, *Windows* and *Agents of change* (Ceschin, 2014b). Even if not referring to transition studies, researchers in the area of design for social innovation have proposed to use *Living Labs* to experiment, explore and support the scaling-up of grassroots social innovations (Hillgren, Seravalli and Emilson, 2011). In addition to these, a group of scholars have developed curriculum on what they call as transition design for the first time (Irwin, Tonkinwise and Kossoff, 2015). It is understood that this curriculum is not specifically referenced to system innovations and transitions theories but to a wider body of literature studying change in systems.

More recently, design research efforts have started to be focused on cities (e.g. Ryan, 2013b; Ryan et al., Forthcoming), which are essentially systems of socio-technical and socio-ecological systems. This focus on cities, as distinct from conventional sustainable urban design and planning which focuses on urban form, urban growth, liveability, walkability, energy reduction and place-making separately and sustainable architecture which focuses on individual buildings, finds its ground in theoretical framings of cities as complex adaptive systems (see e.g. Bettencourt and West, 2010; Portugali, 2012). Framing cities as complex adaptive systems requires understanding and taking into account the interrelationships between technologies, ecosystems, social and cultural practice and city governance in design decisions (Marshall, 2012). In order to achieve this, design for system innovations and transitions integrates different theoretical domains that might be relevant to cities as well as utilises a multiplicity of supportive design approaches such as speculative design, design futures and participatory design.

6. Discussion and Conclusions

6.1 DfS Evolutionary Framework

A recent review on sustainability-oriented innovations (Adams et al. 2015) showed that innovations for environmental and social benefits have evolved from a narrow technical, product and process-centric focus towards large-scale system level changes. Adams et al. (2015) also identify two important dimensions that characterise this evolution:

- *Technology/People:* evolution from a technically focused and incremental view of innovation towards innovations in which sustainability is seen as a socio-technical challenge where user practices and behaviours play a fundamental role. This is linked to an increasing attention towards the social aspects of sustainability.
- *Insular/Systemic:* evolution from innovations that address the firm's internal issues towards a focus on making changes on wider socio-economic systems, beyond the firm's immediate stakeholders and boundaries.

Drawing on these dimensions, Adams et al. (2015) proposed an initial framework to picture how the field of sustainability-oriented innovations has evolved. Taking inspiration from their analysis model we developed an adaptation of that framework (Figure 1), which is then used to map DfS approaches.

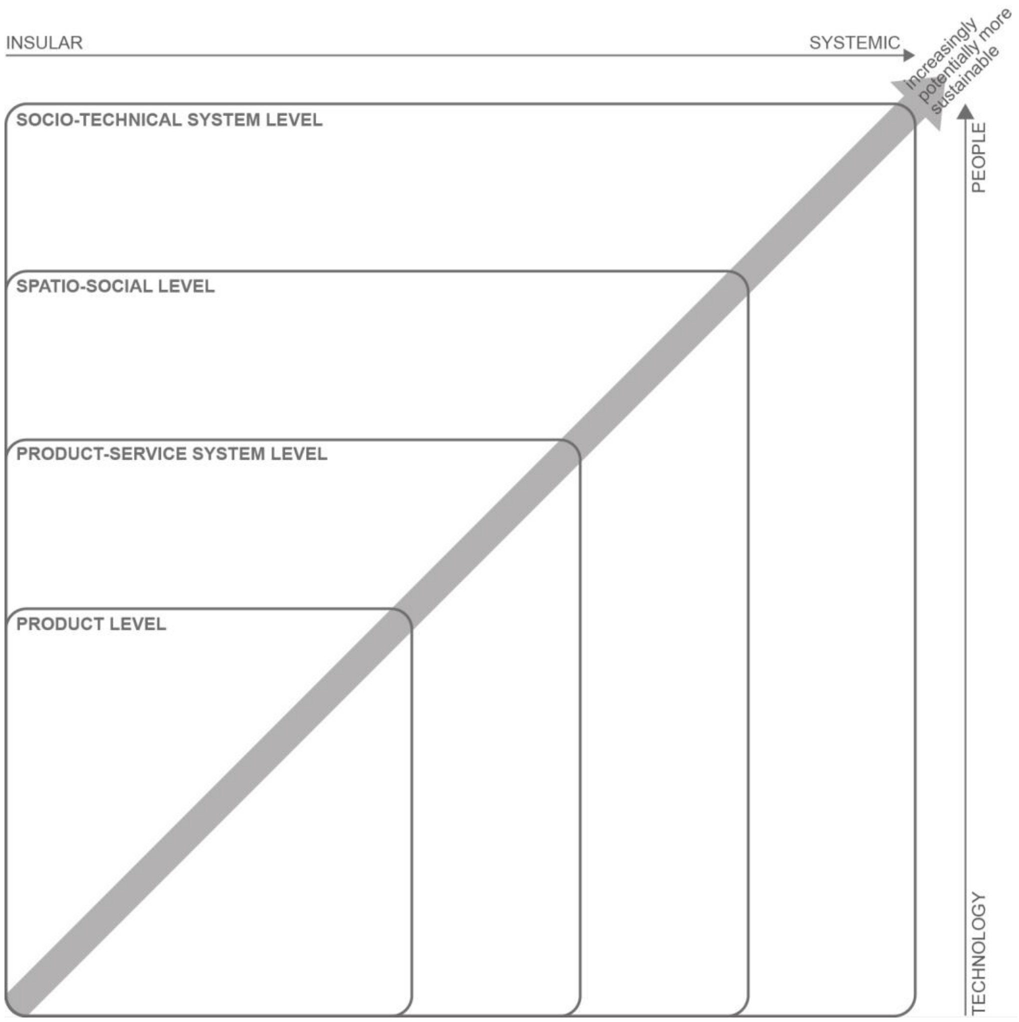

Figure 1 The DfS Evolutionary Framework.

In the previous sections the DfS approaches have been categorised in four different innovation levels: *Product innovation level, Product-Service System innovation level, Spatio-Social innovation level* and *Socio-Technical System innovation level*. These four levels can be layered on our framework, onto which we position the DfS approaches. The process of constructing the framework and mapping the approaches has iteratively developed (the positioning of the approaches has been driven by the initial framework and at the same time has also influenced the identification of the four previously mentioned innovation levels). Each DfS approach is mapped as an area, in order to show the overlaps across different innovation levels. A colour code is used to indicate whether the approach is addressing the environmental dimension of sustainability and/or the socio-ethical one. The resulting framework (Figure 2) is meant to provide an understanding of the overall evolution of DfS, as well as a clear picture of how the various DfS approaches contribute to particular sustainability aspects. The framework also visualise linkages, overlaps and complementarities between the different DfS approaches. A table summarising the key features of each DfS approach is also provided (Table 1).

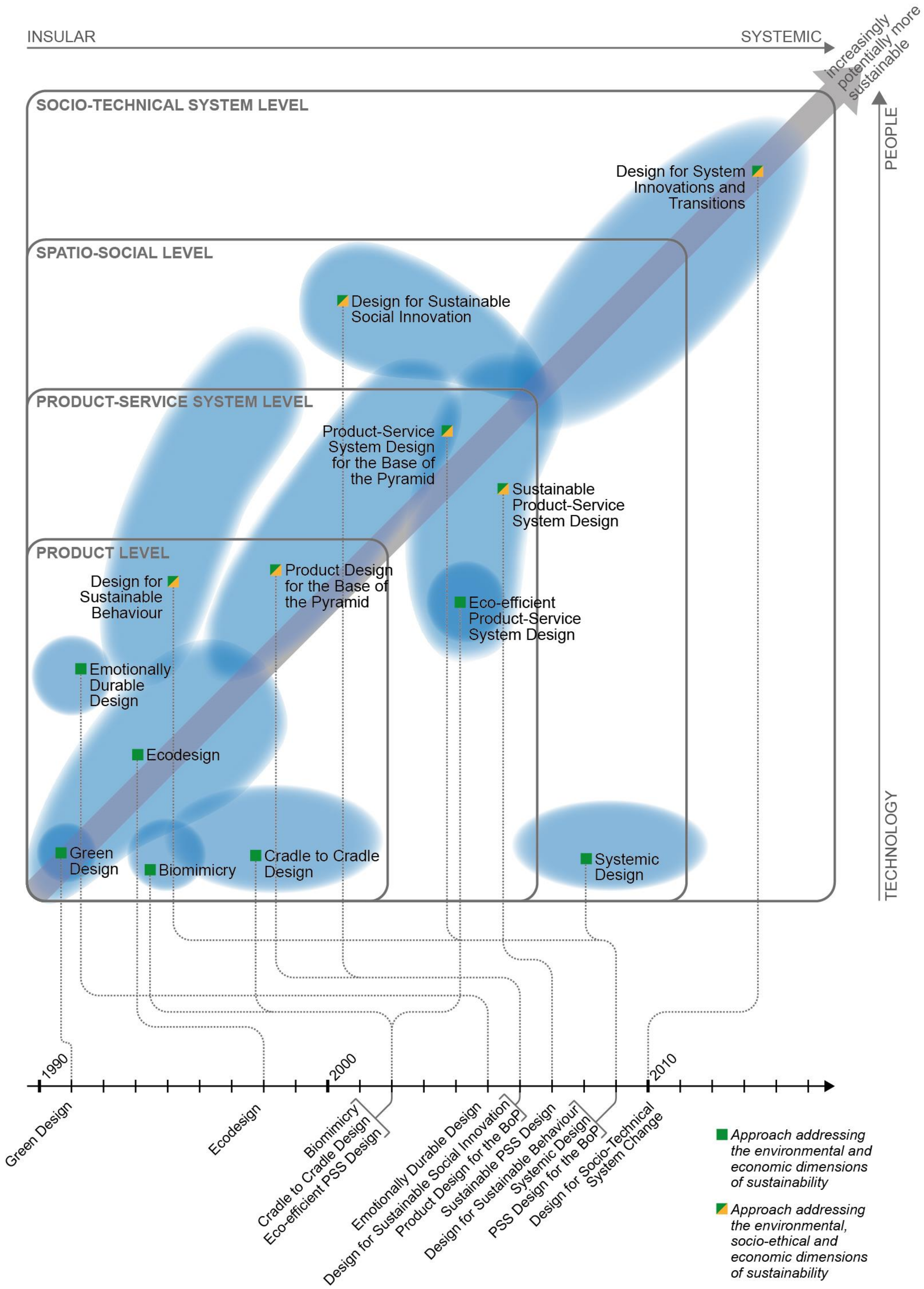

Figure 2 The DfS Evolutionary Framework with the existing DfS approaches mapped onto it. The timeline shows the year when the first key publication of each DfS approach was published.

Table 1 Main characteristics of DfS approaches.

Approach, focus & main contributors	Limitations	Potential future research directions
PRODUCT INNOVATION LEVEL		
Green Design Lowering environmental impact through redesigning individual qualities of individual products *Burall (1991); Mackenzie (1997); Fiksel (1996)*	-Lacks depth, promotes green consumerism (Madge, 1997); -Focuses on single-issues therefore does not provide significant environmental gain.	-Exploring potential synergies with other approaches
Ecodesign Lowering environmental impact focusing on the whole life-cycle of products from extraction of raw materials to final disposal *Tischner and Charter (2001); Brezet and van Hamel (1997); Binswanger (2001)*	-Lacks complexity, focuses only on environmental problems and disregards problems which cannot be accounted for in life-cycle assessments (Gaziulusoy, 2015); -Associated efficiency gains did not resolve the impact due to ever increasing consumption, has a technical perspective with a limited attention to the human related aspects (e.g. user behaviour in the use phase) (Ryan 2002; 2003; 2013a; Bhamra, Lilley and Tang, 2011).	-Exploring potential synergies with other approaches
Emotionally Durable Design (EDD) Strengthening and extending in time the emotional attachment between the user and the product *Van Hinte (2007); Mugge et al. (2005); Chapman (2005); Mugge (2007)*	-It is particularly challenging to effectively stimulate product-attachment: the same product can generate different meanings and different degrees of attachment on different individuals (Mugge, 2007); -Product attachment determinants are less relevant for some product categories (e.g. utilitarian products) (Mugge et al. 2005); -For some product categories extending longevity beyond a certain point might not be environmentally beneficial (Vezzoli and Manzini, 2008); -Manufacturers might be averse to implement product attachment strategies because this might lead to reduce sales (Mugge et al. 2005).	-Undertake studies exploring product attachment during the whole lifespan of a product (Mugge, 2007); -Test the effectiveness of EDD strategies in different product categories; -Investigate the role of culture and user values in product attachment (Mugge, 2007).
Design for Sustainable Behaviour (DfSB)	-Ethical implications of applying DfSB (who is entitled to drive user	-Development of assessment metrics and techniques for

Making people to adopt a desired sustainable behaviour and abandon an unwanted unsustainable behaviour *Lilley (2009); Lockton, Harrison and Stanton (2010); Bhamra, Lilley and Tang (2011)*	behaviour?) (Brey, 2006; Bhamra, Lilley and Tang, 2011); -Lack of metrics to measure the effect of DfSB strategies and a lack of evidence based examples (Niedderer et al. 2014); -Business stakeholders might not be incentivised in implementing DfSB strategies because this might not be counterbalanced by financial gains (Lilley, 2009; Niedderer et al. 2014).	analysing and evaluating of DfSB cases (Niedderer et al. 2014); -Test the effectiveness of DfSB strategies (Niedderer et al. 2014); -Develop a more accessible language and tools for professionals (Niedderer et al. 2014).
Cradle-to-Cradle Design (CTC) Emphasis on a regenerative approach by the industry and closing the loops; focus on non-human species and future generations *McDonough and Braungart (2002)*	-These emphases remain at a rhetorical level and, despite its inspiring vision, CTC design is technically not well justified (Bakker et al., 2010; Gaziulusoy, 2015).	-Improving its underlying assumptions; -Exploring synergies with other approaches.
Biomimicry Design (BM) Mimicking nature in design of forms, products and systems by using nature as model, measure and mentor *Benyus (2002)*	-Claiming that innovation resulting from mimicking nature is sustainable is misleading (Volstad and Boks, 2012) for isolating a principle, structure or process from nature and imitating it does not necessarily yield to sustainability (Reap, Baumeister and Bras, 2005); -Technologically-optimistic (Gaziulusoy, 2015)	-Improving its underlying assumptions; -Exploring synergies with other approaches
Design for the Base of the Pyramid (DfBoP) Improving the lives of people who live at the base of the pyramid through market-based solutions *Kandachar et al. (2009); Jagtap and Kandachar (2010); Gomez Castillo et al. (2012); Jagtap et al. (2013)*	-Targeting the poor as consumers has raised criticisms: in particular, moral dilemma that BoP approaches do not differentiate between satisfying essential needs and offering non-essential goods (Karnani, 2007; Oosterlaken, 2008; Jaiswal, 2008).	-Better explore the application of Product-Service System design to the BoP (Ceschin et al. 2015).
PRODUCT-SERVICE SYSTEM INNOVATION LEVEL		
Product-Service System design *PSS design for eco-efficiency:* design of	-Not all PSSs result in environmentally beneficial solutions (UNEP, 2002); -PSS changes could generate	-Better understand what factors influence user satisfaction, as well as how to measure and evaluate this satisfaction (Vezzoli et al.

product-service propositions where the economic and competitive interest of the providers continuously seeks environmentally beneficial new solutions. *Brezet et al. (2001); Manzini et al. (2001); UNEP (2002); Tukker and Tischner (2006)* *PSS design for sustainability:* as above, but integrating also the socio-ethical dimension of sustainability. *Vezzoli (2007); Vezzoli et al. (2014)* *PSS design for the Bottom of the Pyramid:* as above, but applied to the BoP. *UNEP (2009); Moe and Boks (2010); Schafer et al. (2011); Jagtap and Larsson (2013)*	unwanted environmental rebound effects (e.g. increase in transportation impacts) (UNEP, 2002); -PSSs (especially in the B2C sector) are difficult to be implemented and brought to the mainstream because they challenge existing customers' habits (cultural barriers), companies' organizations (corporate barriers) and regulative frameworks (regulative barriers) (Vezzoli et al. 2015).	2015); -Develop a deeper understanding on the process of introduction and diffusion of sustainable PSSs, and how this can be designed, managed and oriented (Vezzoli et al. 2015); -Identify effective strategies to transfer PSS design knowledge and know-how from research centres and universities to companies and designers (Vezzoli et al. 2015).

SPATIO-SOCIAL INNOVATION LEVEL

Design for Social Innovation Assisting with conception, development and scaling-up of social innovation *Manzini (2007); Manzini (2014); Meroni (2007)*	-Criticisms have been raised about the naiveté of designers proposing superficial solutions and high cost of design services (Hillgren et al., 2011); -A sole focus on social innovation is not likely to achieve the levels of change required in large socio-technical systems meeting society's energy, mobility or housing/ infrastructure needs.	-Further explore the role of designers in social innovation processes, particularly in replication and scaling-up (Jégou and Manzini, 2008; Manzini and Rizzo, 2011; Hillgren et al., 2011); -Develop social innovation toolkits (e.g. Murray, Caulier-Grice and Mulgan, 2010); -Research about how to change professional culture and improve design education to support social innovation.
Systemic Design Designing locally-based productive systems in which waste from one productive process becomes input to other processes. *Bistagnino (2009, 2011); Barbero and Toso (2010)*	-The approach is mainly focused on the production aspects, without addressing the issue of reducing individual consumption (Gaziulusoy, 2015).	-Exploring synergies with other approaches.

SOCIO-TECHNICAL SYSTEM INNOVATION LEVEL		
Design for System Innovations and Transitions Transformation of socio-technical systems through (strategic) design *Ceschin (2012); Gaziulusoy (2010); Joore (2010); Irwin et Al. (2015)*	-Too "big picture" and need to be supported by approaches that focus on development of products and services that can be part of new socio-technical systems.	-Developing theoretical insights and practical tools to linking micro-innovation with macro-innovation; -Investigating how other DfS approaches can support design for system innovations and transitions.

6.2 Reflections and Observations Emerging from the DfS Evolutionary Framework

Looking at the framework, a first consideration can be done on the ***relationships between the various DfS approaches***, and in particular on their linkages, overlaps and complementarities. To begin with, we must acknowledge that there is not always a clear separation between the approaches. In a few cases we can see this distinction (e.g. *Emotionally Durable Design* and *Systemic Design* have a completely different focus and no point of contact), but in general the approaches overlap with one another and are interrelated.

For example, *Design for Social Innovation* and *Sustainable PSS design* have shared elements: PSS design can in fact be combined with, and applied to, community-based innovations. Another example is related to *Sustainable PSS Design* and *Design for the BoP*, which overlap on *Sustainable PSS design for the BoP*. Similarly, *Systemic Design* shares some elements and principles with *Cradle to Cradle Design* and *Biomimicry*.

It is also interesting to highlight how some approaches complement one another. For example, at product innovation level, *Ecodesign*, *Emotionally Durable Design* and *Design for Sustainable Behaviour* provide a set of complementary strategies to improve products' environmental performance: the first of these approaches looks at the stages and processes in product life cycle; the second one focuses on the emotional attachment between the user and the product; the third one investigates how user behaviour can be influenced through product design.

The framework also shows how some approaches have evolved into others. For example, there is a clear link between *Green Design* and *Ecodesign*, with the former gradually evolving into the latter.

Finally, it must be highlighted that some approaches are not limited to a single innovation level and they cross over various innovation levels. For example *Design for Sustainable Behaviour* can be applied at a Product, Product-Service System and Spatio-Social levels. Similarly, *PSS Design* is relevant to both the second and the third levels and Design for System Innovations and Transitions cross-cut spatio-social and socio-technical system levels.

Another consideration can be made on the ***importance of each DfS approach*** in regard to the overall sustainability goal. Nowadays it is a common understanding that sustainability is a challenge to be addressed at a socio-technical system level. However, this does not mean that some DfS approaches are less important than others. It is true that the approaches at the lower level (the ones focusing on product innovation) cannot alone be sufficient to achieve sustainability, but it would be a mistake to consider these approaches less useful. For example, PSS innovations require material artefacts that need to be properly designed. The potential environmental benefits of a PSS cannot be achieved if the products included in the solution are not designed to reduce and optimise resource consumption. Therefore, each DfS approach should be acknowledged for associated strengths and shortcomings, and should be utilised in conjunction with complementing approaches for any given project following a systemic analysis because addressing sustainability challenges requires an integrated set of DfS approaches spanning various innovation levels. Approaches that fall under Socio-technical Innovation Level demonstrate this requirement well. Design for System Innovations and Transitions focuses on transforming systems by actively encouraging development of long-term visions for completely new systems than we currently have and linking these visions to activities and strategic decisions of design and innovation teams. Achieving these visions will require design and innovation teams to select one or more of the approaches in lower levels and use in development of new products and services (Level 1), new business models (Level 2), new social practices (Level 3) that can be part of the envisioned future systems.

Finally, some considerations can be made on the different sets of ***skills required from the practitioners of various DfS approaches***. We highlighted before that the focus of DfS has progressively expanded from single products to complex systems. We can observe that this has been accompanied by an increased need for human-centred design knowledge and know-how. Initial DfS approaches related to the product innovation level (i.e. *Green Design*, *Ecodesign, Biomimicry*), predominantly require technical knowledge (e.g. on materials, production processes, renewable energies, etc.) and know-how (e.g. Life Cycle Assessment tools, ecodesign tools, etc.). On the other hand, more recent product DfS approaches, such as *Emotionally Durable Design*, *Design for Sustainable Behaviour*, require designer to be provided with a different set of expertise. In particular human-centred design skills become crucial for them. For example they need to understand consumption dynamics (what users want and why) and behaviour dynamics (behaviour change models and strategies). Thus, techniques to gather insights from users (such as cultural probes, ethnographic observations, focus groups, etc.), and techniques to co-design with them become essential in the designer toolkit. A similar observation can be made on the DfS approaches related to the other innovation levels. For example in *PSS design* the development of new business models and new ways of satisfying customers require an in depth understanding and involvement of users, and in *Design for social innovation* the understanding and involvement of communities in co-design process is essential.

We can also note that enlargement of the design scope requires designers to be equipped with strategic design skills. Manzini and Vezzoli (2003) emphasised the need for PSS design for sustainability to move from product thinking to system thinking and to become more strategic. This entails that designer must be capable to: address sustainability operating on the integrated system of products, services and communication through which a company (or an institution, NGOs etc.) presents itself (Manzini, 1999; Meroni, 2008; Vezzoli, 2007); create clear, comprehensible and shared visions to orient innovations (Borja de Mozota, 1990); contributing to create relations between a variety of stakeholders of a value constellation (Zurlo, 1999), and act as facilitator to stimulate a strategic dialogue and co-design processes with them (Meroni, 2008). This is also true for the Spatio-social level (for example, in relation to *Design for social innovation* see Meroni (2008) and Sangiorgi (2011)), and becomes even more crucial when operating at a socio-technical system (Ceschin, 2014a).

6.3 Concluding Remarks

DfS field has broadened its interventional scope over the years displaying a chronological evolution. In the first half of the 90's DfS was prevalently focused on the product level, with the development and consolidation of *Green Design* and *Ecodesign.* Other approaches at the product level were delineated in the late 90's (see *Biomimicry*), and in the first half of the past decade (see *Cradle to Cradle Design*, *Emotionally Durable Design*, *Design for the BoP*, *Design for Sustainable Behaviour*), with some approaches (for example *Design for Sustainable Behaviour*) still primarily remaining within the interest scope of academic research. Looking at the Product-Service System Design approaches, the first discussions took place in the late 90's but the main boost to the development of the approaches came in the 2000's. In relation to the Spatio-Social level, *Design for Social Innovation* was initially delineated in the first half the 2000's and is currently under investigation and development. The approaches on both the PSS and the Spatio-Social levels are not fully consolidated, and the research interest on various aspects of these approaches is still very high (as shown, e.g. in relation to PSS design, by Vezzoli et al. (2015)). The attention on the role of design at the socio-technical system level is even more recent, with the first PhD researches on the topic completed in the last few years (Ceschin, 2012, Gaziulusoy, 2010, Joore 2010). This area is increasingly gaining research attention in design schools.

The focus of DfS has also progressively expanded from single products to complex systems. This has been accompanied by an increased attention to the 'people-centred' aspects of sustainability. In fact, while the first approaches have been focusing predominantly on the technical aspects of sustainability (e.g. see *Green Design*, *Ecodesign, Biomimicry*), the following ones have recognised the crucial importance of the role of users (e.g. see *Emotionally Durable Design*, *Design for Sustainable Behaviour*), communities (e.g. see *Design for Social Innovation*), and more in general of the various actors and dynamics in a socio-technical system (e.g. see the fourth innovation level).

Similarly, the sustainability focus of the various approaches have expanded. The earlier approaches (and in particular most of the approaches at the Product level) deal with the environmental aspects of sustainability. Moving on, aspects such as labour conditions, poverty alleviation, integration of weak and marginalised people, social cohesion, and more in general quality of life, have been increasingly integrated into the later DfS approaches (e.g. see *PSS Design* and in particular *Design for Social Innovation*).

The enlargement of the design scope has also entailed a shift from insular to systemic design innovations. In fact we can observe that initial DfS approaches (and in particular most of the approaches at the Product level) focus on sustainability problems in isolation (e.g. improving recyclability, improving product energy efficiency in use, etc.), whose solutions can be developed and implemented by an individual actor (e.g. a firm). On the other hand, PSS innovations are much more complex and their implementation might require a stakeholder value chain that includes a variety of socio-economic actors. In these cases the activities of an actor (e.g. firm) need to be linked and integrated with other process outside that actor. The same can be said for example for social innovations, which might require forming coalitions with a variety of local stakeholders. Changes at the socio-technical system level require an interwoven set of innovations and therefore a variety of socio-economic actors are implicated, including users, policy-makers, local administrations, NGOs, consumer groups, industrial associations, research centres, etc.

To conclude, this paper contributes into design theory in general and DfS field specifically by providing a review of historical evolution of response to sustainability problems in design profession and by proposing a framework. This evolutionary framework displays how the various DfS approaches contribute to particular sustainability aspects. The proposed framework in meant to support practitioners and organisations to navigate the complex DfS landscape. The framework is also meant to engage design researchers in the discussion on how DfS has evolved in the past two decades and how it will evolve in future.

7. References

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